UNIVERSITY OF NAIROBI

EFFECTS OF CLIMATE VARIABILITY ON ECOHYDROLOGICAL CONDITIONS AND THEIR INFLUENCE ON MALARIA RISK IN BARINGO COUNTY, KENYA

AMADI, JACINTER ALUOCH (M.Sc.)
I85/96148/2014

A thesis submitted in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy in Climate Change and Adaptation of the University of Nairobi

2018

PLAGIARISM STATEMENT

This thesis has been written by me and in my own words, except quotations from published and unpublished sources, which are clearly indicated and acknowledged as such. I am conscious that the incorporation of material from other works or a paraphrase of such material without acknowledgement will be treated as plagiarism, subject to the custom and usage of the subject, according to the University Regulations on Conduct of Examinations. The source of any picture, map or other illustration is also indicated, as is the source, published or unpublished, of any material not resulting from my own experimentation, observation or specimen collecting.

Signature: ………………………………… Date: ………………………..

Amadi, Jacinter Aluoch (M.Sc.)

DECLARATION

I declare that this thesis is my original work and has not been submitted elsewhere for award of any degree. Where other people's work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements.

Signature: ………………………… Date: …………………

Amadi, Jacinter Aluoch

This thesis is submitted for examination with our approval as research supervisors:

Prof. Daniel O. Olago
Institute for Climate Change and Adaptation
University of Nairobi
P.O Box 30197-00100
Nairobi, Kenya ……….…………… …….……………
dolago@uonbi.ac.ke Signature Date

Dr. George O. Ong'amo
School of Biological Sciences
University of Nairobi
P.O Box 30197-00100
Nairobi, Kenya ………………………. …….……………
gongamo@uonbi.ac.ke Signature Date

Dr. Silas O. Oriaso
Institute for Climate Change and Adaptation
University of Nairobi
P.O Box 30197-00100
Nairobi, Kenya ……….……………. …….……………
soriazzo@uonbi.ac.ke Signature Date

DEDICATION

To my son (John Derrick) who endured my absence during this study. To my family and friends whose prayers and support made this work a success.

ACKNOWLEDGEMENT

I thank Prof. Daniel Olago, Dr. George Ong'amo and Dr. Silas Oriaso for their guidance during this study. Your unique contributions and teamwork made this transdisciplinary research achievable.

This research was partially supported by funds from the WHO's Special Programme for Research and Training in Tropical Diseases (TDR) through a grant agreement with the International Development Research Centre of Canada (106905-00). The funded Project (No. B20278) was a collaborative research between University of Nairobi and Jaramogi Oginga Odinga University of Science and Technology, Kenya. I am grateful to Prof. Benson B. A. Estambale and Prof. Isaac K. Nyamongo who incorporated me in the project. This study would not be successful without the support of field staff in Kabarnet, Baringo County. The field coordinator, Douglas Anyona, and the field assistants Macrae Mbalanya and Juliet Jepkosgei, I am thankful for your assistance and endurance during data collection.

I am grateful to the Association of African Universities (AAU) for the grant award that supported the final stages of fieldwork and thesis preparation.

I wish to acknowledge the support of Mr. Mark Rotich and Mr. Richard Bor from the Division of Vector-borne Diseases, Marigat in providing laboratory space and equipment and in confirming mosquito identifications. My appreciation goes to Baringo County community members, local administration, county and sub-county health officers and those not mentioned for their cooperation and valuable knowledge. I also thank my family, friends and colleagues at Kenyatta University for their moral support.

ABSTRACT

Despite current gains in malaria reduction, the disease continues to have devastating health and livelihood impacts especially in sub-Saharan Africa where over 80% of global malaria cases exist. Malaria is an environmentally sensitive disease linked to climatic and environmental factors. Changes in the aforementioned factors alter the distribution and abundance of malaria vectors and consequently malaria transmission risks. The aim of this study was to evaluate the influence of climatic and ecohydrological factors on malaria vectors and develop a framework for malaria risk reduction in Baringo County, Kenya. Remotely sensed climate and normalized difference vegetation index (NDVI) data were used in Mann-Kendall trend analysis over the period 2003-2016. Sampling of mosquito larvae was conducted monthly from December 2015 to December 2016. Using a generalized linear mixed model (GLMM), climate and ecohydrological variables (land cover, vegetation health, wetness index, slope and discharge) were used to model *Anopheles gambiae s.l.* distribution. Clinical malaria cases were used in malaria trend analysis over the 2005-2014 period, this being the duration over which hospital records overlapped with climate data. A triangulation of focus group discussion, key informant interviews and household survey was used to assess lay knowledge on climate and malaria risks and in developing a malaria reduction framework for communities in Baringo County. During the 2003-2016 period, a significant increase in mean annual minimum and maximum temperatures was observed in the lowland zone ($p < 0.05$). There was no change in total annual rainfall contrary to the local perception that rainfall had decreased. The March April May (MAM) rains season was reported as being unreliable and depressed. During the same study period, an increase in annual vegetation health was observed in the riverine ($tau = 0.103$; $p = 0.047$) and lowland zones ($tau = 0.051$; $p > 0.05$). A significant increase in Lake Baringo water levels occurred during the 2011-2014 period ($tau = 0.569$; $p < 0.001$). Discharge in River Arror decreased significantly ($tau = -0.412$; $p < 0.001$) amidst non-significant changes in rivers Perkerra and Kessup. NDVI had a one-month lagged response to rainfall and a zero-lag response to T_{min} and T_{max}. Higher *Anopheles gambiae s.l.* abundance occurred in the riverine zone compared to the lowland zone ($W = 13$; $Z = -2.04$; $p < 0.05$; $r = 0.59$). Rainfall, slope and vegetation health significantly influenced the distribution of *Anopheles gambiae s.l.* mosquito larvae at $p = 0.00041$, $p = 0.012$, and $p = 0.038$ respectively. Malaria trends increased significantly in the riverine zone during the 2005-2015 period ($tau = 0.352$; $p < 0.001$. There was a coexistence of misconceptions and correct medical knowledge on the causes and modes of malaria transmission. Night and early morning outdoor occupation increased exposure of residents to mosquito bite and malaria transmission. There was over reliance on mosquito nets for malaria control while supplementary strategies such as environmental management and use of chemical sprays were largely underutilized. In addition to mosquito nets currently in use, measures including unclogging irrigation canals, draining pools near homes, managing *Prosopis* bushes, fogging, use of screens, clean-up campaigns and enhanced malaria surveillance were proposed in the malaria risk reduction framework. Awareness and education should be conducted to demystify misconceptions and promote behaviour change. The time lags between peak malaria cases and the assessed factors can inform timely distribution of resources to deter malaria transmission. The county government should give prioritized consideration to the riverine zone with regard to malaria surveillance and resource distribution. Implementation of community-driven integrated approaches will result in universal utilization of malaria control measures and a substantial reduction in malaria prevalence in Baringo County.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND SYMBOLS

AAU	Association of African Universities
ACSM	Advocacy Communication and Social Mobilization
ACT	Artemisinin-based Combination Therapy
AIC	Akaike Information Criterion
ANOVA	Analysis of Variance
BCG	Baringo County Government
CBDRM	Community Based Disaster Risk Management
CCF	Cross Correlation Function
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station
CRECO	Constitution and Reform Education Consortium
DC	District Commissioner
DEM	Digital Elevation Map
DJF	December January February
DOMC	Division of Malaria Control
DRR	Disaster Risk Reduction
DTR	Diurnal Temperature Range
ERC	Ethics and Research Committee
FAO	Food and Agriculture Organization
FEWS NET	Famine Early Warning Systems Network
FGD	Focus Group Discussion
GHA	Greater Horn of Africa
GHG	Greenhouse Gases
GIS	Geographic Information System
GLMM	Generalized Linear Mixed Model
GPS	Global Positioning System
INTs	Insecticide-treated Nets
IPCC	Intergovernmental Panel on Climate Change
IPTp	Intermittent Preventive Treatment in pregnancy
IRI	International Research Institute
IRS	Indoor Residual Spray

ITCZ	Intertropical Convergence Zone
IVM	Integrate Vector Management
JJA	June July August
KII	Key Informant Interview
KIRA	Kenya Interagency Rapid Assessment
KMIS	Kenya Malaria Indicator Survey
KMS	Kenya Malaria Strategy
KNBS	Kenya National Bureau of Statistics
KNH	Kenyatta National Hospital
KWS	Kenya Wildlife Service
LLINs	Long Lasting Insecticide-treated Nets
LSM	Larval Source Management
LST	Land Surface Temperature
MAM	March April May
MCS	Malaria Communication Strategy
MCU	Malaria Control Unit
MICE	Multivariate imputation by chained equations
M-K	Mann-Kendall
MODIS	Moderate Resolution Imaging Spectroradiometer
NACOSTI	National Commission for Science Technology and Innovation
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NGO	Non-Governmental Organization
NMCP	National Malaria Control Programme
NMS	National Malaria Strategy
OND	October November December
RCP	Representative Concentration Pathways
RDT	Rapid Diagnostic Test
RVF	Rift Valley Fever
SFDRR	Sendai Framework for Disaster Risk Reduction
SMK	Seasonal Mann-Kendall

SMS	Short Message Service
SON	September October November
SST	Sea Surface Temperature
STRM	Shuttle Radar Topographic Mission
TDR	Special Programme for Research and Training in Tropical Diseases
T_{max}	Maximum Temperature
T_{min}	Minimum Temperature
TWI	Topographic Wetness Index
UNISDR	United Nations International Strategy for Disaster Reduction
UoN	University of Nairobi
URTI	Upper Respiratory Tract Infection
USAID	United States Agency for International Development
USGS	United States Geological Survey
WARMA	Water Resources Management Authority
WHO	World Health Organization
WRI	World Resources Institute

GLOSSARY OF TERMS

Chemoprevention: Administration of full treatment courses of an antimalarial medicine to children to prevent malarial illness (WHO, 2013b).

Ecohydrology: The study of dynamic interaction of climate, soil and vegetation as they exchange water, carbon, energy and nutrients at a range of scales in space and time (Ruddell and Kumar, 2009). In this study, ecohydrological influence on mosquito abundance is explored.

Ecophenotypic plasticity: Modifications in behaviour of organisms that are linked to environmental influences and are not heritable (Govere *et al.*, 2000).

Hydrologic regime: The temporal patterns of inundation or flow (Brooks, 2009).

Hydroperiod: The duration of surface inundation or flow (Brooks, 2009).

Integrated vector management (IVM): According to (WHO, 2004), IVM is a rational decision-making process geared towards reducing vector population or interrupting disease transmission. The IVM has five key elements: (1) evidence-based decision-making, (2) integrated approaches, (3) collaboration within the health sector and with other sectors, (4) community and other stakeholders' engagement, and (5) policy and legislative framework.

Transdisciplinary approach: An integrated approach to problem solving that transcends traditional boundaries by integrating knowledge between society and academia in order to solve complex social problems (Klein, 2013).

Vector bionomic: The study of ecology of a vector species (WHO, 1975).

CHAPTER ONE: INTRODUCTION

1.1 Background information

Climate variability, defined as deviations in the mean state of climate over temporal scales ranging from month, season or year (IPCC, 2014a), occurs due to natural or anthropogenic alterations in the earth's climate system. Satellite and *in situ* observations have provided strong evidences attributing climatic trends to increased anthropogenic emission of greenhouse gases (GHG) (IPCC, 2013b). This is reflected in extreme temperatures, changes in precipitation patterns, and increased frequency of extreme events amongst other impacts (IPCC, 2007). Generally, global mean surface air temperature has continued to increase, with the period between 1983 and 2012 being the warmest years over the last 1000 years (IPCC, 2014b). Global warming causes more hot days and nights, fewer cold days and nights and increased frequency or intensity of warm spells (IPCC, 2014b). Further, global-scale changes in precipitation pattern and frequent regional heavy precipitation events are attributed to anthropogenic influences (IPCC, 2013b). The aforementioned seasonal and inter-annual variations in temperature and rainfall are the key drivers in ecological and hydrological systems. Together, they cause changes in soil moisture, surface water, and vegetation productivity (Tietjen *et al.*, 2009).

Ecological and hydrological (ecohydrology) conditions are sensitive to climate, displaying short-term variations depending on changes in seasonal and annual weather patterns (Brooks, 2009). Precipitation and temperature changes have the greatest effect on stream flow (Brooks, 2009) as well as periods of pool formation (Bomblies *et al.*, 2009; Pumo *et al.*, 2016). The resulting transient and perennial pools are habitats that sustain rich invertebrate communities (Gilioli and Mariani, 2011). Thus, changes in the hydro-regime will likely affect various ecological processes and communities (Settele *et al.*, 2014), causing changes in the quantity and quality of aquatic habitats and consequently affecting productivity and biodiversity of such ecosystems (Thieme *et al.*, 2010). Soil moisture content is one of the important variables in surface hydrology. It acts as a link between hydrological processes in the atmosphere, hydrosphere and biosphere (Grashey-Jansen *et al.*, 2014). Soil moisture changes, which are a product of interaction among the aforementioned systems, can create niches that species occupy or can lead to disappearance of existing ones.

Vegetation, the part of the biosphere that characteristically controls soil moisture content, causes significant effects on the local precipitation (Baudena *et al.*, 2008). Vegetation cover slows down surface runoff, enhances infiltration and affects water loss from the soil through evaporation and transpiration (Tietjen *et al.*, 2009). Consequently, changes in ecohydrological conditions may cause shifts in species geographic ranges, seasonal distribution and abundances. Mosquitoes are examples of important invertebrates whose survival depend on habitat conditions (Midekisa *et al.*, 2014) and may be affected by changes in ecohydrological conditions. Studies have shown that local variations in hydrology, soil moisture, physiography and land cover influence the availability of mosquito breeding habitats (Patz *et al.*, 1998; Hardy *et al.*, 2013; Midekisa *et al.*, 2014).

Malaria is a vector-borne disease caused by the *Plasmodium* parasite, and transmitted by bites of the female *Anopheles* mosquito (Setiadi *et al.*, 2016). In Africa, *P. falciparum* malaria is most devastating, causing high morbidity and mortality rates (WHO, 2015a). This situation is enhanced by the presence of the most effective and efficient vector species, *Anopheles gambiae s.s.* (Giles) and its congeneric *An. arabiensis* (Patton), herein referred together as *An. gambiae s.l.* (Godfray, 2013). Malaria is considered an environmentally sensitive disease (Chaves and Koenraadt, 2010; Lourenço *et al.*, 2011), linked to climatic and environmental factors. Climate change influences malaria risks either directly via the development rates and survival of both the pathogen and the vectors (Smith *et al.*, 2014), or indirectly through changes in the vegetation and the land-surface characteristics (Niang *et al.*, 2014). For instance, increased ambient temperature increases mosquito (Bayoh and Lindsay, 2003; Paaijmans *et al.*, 2010a) and parasite development rates (Paaijmans *et al.*, 2010b), consequently increasing malaria transmission risks. Variability in frequency, intensity, and amount of precipitation also influence mosquito survival (Mamai *et al.*, 2015), densities (Yewhalaw *et al.*, 2013) and distribution (Walker *et al.*, 2013; Kulkarni *et al.*, 2016) due to alterations in habitat conditions. The distribution of mosquito vectors, their biological adaptation, and presence in a particular environment are the major factors influencing malaria epidemiology (Atkinson, 2009).

1.2 Problem Statement

Malaria contributes to the global disease burden, being endemic in 97 countries (WHO 2015a). Despite current gains in malaria reduction, the disease continues to have devastating health and livelihood impacts (Caminade *et al.*, 2011). Approximately 214 million malaria cases were recorded in 2015, and 88% of these cases and deaths occurred in sub-Saharan Africa (WHO, 2015b). In Kenya, malaria accounts for about 30% of outpatient consultancies, 18% hospital admissions and 6% of in-patient deaths (USAID, 2016). Nearly 75% of the Kenyan population lives in malaria prone zones (WHO 2015a), mostly in epidemic and seasonal transmission zones (Division of Malaria Control, 2011). Kenya is also categorized as having insufficient continuous data to evaluate malaria trends (WHO, 2015b).

Malaria prevention and control efforts in Kenya are biased towards lake endemic and highland epidemic zones (Division of Malaria Control, 2011), with least effort in other malaria endemic zones. One of the neglected but important areas in terms of malaria transmission is Baringo County. Baringo County, characterized by a resource poor population inhabiting an arid to semi-arid zone (Mala *et al.*, 2011a) is categorized as a seasonal malaria transmission zone (Division of Malaria Control, 2011). The county has a substantial malaria burden given its unique geophysical context including the occurrence of different eco-climatic zones. Data on prevention or control of malaria are also limited in these zones (Maes *et al.*, 2014), yet, malaria is among the most prevalent diseases (1-5%) in Baringo (Baringo County Government, 2014). The high malaria prevalence rate could be partly due to incomplete understanding of the environmental determinants of the malaria vector against the backdrop of prevailing heterogeneous conditions. This calls for particular attention to explore the influence of ecohydrological conditions on malaria vectors with a view of integrating complementary strategies in malaria prevention and control.

Ecohydrological studies have often concentrated on hydrological processes and biota (plant growth) (Albertson *et al.*, 2006; Wassen *et al.*, 2006; Gerten *et al.*, 2007; Lauenroth *et al.*, 2014; Shin *et al.*, 2014) and the ecological implications for wetland management (Wolanski *et al.*, 2004; Kopprio *et al.*, 2013). Not much emphasis has been directed towards the effects of climate on ecohydrological systems and the implications of such alterations on vector distribution and abundance. Studies on the climate, ecohydrology, and vector dynamics are scanty and often lacking in dryland areas with seasonal disease transmissions. This study focused on the application of ecohydrological knowledge in understanding malaria vectors and risks in the face of a changing climate. It aimed at understanding the relationship between ecohydrological conditions and mosquito abundance and was geared towards providing information on the climate impact on malaria dynamics. Research on ecohydrological influences on vector distribution could help close the gap in our current understanding of malaria epidemiology and residual transmissions. Information on the aforementioned climate-ecohydrological changes can support decision making for malaria control.

1.3 Research Questions

i. What is the trend of seasonal climate variability (rainfall and temperature) and its influence on ecohydrological systems (vegetation, soils, and hydrology) in Baringo County?
ii. What is the type of relationship between the various components (vegetation, soils, and hydrology) of the ecohydrological systems and malaria vector abundance in Baringo County?
iii. What is the most effective framework that can be used to reduce malaria risks among communities in Baringo County?

1.4 Objectives

1.4.1 Main objective

To investigate the effects of climate variability on ecohydrological conditions and their associated influence on malaria vector abundance, and to develop malaria risk reduction strategies for Baringo County, Kenya.

1.4.2 Specific objectives

i) To assess the influence of seasonal climate variability on ecohydrological systems in Baringo County.
ii) To establish the relationship between various components of the ecohydrological system and malaria vector abundance in Baringo County.

iii) To develop a participatory strategic framework to reduce malaria risks in Baringo County.

1.5 Justification and Significance

1.5.1 Justification

One of the most important impacts of climate variability will be changes in climatic patterns. Such changes will affect ecological and hydrological systems, which in turn will affect nearly every aspect of human and ecosystems wellbeing (IPCC, 2014b). The situation will be aggravated by the uncertainty in regional precipitation changes (IPCC, 2014b). Thus, there is a need for research at local scales to understand local system responses to climate variability. To better understand and solve complex social problems like malaria epidemics, a transdisciplinary approach that transcends traditional disciplines should be emphasized. Traditional investigations with single disciplinary focus will likely miss, or fail to capture key processes and mechanisms that are crucial for understanding vector-borne diseases like malaria. Thus, application of community-based strategies that integrate concepts and tools from multiple disciplines (ecology, hydrology, climate science, and anthropology) will permit significant advancement in understanding and development of practical solutions for malaria prevention and/or control.

1.5.2 Significance

The study provides information on ecohydrological variability and their application in mapping malaria vector distribution at spatial scales where such information is often lacking. The findings will assist in reducing vulnerability and losses associated with malaria outbreaks by informing decision making for malaria control and management. Incorporating research recommendations into government policy, strategies, and adaptation plans will enhance community resilience to vector-borne diseases and improve rural livelihoods and well-being. An integrated approach promotes development of innovative tools and strategies for solving such problems as an integrated system.

1.6 Scope of the study

This study sought to determine the effects of climate variability on ecological and hydrological conditions and the relationships between these factors and malaria vectors in the arid to semi-arid Baringo County that is largely considered to be a seasonal malaria transmission zone. The study was conducted in lowland and riverine zones relating to Lake Baringo and Kerio Valley, respectively. In this study, remotely sensed climate and vegetation data for the 2003 - 2016 period were used. Mosquito larvae were collected monthly over a period of 13 months from December 2015 to December 2016. Quantitative and qualitative data were collected, analysed and triangulated in a transdisciplinary approach and used to generate a framework for malaria control for communities living in Baringo County.

1.7 Overview of Methodological Approach

The study was conducted in Baringo County (00° 26'- 00° 32' N and 36° 00' - 36° 09' E) a typical arid to semi-arid region. The county has an average elevation ranging from 900 m to 2300 m above mean sea level. Climatic and environmental data (Partial Information Formats) for the period between 2003 and 2016 were downloaded from International Research Institute (IRI) for Climate and Society’s climate data library (http://iridl.ldeo.columbia.edu/SOURCES). Raster data were sourced from the United States Geological Survey (USGS) and Famine Early Warning Systems Network (FEWS NET) (https://earlywarning.usgs.gov/fews) and Landsat (https://landsat.usgs.gov) data portals. Rainfall, minimum, and maximum temperatures data were the climatic variables used in analysis. Mean monthly NDVI values were calculated from 16-day composites for the study period. Landsat 8 image with 30 m resolution was used in land cover classification. Topographic wetness was used as proxy for soil moisture. A 30m digital elevation map (DEM) was used to derive the area slope. Samples of mosquito larvae were collected monthly using dipper or pipette. Climatic, ecohydrological and vector data were processed using ArcGIS 10.0 and analysed in R environment. Ecohydrological data and information from focus group discussions were triangulated, and used to develop community based alternative malaria mitigation strategies.

CHAPTER TWO: LITERATURE REVIEW

2.1 Climate change and climate variability

Climate is the statistical description of the mean or variability in weather properties monitored for a period of 30 years or more (IPCC, 2014a). Climate change is the change in the state of the climate that persists for a decade or longer while climate variability refers to variations in the mean state of climate at all spatial and temporal scales (IPCC, 2001). The principal climate parameters are temperature and precipitation. Climate change occur due to natural or anthropogenic alterations in the earth's climate system. Over the last century, anthropogenic emission of greenhouse gases (GHG) has caused an unprecedented increase in global air temperature with far reaching social and ecosystem effects.

2.2 Observed and projected changes in climate

2.2.1 Temperature

There has been unequivocal warming of the climate system over the last two centuries (IPCC, 2014b). Each of the last three decades have successively been warmer than any preceding decade since 1850 (IPCC, 2014b). Studies by Zhang *et al.* (2015) documented a global air temperature increase of 0.85°C during the period 1880 to 2012. Over most parts of Africa, near surface temperature has increased by ≥ 0.5°C during the last 50-100 years (Niang *et al.*, 2014), with minimum temperature increasing more rapidly than maximum temperature (Engelbrecht *et al.*, 2015). Different parts of East Africa have recorded significant increases in temperature over the last five decades (Niang *et al.*, 2014). King'uyu *et al.* (2000) found a warming by up to 0.6°C in minimum temperature in some parts of East Africa during the period 1939 - 1992. A warming trend particularly for the minimum (night-time) temperature was reported in the Greater Horn of Africa (GHA) (Omondi *et al.*, 2014). Wandiga *et al.* (2010) also found increasing maximum temperatures for western Kenya highlands (Kericho) during the period 1978 - 2004. Observed mean surface temperature changes agree with model simulations especially for the period 1951 to 2012 (IPCC, 2013b).

The global average surface temperature is projected to increase by 0.47°C to 1°C during the period 2016 - 2035 for Representative Concentration Pathways RCP4.5 relative to the period 1986-2005 (Kirtman *et al.*, 2013). By the end of the 21st Century, global surface temperature change will likely exceed 1.5°C for all except RCP2.6 (IPCC, 2014b). Further, surface temperature over Africa is projected to rise faster than the global average with the East African region warming by about 2°C or more by 2100 (Niang *et al.*, 2014). Over the East African region, seasonal air temperatures for December, January, February (DJF) are also expected to increase by 0.75°C to 1°C during the period 2016-2035 for RCP4.5 relative to the period 1986-2005 (IPCC, 2013b). The global warming causes change in other important aspects of the climate system such as atmospheric and oceanic circulations, snow / ice cover and precipitation.

2.2.2 Precipitation

Intensified hydrological cycle and enhanced precipitation extremes are likely under a warmer climate (IPCC, 2013a). Globally, an increasing trend in mean precipitation has been observed since 1901 and a downward precipitation trend has been detected in the tropics over the period 1901-2008 (Cubasch *et al.*, 2013). Over short periods, precipitation is considered uncertain at global, regional or local scales (IPCC, 2014b). Across Africa, precipitation is highly variable and more uncertain, exhibiting spatial and seasonal dependence (Niang *et al.*, 2014). Since precipitation exhibits high temporal and spatial variability, there are disparities in observed and modelled trends. Hoscilo *et al.* (2014) found insignificant increases in rainfall over East Africa with the exception of areas around Somalia and western Ethiopia. In contrast, Omondi *et al.* (2014), found a general declining precipitation trend over the GHA. Shongwe *et al.* (2011) projected a more than ~10% increase in mean precipitation over the semi-arid areas of northern Kenya and a general wetter climate for East Africa. Hoscilo *et al.* (2014) noted that the arid and semi-arid regions of sub-Saharan Africa are likely to experience extreme rainfall variability.

The observed seasonal precipitation over East Africa is also variable and inconsistent with projected trends. For example, Niang *et al.* (2014) reported a decline in March, April, May (MAM) rainfall amounts over the last three decades. Other studies such as that by Wandiga *et al.* (2010) found varying spatial trends. They reported non-significant change in the MAM rains season in some parts of Kenya and Uganda while a site in Tanzania had declining trend. Nonetheless, models revealed contradictory seasonal trends. A study by Shongwe *et al.* (2011)

projected an increase by more than ~ 15% in mean precipitation during MAM season by the mid-21st Century. Other studies have projected increased precipitation particularly for the October, November, December (OND) (short rains) season (Kirtman *et al.*, 2013). Seasonal and inter-annual variations in climate factors play a key role in the dynamics of ecological and hydrological systems.

2.3 Influence of climate variability on ecohydrological conditions

2.3.1 Surface hydrology

Seasonal to year-to-year variations in climatic factors influence the hydrologic regime of both lotic and lentic ecosystems (Brooks 2009). Transient ecosystems such as ponds and pools are challenged by climatic changes since they are hydrologically disconnected from other aquatic systems (Brooks 2009). The hydro-regime is the leading abiotic influence on the ecology of aquatic systems (Brooks 2009) since it affects composition, richness, abundance and productivity across all levels of trophic organization (Royan *et al.*, 2013). In particular, the hydro-period of ephemeral water bodies affects species composition and richness (Brooks, 2009). Climate change will affect hydrological processes with significant alterations in other important ecohydrological conditions such as soil moisture and vegetation productivity (Settele *et al.*, 2014).

2.3.2 Soil moisture

In dry land areas, soil moisture availability controls the dynamics of natural vegetation (Grashey-Jansen *et al.*, 2014), feedbacks to climate (Seneviratne *et al.*, 2010) and affect most hydrological processes (Vivoni *et al.*, 2008; Liu *et al.*, 2015). Soil moisture is a source of water for the atmosphere through its impact on evapotranspiration from land (Liu *et al.*, 2015). Soil moisture-temperature interactions substantially impacts near surface climate (Petrie and Brunsell, 2012) and relates to the occurrence of extreme hot temperatures (Seneviratne *et al.*, 2010). An increase in air temperature results in a higher evaporative demand, consequently causing a decrease in soil moisture (Seneviratne *et al.*, 2010). Soil moisture-precipitation feedback has been suggested to play a significant role in rainfall variability as well as variability in large-scale water balance such as the African monsoon (Baudena *et al.*, 2008). Other factors that influence soil moisture are soil type, topography, and vegetation cover

(Martínez *et al.*, 2014). Soil moisture and vegetation mutually influence each other and are linked through transpiration (Gerten *et al.*, 2007).

2.3.3 Vegetation

Water is a principal factor controlling vegetation growth (Baudena *et al.*, 2008), thus rainfall and vegetation are closely related (Chikoore and Jury, 2010). In semi-arid tropical environments, vegetation growth cycles correspond to not only seasonality, but also variability and unpredictability of rainfall (Herrmann *et al.*, 2005). However, at small scale, there are other weaker factors influencing vegetation change, such as human induced land use changes and conservation efforts (Herrmann *et al.*, 2005). Surface temperature largely controls vegetation through its effects on evapotranspiration (Sandholt *et al.*, 2002). Zhou *et al.* (2015) found a positive association between increased vegetation greenness and warming trends in the semi-arid areas of Central Asia. However, Zhou *et al.* (2015) noted that significant warming causes high evapotranspiration and thus may negatively affect vegetation greenness. Vegetation-climate feedback occurs when increased surface roughness slows down runoff, enhances infiltration, and affects water loss from the soil (Tietjen *et al.*, 2009). Vegetation also controls soil moisture change, causing significant effects on the local precipitation (Baudena *et al.*, 2008). The frequency, intensity, and duration of alteration of ecohydrological conditions affect invertebrate fauna including mosquito vectors that respond to their influence (Bhat *et al.*, 2010).

2.4 Influence of ecohydrological conditions on mosquito distribution and malaria risks

The distribution of mosquito vectors, their biological adaptation, and presence in a particular environment are the major factors influencing malaria epidemiology (Atkinson, 2009). Kenya is categorized into four epidemiological zones: (1) the endemic zone (areas around Lake Victoria and coastal regions (2) seasonal malaria transmission areas (arid and semi-arid areas of northern and south eastern areas), (3) highland epidemic areas (western highlands), and (4) low malaria risk areas (central highlands and Nairobi) (Division of Malaria Control, 2011). *An. gambiae s.l.* and *An. funestus* are common mosquito vectors in the western highlands and lake endemic zones (Opiyo *et al.*, 2007; Omukunda *et al.*, 2013; Ototo *et al.*, 2015) while *An. arabiensis* and *An. pharoensis* dominate the arid seasonal transmission areas (Mala *et al.*, 2011b). However, recent studies have shown that *An. arabiensis* is dominating the previously *An. gambiae s.s.* ecological zone (Ototo *et al.*, 2015) probably due to its ecophenotypic plasticity (Hay *et al.*, 2000). At the Kenyan coast, Mwangangi *et al.* (2013) reported that *An. arabiensis* and *An. merus* have, in some areas, replaced the previously dominant *An. gambiae s.s.* and *An. funestus* species. Currently, *An. arabiensis* show the most ubiquitous distribution in Kenya (Okara *et al.*, 2010; Deredec *et al.*, 2016).

Malaria vectors have idiosyncratic habitat preferences. Specifically, *An. gambiae s.l.* prefer shallow, sunlight and transient water bodies without aquatic plants, such as ground depressions that include pools, puddles and hoof prints (Benedict *et al.*, 2010). It has also been suggested that the choice of temporary habitats allows members of *An. gambiae s.l.* to avoid predation (Sinka *et al.*, 2010). In contrast, *An. funestus* prefer large and more permanent water bodies with emergent vegetation (Zhou *et al.*, 2007; Chaves and Koenraadt, 2010), like seepages, rice fields (Ceccato *et al.*, 2005) and marshes (Michel *et al.*, 2005; Walker and Lynch, 2007). Additional habitat conditions for *An. gambiae s.l.* include capability of surviving in wet mud, consequently enhancing their survival in uncertain environments (Dale and Knight, 2008). *Anopheles gambiae s.s.* is adapted to wetter and humid areas whereas *An. arabiensis* is adapted to drier climate (Tonnang *et al.*, 2014). The distinct habitat preferences of malaria vectors contribute to the ubiquity of their distribution (Paaijmans *et al.*, 2008).

The distribution of mosquito vectors is conditional to biotic and abiotic characteristics of the environment. Temperature is a principle abiotic factor that affects vector development, survival and distribution, consequently affecting malaria transmission (Zhou *et al.*, 2004; Lourenço *et al.*, 2011; Paaijmans and Thomas, 2011). This is due to the fact that *Anopheles* mosquitoes intimately depend on ambient temperature (15°C to 34°C) for their survival (Afrane *et al.*, 2012). Low temperatures (below 15°C) substantially inhibit aquatic stage development while very high temperatures (above 34°C) increase mortality of both larval and adult stages (Lyons *et al.*, 2013). The development rate, feeding and survival of adult mosquitoes increase in the intermediate temperature range (24°C to 28°C), often causing escalated disease prevalence (Lyons *et al.*, 2013). Significant declines in survival of *Anopheles* larvae have been observed at 15°C and 35°C, *An. arabiensis* tolerating higher temperatures (32°C) compared to *An. gambiae s.s.* (24°C) and *An. funestus* (25°C) (Lyons *et al.*, 2013).

Rainfall and standing water are other key factors for immature mosquito development (Lourenço *et al.*, 2011). Malaria mosquitoes breed in temporary ponds that flood after rainfall and persist for about 10 - 14 days, and therefore, the frequency and amount of rainfall are indicators of the presence and persistence of mosquito breeding habitats (Stresman, 2010). The relationship between rainfall and mosquito density has been repeatedly confirmed (Zhou *et al.*, 2004; Afrane *et al.*, 2012). However, this relationship is not a direct one since certain amounts of rainfall do not lead to mosquito density increases (Lourenço *et al.*, 2011). For instance, excessive rainfall reduces mosquito density by flushing larvae out of small pools (Hay *et al.*, 2000). According to Afrane *et al.* (2012), the interaction between temperature and precipitation considerably affects the ecology of *Anopheles* mosquitoes and mosquito-borne diseases.

The distribution of rainfall over the year, soil conditions before the onset of the rains and vegetation cover all influence malaria vector populations (Chaves and Koenraadt, 2010). In dry land areas, permanent and localized water sources promote year-on-year low level larval production by providing “larval seeds” to newly formed rain-fed habitats (Mala *et al.*, 2011a). At local scale, factors such as soil moisture and land use/ land cover changes have been reported to influence malaria risks (Stresman, 2010). Soil moisture levels determine the number of infective bites on human hosts (Chaves and Koenraadt, 2010). In western Kenya, Patz *et al.* (1998) demonstrated that modelled soil moisture and vegetation cover can be used to predict *An. gambiae* biting rates and malaria risk. Other studies used vegetation greenness to detect suitable conditions for mosquito development (Rodgers and Oliver, 2007; Dambach *et al.*, 2012). While comparing the effects of different land cover types on the malaria vector *An. gambiae s.l.,* Munga *et al.* (2006) suggested that factors such as land cover type influence mosquito productivity. Likewise, vegetation growth stages play a considerable role in determining mosquito vector abundance (Ceccato *et al.*, 2005). Irrespective of the association with rainfall, increased vegetation density provide suitable habitat for immature mosquitoes (Juri *et al.*, 2015) as well as resting sites and sugar feeding requirements for adult mosquitoes

(Lourenço *et al.*, 2011), and refuge from climatic conditions (Ceccato *et al.*, 2005). Mosquitoes are ubiquitous, abundant, and adaptable, with minimal habitat requirements (Yawson *et al.*, 2004; Sinka *et al.*, 2010). These survival and adaptation tactics make malaria control a challenge, thus numerous interventions have been developed and adopted.

2.5 Existing malaria prevention and control strategies

2.5.1 Institutional strategies

The World Health Organization (WHO) has in place a multipronged approach for malaria control and elimination. This has led to a substantial reduction in malaria deaths and cases as reported during the 2001-2015 period. Vector control is a principal strategy for malaria control and elimination (Karunamoorthi, 2011). The WHO recommends various vector control strategies including the use of insecticide-treated nets (ITNs), indoor residual spraying (IRS) and larval source management (LSM) (WHO, 2013a). Other malaria control mechanisms include intermittent preventive treatment in pregnancy (IPTp), prior diagnostic testing, and use of artemisinin-based combination therapy (ACT) treatment. In Kenya, the National Malaria Strategy (NMS) 2009-2017 reflects the WHO recommendations for vector control including integrated vector management (IVM). In the semi-arid zones, the government recommends the use of long lasting insecticide-treated nets (LLINs) among pregnant women and children under one year (Division of Malaria Control, 2011) contrary to the whole population as recommended in other epidemiological zones. The Kenya Health Policy 2012-2030 emphasizes, amongst other mechanisms, a multi-stakeholder involvement in malaria control. This supports the NMS that calls for scaled-up community management of malaria as well as communication campaigns for improved knowledge (Division of Malaria Control, 2011).

Numerous campaigns and socio-economic developments have led to malaria elimination from some parts of the world; however, in the tropics, malaria remains a major cause of illness and death (Berdud *et al.*, 2016). The use of policy-anchored ITNs and IRS remain the most dominant vector control tools used in minimizing and interrupting malaria transmission worldwide (WHO, 2013a; WHO, 2015a). For long-term benefit, malaria control will require tailored national strategies, extensive applied research and strong collaboration among stakeholders (Mlozi *et al.*, 2006; Opiyo *et al.*, 2007; WHO, 2013a). Community engagement is recognized as a crucial component in malaria control programs (WHO, 1975).

2.5.2 Individual and community-based strategies

The principal malaria control approaches have been widely promoted in Africa (De Allegri *et al.*, 2013). The ITNs and IRS operate at individual and household levels with impacts on the entire community (Chanda *et al.*, 2013; WHO, 2013a). Bhattarai *et al.* (2007) found that a combination of LLINs and ACT substantially reduced malaria prevalence in Zanzibar. In Burkina Faso, the use of ITNs among households, IPT for pregnant women and ACT for children under five years contributed significantly in reducing malaria transmission (De Allegri *et al.*, 2013). Both IRS and mass distribution of ITNs are recognized to have resulted in decreased malaria transmissions in western Kenya (Wanjala *et al.*, 2015; Bousema *et al.*, 2016). Despite these gains, a recent study found that insecticide decay and development of resistance, in part, decreased effectiveness of these first line interventions and recommendations have been made on development and use of alternative vector control tools (Wanjala *et al.*, 2015).

Community based strategies against malaria transmission include the use of school children as health ambassadors. This was found to contribute to decreased malaria prevalence, improved knowledge and health practices in Thailand (Okabayashi *et al.*, 2006) and Ghana (Ayi *et al.*, 2010). Ghosh *et al.* (2006) found that a community-based health education program reduced malaria prevalence through intensified knowledge and attitude change among a rural community in India. Knols *et al.* (2016) suggested the use of eave tubes as an additional and cost effective way of controlling *Anopheles* mosquitoes at household level. The ITN and IRS are limited at protecting individuals who stay away from homes during peak vector feeding times (Cotter *et al.*, 2013). As such, the use of insect repellent and personal protection could be feasible among such risk groups (Cotter *et al.*, 2013; Debboun and Strickman, 2013).

Studies have shown that the use of ITNs, IRS, personal protection products and other malaria treatment interventions significantly reduce malaria cases (Bhattarai *et al.*, 2007; Debboun and Strickman, 2013; Deressa *et al.*, 2014; Moiroux *et al.*, 2014; Van Eijk *et al.*, 2016).

However, these mechanisms have never been shown to eliminate malaria transmissions (Debboun and Strickman, 2013). In the tropics, residual malaria transmission may render malaria elimination unattainable without improved or new vector control tools or strategies (Killeen, 2014; Wanjala *et al.*, 2015). According to Beier *et al.* (2008), integrated vector management (IVM) remains the most sustainable malaria control strategy since core intervention mechanisms that target adult mosquitoes might not cater for reduction in residual malaria transmissions.

An integrated approach requires incorporating complementary larval control mechanisms to the principal strategies (Beier *et al.*, 2008; Imbahale *et al.*, 2012; Chirebvu and Chimbari, 2015). The larval source management (LSM) includes habitat modification, habitat manipulation, larviciding and biological control (Tusting *et al.*, 2013; WHO, 2013a). Modification of larval habitat provides a long-term and cost effective solution in areas where larval habitats occur seasonally, are well defined and easily accessible (Fillinger and Lindsay, 2006). Dale and Knight (2008) suggested that, efficient identification of larval habitat using local surveillance is necessary for successful vector management. Imbahale *et al.* (2012) found that incorporating LSM in vector management programs effectively reduced malaria transmission in the highlands of western Kenya. Other studies have also shown that larviciding is effective against several malaria vectors (Hanafi-Bojd *et al.*, 2012; Chaki *et al.*, 2014). Perhaps, LSM could be the best malaria vector control mechanism especially among species that exhibit behavioural evasiveness like *An. arabiensis* (Hardy *et al.*, 2013; Russell *et al.*, 2013; Killeen, 2014). These vector control options when integrated with principal interventions could substantially reduce residual malaria transmission at local level (Chanda *et al.*, 2013).

In Kenya, current malaria control strategies have not given precedence to LSM interventions (Maheu-Giroux and Castro, 2013). This provides a strong case for development of better larval management tools that target Anopheline species. For example, a study in Tanzania showed that larval habitat hydrology and geomorphology controlled the occurrence and productivity of *Anopheles* mosquitoes (Hardy *et al.*, 2013). Hardy *et al.* (2013) suggested that effective malaria control requires understanding at a local scale where the hydrological and geomorphological mechanisms are important in vector habitat formation. Additional research and pilot studies are needed to demonstrate that measures beyond commonly used interventions such as LLINs and IRS can substantially improve community resilience to malaria epidemics (Beier *et al.*, 2008; Mboera *et al.*, 2013). Effective malaria control and elimination in semi-arid northern Kenya, particularly Baringo County, will require detailed and area-specific understanding of ecohydrological conditions and their effects on mosquito abundance, to further the development of contextualized community-based malaria mitigation and adaptation strategies.

CHAPTER THREE: STUDY AREA AND METHODS

3.1 Introduction

This chapter presents a detailed description of the research methodology. The first section describes the location, biophysical and socio-economic contexts of the study area. The second section describes the conceptual framework of the study. The third section provides information on data sources, methods and techniques used during data collection. Qualitative data was obtained through focus group discussions (FGDs) and key informant interviews (KII) while quantitative data was collected using household survey questionnaires. Section four provides comprehensive data processing and analysis techniques. The last section provides information on ethical considerations of the study.

3.2 The Study Area

3.2.1 Location and description

Baringo County Kenya, located at latitude 00° 26'- 00° 32‘N and longitude 36° 00′- 36° 09' E, borders Turkana County to the North, Samburu and Laikipia Counties to the East, Nakuru County to the South, Kericho and Uasin Gishu Counties to the South West, Elgeyo Marakwet County to the West, and West Pokot County to the North West. The county has six sub-counties namely; Tiaty, Baringo South, Mogotio, Eldama Ravine, Baringo Central, and Baringo North. Baringo County is classified into four ecological zones based on altitude, vegetation types and climatic characteristics. The zones were identified as highland (1500-2300 m a.s.l.), mid-altitude (1000-1500 m a.s.l.), riverine (1100-1200 m a.s.l.) and lake ecosystem (lowland, below 1000 m a.s.l). For the purposes of this study, riverine and lowland zones (Figure 1) were selected for the study due to their distinctly different climatic and altitudinal conditions as well as malaria prevalence (Omondi *et al.*, 2017).

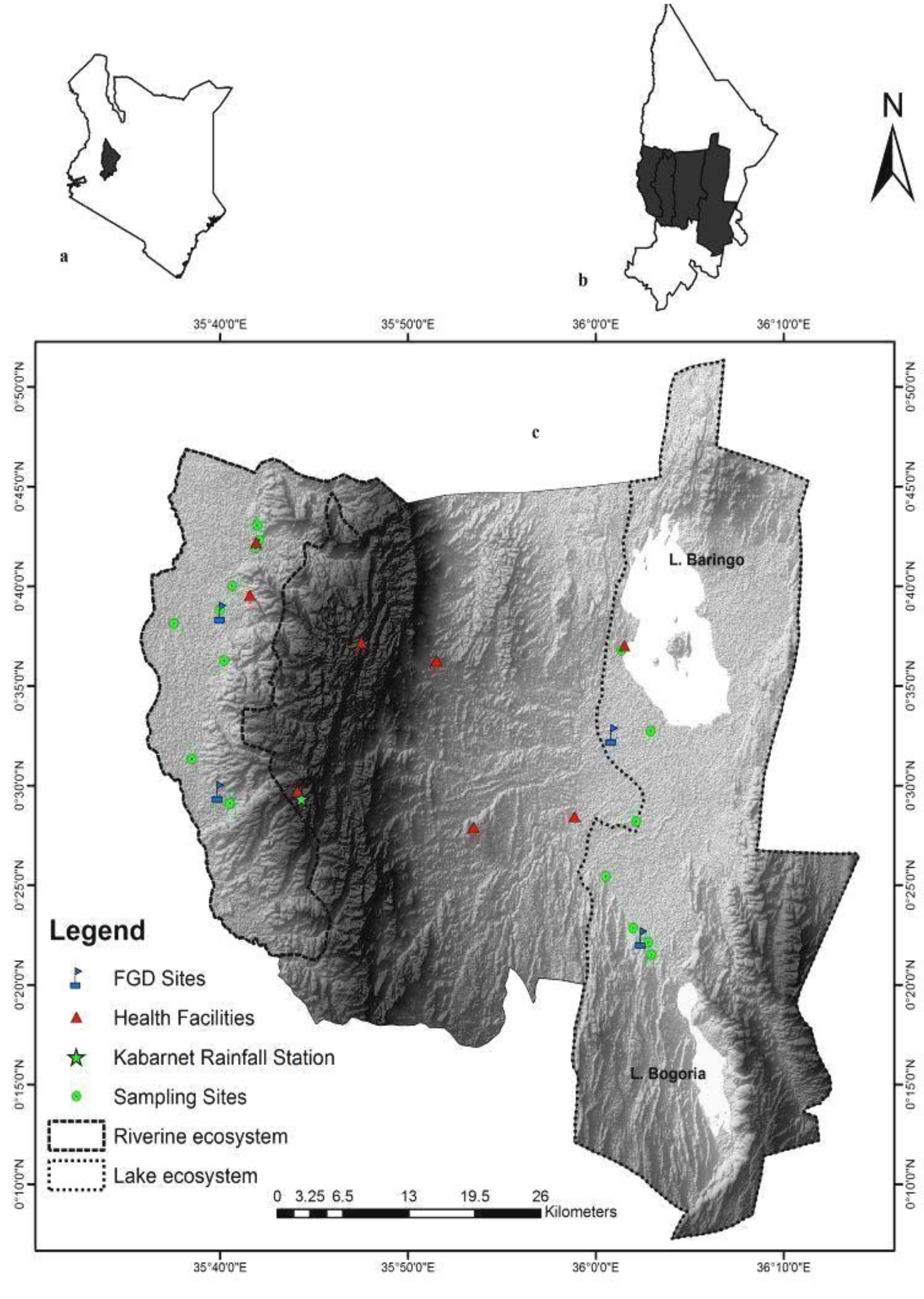

Figure 1: Map of Baringo County (Kenya) showing selected ecological zones, larval sampling sites, health facilities and FGD sites.

3.2.2 Biophysical setting

3.2.2.1 Climate

The daily air temperature ranges from 16°C to 42°C (Odada *et al.*, 2006) while mean monthly minimum and maximum temperatures are 20°C and 35°C respectively (Kaimba *et al.*, 2011). Average annual rainfall ranges from 300 to 600mm (Odada *et al.*, 2006). The rainfall pattern is bimodal and controlled by the annual evolution of the Intertropical Convergence Zone (ITCZ). The region has two rainfall seasons: March, April, and May (MAM) and October, November, December (OND).

3.2.2.2 Vegetation

Baringo County has different vegetation types ranging from riverine forests, wooded bushland, bushed thicket, bushed grassland and swamps. The distribution of the vegetation types strongly correlates to combinations of topography, soil types, elevation, drainage systems and soil moisture content (County Council of Baringo, 2007). The dominant vegetation are riparian forests and woodland in the riverine zone and wooded grassland and shrub in the lowland zone (White, 1983).

3.2.2.3 Soils and drainage

Clay soil with low infiltration rate predominates in the lowland zone. In the riverine zone, Fluvisols with sandy loam texture occur in areas around Lake Kamnarok while sandy clay to heavy clay soils with moderate to very poor drainage occur in other parts of Kerio Valley. The county has diverse rock formations including phonolites, trachytes, basalts, pyroclastic and Holocene flood deposits (Olago *et al.*, 2009). Baringo County lies within two drainage basins: the Baringo-Bogoria basin and Turkana basin (Olaka *et al.*, 2010). In the riverine zone, Kerio River flows north into Lake Turkana. Numerous ephemeral and some seasonal rivers that flood during rainy seasons are major features in the riverine zone. Lakes Baringo, Bogoria, and 94 occur in the Baringo-Bogoria basin. Two perennial rivers, Perkerra and Molo, feed Lake Baringo while Lake Bogoria is majorly fed by River Waseges in addition to several hydrothermal springs.

3.2.2.4 Biophysical vulnerabilities

The prevailing harsh climatic conditions coupled with projected climate change may expose the local communities living in Baringo County to several vulnerabilities including drought, flooding, famine, and outbreak of diseases such as cholera, malaria, yellow fever, rift valley fever (RVF), amongst other water-borne and vector-borne diseases. For instance, the 2012/2013 floods were preceded by the 2011 drought (considered the worst in 60 years) that immensely affected communities in Baringo County and larger Northern Kenya.

3.2.3 Socio-economic setting

3.2.3.1 Social setting

Baringo County had an estimated population of 655,641 in 2014 (KNBS, 2015). The population is largely rural and child rich. The poverty level was estimated at 58.5 % (KNBS, 2010). There are over 100 health facilities in Baringo, majority being underutilized due to lack of staff and equipment (Baringo County Government, 2014). The most prevalent diseases are upper respiratory tract infection, malaria and pneumonia (Baringo County Government, 2014). Malaria accounts for about 11.8% of outpatient visits (KIRA, 2014). The county has a poor road network, mainly earth and mixed types (Baringo County Government, 2014). The study area lies within four locations, namely; Kabarnet Soi, Kamnarok Soi, Loboi, and Njemps with a total population of 1,371 households (KNBS, 2010).

3.2.3.2 Economic setting

Baringo is largely rangeland with pastoralism, irrigation farming and apiculture being the dominant livelihood activities (Baringo County Government, 2014).

3.2.3.3 Socio-economic vulnerabilities

The synergistic effects of extreme climatic conditions particularly drought, and high poverty levels expose the communities to myriad socio-economic challenges. Inter-communal conflicts attributed to land ownership and competition over resource such as pasture and water occur in Baringo County (Mutsotso, 2017). Overgrazing and prolonged drought may cause further shortage of already scarce resources such as pasture and water that negatively affect local food security and livelihoods.

3.3 Conceptual framework

The conceptual framework is illustrated in Figure 2. Anthropogenic emission of greenhouse gases cause warming of the global air temperature (IPCC, 2014c). Global warming alters earth's climate system with far reaching impacts. These impacts include regional and local scale changes in seasons, extreme weather events and changes in species distribution and range (IPCC, 2014b). Of health concern is the potential shifts in population and distribution of mosquitoes, vectors of diseases such as malaria. The changing climate affects components of the ecohydrological system including vegetation, surface water, and soil moisture. Ecohydrological alterations influence the availability of mosquito breeding habitats, abundance and distribution, consequently impacting malaria risk. In sub-Saharan Africa, the public health burden posed by *P. falciparum* malaria is highest among rural communities, threatening lives and livelihoods (Snow, 2014).

The National Malaria Strategy (NMS) outlines LLINs and case management as primary strategies in dealing with malaria in semi-arid seasonal transmission areas such as Baringo County (Division of Malaria Control, 2009). These strategies are ineffective in reducing malaria prevalence since majority of the population remain vulnerable due to low LLIN coverage and outdoor transmissions. The WHO proposes a multi-pronged, IVM approach that when adopted results in substantial reduction in malaria transmission and possible malaria elimination (WHO, 2016). Local communities and stakeholders' participation in an IVM approach result in development and adoption of actionable plans and adaptation strategies. Adopting strategic malaria reduction strategies boosts community resilience by minimizing the health and social-economic impacts of climate change and variability.

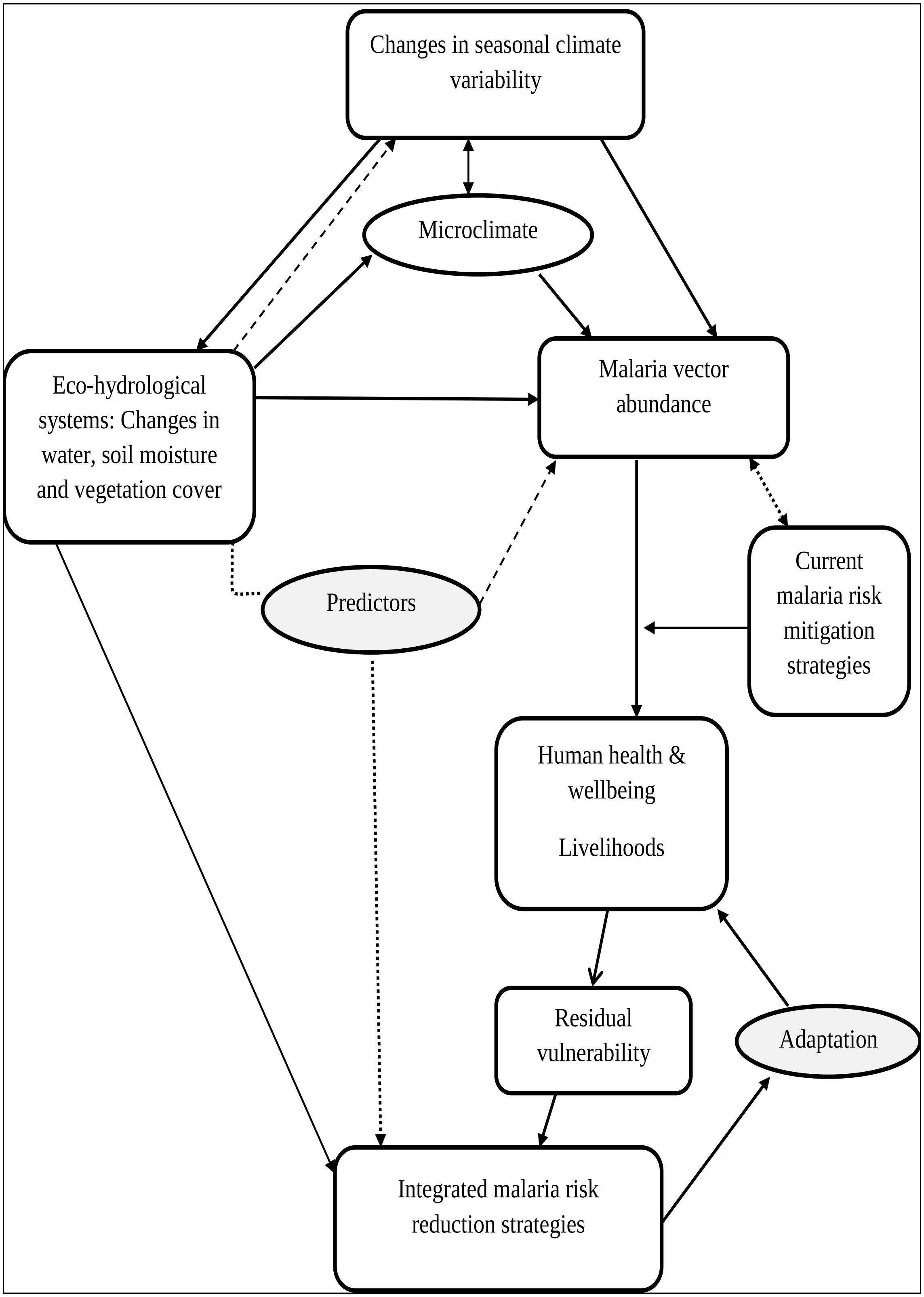

Figure 2: Conceptual framework for climate variability, ecohydrological changes, and malaria risks mitigation.

3.4 Methods

3.4.1 Trends in climatic and ecohydrological factors

3.4.1.1 Secondary data acquisition and collection

Land surface temperatures (T_{max} and T_{min}) for the period 2003 – 2016 were estimated from the USGS LandDAAC MODIS 1km 8-day version_005 dataset (Table 1). Climate Hazards Group InfraRed Precipitation with Station Data (Table 1) time series for the same period as temperature data was used to estimate rainfall in the region.

Table 1: Remotely sensed data, their sources and resolutions

Indicator	Data product	Source	Spatial resolution	Temporal resolution	Temporal range
Rainfall (mm)	CHIRPS	International Research Institute (IRI) Climate Data Library (http://iridl.ldeo.columbia.edu/SOURCES)	5 Km	Daily	2003-2016
T_{min}(°C)	Minimum Land Surface Temperature	International Research Institute (IRI) Climate Data Library (http://iridl.ldeo.columbia.edu/SOURCES)	1 Km	8-day	2003-2016
T_{max} (°C)	Inferred maximum temperature	International Research Institute (IRI) Climate Data Library (http://iridl.ldeo.columbia.edu/SOURCES)	1 Km	8-day	2003-2016
NDVI	MODIS-Aqua MODI13Q1	International Research Institute (IRI) Climate Data Library (http://iridl.ldeo.columbia.edu/SOURCES)	1 Km	16-day	2003-2016
Land cover	Landsat 8	USGS http://glovis.usgs.gov	30 m	Daily	Single day (27/12/2015)
Topographic wetness	Landsat 8	USGS http://glovis.usgs.gov/	30m	Daily	Single day (27/12/2015)
Slope	NASA SRTM data	https://lpdaac.usgs.gov/products/measures_products_table	30m	-	-

Daily precipitation data with a resolution of 0.05 were used to derive the total monthly and annual precipitation for each zone. Sixteen day mean values of the NDVI were derived from MODIS imagery from the Aqua Satellite for the 2003-2016 period (Table 1). The 16-day composites were averaged into monthly and seasonal means for each year. Rainfall, temperature, and NDVI data sets were downloaded as per the ecological zones. Table 1 summarizes the data sets used in the study, their sources, resolutions, and temporal ranges.

Daily discharge (m^3/s) for rivers Arror, Perkerra and Kessup and Lake Baringo water levels data for the period 2011 – 2014 were obtained from the then Water Resources Management Authority (now the Water Resources Authority under the Water Act, 2016) office in Kabarnet and were used to compute monthly averages. Data gaps in the daily records permitted analysis over a four-year period from 2011 to 2014. The gaps were imputed using MICE package in R software. All data were grouped into seasons as follows: (1) “long” dry season - December, January, February (DJF), (2) “long” rains season - March, April, May (MAM), (3) “short” dry season - June, July, August (JJA), (4) “short” rains season - September, October, November (SON).

3.4.1.2 Fieldwork

Community knowledge on rainfall and temperature trends; vegetation changes and stream flow during the past 10-20 years was assessed using FGDs, 2016 being the reference year. Table 2 shows the site locations and distribution by gender for the FGD discussions held in September 2016. Villages were divided into strata using administrative units. Eighty-six (86) people (47 women and 39 men) participated in eight (four gender specific) FGDs based on how long they had lived in the area, their knowledge, and personal experiences with climate hazards and malaria. The FGD guide (Appendix I) was pretested in one female FGD in Barwessa to assess content suitability, participatory processes, duration and to identify emerging issues. Individuals 40 years and above, who had lived in the area for a minimum of 10 years, were purposively selected for participation in the FGDs. The FGD sessions lasted 1 - 1 ½ hours and data was captured using a combination of audio records and note taking. The outcomes of the FGDs were used to establish important themes covered during household interviews.

Table 2: Summary of the dates, locations and the gender segregation in the FGDs

Dates	**Sites**	**Locations**	**Latitude**	**Longitude**	**FGDs**	
					Women only	Men only
27/09/2016	Litein	Kamnarok soi	0.64480	035.66726	13	12
28/09/2016	Salawa	Kabarnet soi	0.49480	035.66486	7	9
29/09/2016	Salabani	Njemps	0.54231	036.01435	11	12
30/09/2016	Kapkuikui	Loboi	0.37245	036.04063	16	6
Total attendance					47	39

Random sampling was used to administer 300 household questionnaires (Table 3) to households in the two ecological zones based on (Krejcie and Morgan, 1970) (equation 1). Semi-structured questionnaire was used during interviews. The questionnaire was first pretested in Marigat and Barwessa using a total of 30 respondents in October 2016. The two sites were eliminated during actual survey. Requisite changes were made on the questionnaire before data collection (Appendix II).

Table 3: The proportion of households surveyed during the study

Ecological zone	Location	Village	No. of Households
Riverine	Kabarinet soi	Salawa	70
Riverine	Kamnarok soi	Kabutiei	80
Lowland	Njemps	Salabani	80
Lowland	Loboi	Kapkuikui	70

$S=X^2NP(1-P) / d^2(N-1) + X^2P(1-P)$ Equation (1)

Where:

S ~ required sample size,

X^2 ~ the table value of Chi square for one degree of freedom at 95% confidence level (3.841)

N ~ population size

P ~ the proportion in the target population estimated (assumed to be 0.5)

d ~ the degree of accuracy expressed as a proportion (0.05)

During the survey, there was a near equal representation of males and females (Table 4). This provided a gender representation of opinions and views over matters relating to climate change and malaria epidemics (Table 4). Demographic characteristics were cross-tabulated with community perceptions and the results are presented in subsequent chapters. The age of the respondents ranged from 20 to 89 years, with a mean estimated age of 44 years. Respondents with more than 44 years of age were considered to have good historical knowledge of the past climate and weather events.

Table 4: Demographic information of the respondents (n = 300)

Gender			**Male**	**Female**
Lowland			66 (44.0%)	84 (56.0%)
Riverine			73 (49.0%)	77 (51.0%)
Total			139 (46.3%)	161 (53.7)
Level of Education	**Total frequency**	**(%)**	**% Male**	**% Female**
None	65	21.7	32.3	67.7
Primary	159	53.0	44.0	56.0
Secondary	53	17.7	58.5	41.5
Middle-level College	20	6.7	75.0	25.0
University	3	1.0	66.7	33.3

Majority of the respondents (53 %) had primary school education as shown in Table 4. Other respondents had secondary education (17.7%), middle level education (7%), and university education (1%). About 22% of respondents had no education. Majority of men had middle-level education. Generally, the levels of education presented were satisfactory for accurate data collection. Enumerators who were fluent in local dialects (Tugen and Ilchamus) assisted illiterate respondents during data collection.

3.4.1.3 Data analysis

Rainfall, temperature, and ecohydrological data were first scrutinized for missing values. Missing records over the selected study periods were less than 5% and were imputed using the multivariate imputation by chained equations (MICE) package in R software (Shah *et al.*, 2014). Seasonal and annual time series were derived from the daily, eight-day, 16-day, and monthly datasets. Trends in rainfall, temperature, NDVI, river discharge and lake levels were analyzed using non-parametric Mann-Kendall (M-K) test with Sen's estimator and Seasonal Mann-Kendall (SMK) test (Mann, 1945; Kendall, 1975) in R version 3.2.2 software (R Core Team, 2015).

Diagnostic tests for climate and ecohydrological data sets were conducted using Shapiro-test and Q-Q-norm plots. Thus, vegetation and discharge data were log transformed to linearize the fit before regression analysis was conducted. In order to eliminate the negative logarithms, datasets were multiplied with a constant value of 10. A cross correlation function (CCF) was used to assess the relationship between vegetation, discharge, and lagged (0, 1, 2 and 3-month intervals) climate variables (rainfall and temperature) as used in studies by (Gownaris *et al.*, 2017). Multiple regression models were created with NDVI and discharge as the response variables and rainfall, T_{max} and T_{min} as predictor variables. The additive models developed (Logan, 2011) were compared using ANOVA test in order to select the best fit model for final analysis. This was followed by backward stepwise variable selection performed using the function "step" in MASS package in R. Non-significant variables were excluded sequentially from the final model based on Akaike Information Criterion (AIC) values. The short rains season (SON) was used as a reference season in the models. Dummy variables were included in the data to account for seasonality. Seasons were ordered as: (S1) - DJF, (S2) - MAM, (S3) - JJA, and (S4) - SON.

Audio files from FGDs were transcribed and each script verified by comparing the notes to the transcribed scripts. This was followed by data entry, cleaning and coding into emergent themes using the content analysis method in NVivo version 10. Major themes included temperature changes, rainfall pattern, vegetation changes, hydrological changes, flood events, drought events, climate and livelihoods, climate alterations and malaria, occupation and malaria risks, malaria control methods and barriers to malaria control. The major themes in all transcripts were further coded into sub-themes which were then clustered together using comparable topics. This was followed by a tally of the groups that had similar themes / sub-themes. Household survey data was entered, cleaned and analysed in STATA version 13.1. Chi-square test was used to identify associations between variables.

3.4.2 Relationship between ecohydrological factors and malaria vector

3.4.2.1 Secondary data acquisition and collection

A 30m resolution Landsat 8 image for Baringo County was acquired for 27th December 2015. The dates were screened and selected based on minimum cloud cover in the scene. Supervised land cover classification was conducted in R software. The land cover types were classified based on Food and Agriculture Organization (FAO) classification scheme (Di Gregorio, 2005). The accuracy of land cover types was verified by field observation and with the aid of a GPS receiver for georeferencing. The NDVI (Band 5 – Band 4) / (Band 5 + Band 4) map generated from the Landsat image was used to assess the vegetation health of the study area as described by (Tucker, 1979). Bands 5 and 4 correspond to near-infrared and red channels in the spectral reflectance. MODIS land surface temperature and precipitation (CHIRPS) raster data both at 5 km resolution were also used to generate species suitability map.

Topographic wetness index (TWI) derived from the Landsat image was used as proxy for moisture content. Topographic wetness is a suitable proxy for soil moisture and an important ecohydrological factor influencing the duration and occurrence of mosquito breeding habitat (Nmor *et al.*, 2013). Six spectral bands, from radiometrically corrected imagery were used in deriving the topographic wetness. Tasseled cap transformation was applied to the bands based on the coefficients (Liu *et al.*, 2014). The values were standardized by a scaling factor creating a range of zero to one where one represented areas of high topographic wetness value while zero represented areas with low wetness value. Area slope was generated from the Shuttle Radar Topography Mission (SRTM) digital elevation map (DEM).

3.4.2.2 Field work - entomological survey

Based on ecological zonation, stratified random sampling was employed in selecting 16 sampling sites. In the riverine zone sampling sites were Salawa, Tilalwa, Ketiborok, Mbakarpei, Litein, Kamnarok, Enot, Barwessa Secondary and Barwessa River. Kapkuikui, Loboi, Salabani, Robert’s camp, Nteppes, Eldume and Tirion were selected in the lowland zone. All sampling sites were georeferenced using a Garmin Etrex 10 handheld GPS receiver. Mosquito larvae were collected on a monthly basis for a period of 13 months from December 2015 to December 2016.

In each ecological zone, permanent and transient breeding habitats were sampled for the presence of *Anopheles* species. Sampling of mosquito larvae was carried out in various permanent habitats including lake edge, river fringe, canal overflow, swamp edge, drain, pan dam, and water pit (Appendix III). Hoofs prints, rain pools and concrete tank were the transient sampling sites surveyed. In each habitat, 10 dipper samples (350 mL) were taken using slow dip technique (Elliott, 1977). A pipette was used for larval collection in habitats where dipping was not possible. All samples were preserved in 95% ethanol for later identification. Immature mosquitoes were identified morphologically to species level using (Highton, 1983) and (Gillies and Coetzee, 1987) keys. During the study, a total of 3,460 mosquito larvae belonging to 11 species were collected and preserved.

3.4.2.3 Data analysis

The relationship between climatic-ecohydrological factors and *Anopheles* larvae distribution was conducted using a generalized linear mixed model (GLMM) with negative binomial regression (Bliss and Fisher, 1953). Two-tailed correlation analysis was used to determine factors associated with *Anopheles* larvae. To build the models six-predictor variables including temperature, rainfall, TWI, vegetation cover, vegetation health, and slope were used. All predictor variables were standardized to values ranging between 0 - 1 and then resampled to 100 m resolution to enable comparison. *Saaty* pair-wise comparison enabled ranking of land cover classes (Saaty, 2008). The best model was selected based on the lowest AIC value.

3.4.3 Framework for malaria risk reduction

3.4.3.1 Data collection

A combination of FGDs, KIIs (Appendix IV), and questionnaires data were used to gather information on local knowledge about cause, treatment and prevention of malaria. Appendix V shows the details of the 12 key informants and the dates when the interviews were conducted. Monthly clinical malaria cases for the period 2005 – 2014 were obtained from four health facilities namely Barwessa and Keturwo dispensaries in the riverine zone and Kampi ya Samaki health centre and Marigat sub-county hospital in the lowland zone (Appendix VI).

3.4.3.2 Stakeholder identification and framework development

Local communities are at the core of any risk management plan. Their perception, views, and understanding of the problem is crucial in designing actionable solutions. In this study, community identification was based on the matrix ranking (Abarquez and Murshed, 2004) in which stakeholders in the lowland and riverine zones were purposively selected and participated in the development of a malaria risk reduction plan. The local provincial administrations aided the identification of the stakeholders. Two participatory stakeholders' discussions were conducted during the month of May, 2017, in Salawa and Marigat. The meetings had 21 and 25 participants drawn from the riverine and lowland zones, respectively (Appendix VII). A community based disaster risk management (CBDRM) process (Abarquez and Murshed, 2004) guided the development of the malaria risk reduction plan for communities living in Baringo County. Themes identified during the FGDs, KIIs and questionnaires were used during discussions. A combination of ranking, seasonal calendars and group discussions were used during malaria risk assessment and planning process. The outcomes are described in section 4.6.9.

3.4.3.3 Data analysis

Methods used to analyse qualitative data from FGDs and KIIs were similar to those outlined in section 3.4.1.3. Quantitative data from questionnaires were analysed as indicated in section 3.4.1.3. Daily Malaria data for the 2005-2014 period was used in trend analysis, this being the duration when data was available in all health facilities. The methods for malaria trend analysis were similar to those of climatic data analysis outlined in section 3.4.1.3. Annual malaria cases (total) for the year 2014 was used to map the spatial distribution of malaria cases using ArcMap 10.0.

3.5 Data synthesis

Analysis of rainfall, minimum and maximum temperatures, NDVI, and discharge trends was conducted to identify the pattern in climate, vegetation and discharge changes in the lowland

and riverine zones. To determine the influence of climatic factors (rainfall and temperatures) on vegetation greenness as well as discharge, regression analysis was performed with lags ranging from 0 to 3 months. This was followed by a GLMM by negative binomial regression to model the association between *Anopheles* larvae and six predictor variables, namely; temperature, rainfall, TWI, vegetation cover, vegetation health, and slope. Significant variables from environmental analysis were triangulated with data from household survey, FGDs and KIIs and used during stakeholders' discussions to develop a framework for malaria risk reduction for communities living in Baringo County.

3.6 Ethical considerations

Research authorization was obtained from the National Commission for Science, Technology, and Innovation (NACOSTI) reference number NACOSTI/P/15/47798/8347. This research also received clearance from the KNH/UoN-Ethics and Research Committee reference number KNH-ERC/R/75. Permission to administer questionnaires and conduct FGDs and KIIs was obtained through a written informed consent. For illiterate participants, consent taking took place in the presence of a literate witness who verified that the information was understood by the participant and consent given at free will. The identification of participants was done through community key persons such as Chiefs and Assistant Chiefs.

CHAPTER FOUR: RESULTS AND INTERPRETATION

4.1 Introduction

This chapter sequentially provides results and detailed discussions of the study objectives. Sections 4.2 and 4.3 provide result and interpretation of outputs of the first objective. The last two sections (4.4 and 4.5) deal with output and discussion of the second and third objectives respectively. Globally, discussion of results triangulates scientific and community perspectives in a transdisciplinary approach.

The main livelihood activities of the communities were crop farming and livestock rearing which stood at 54.7% and 18.3%, respectively. About 12% of the respondents were self-employed with a high proportion (75%) living in the lowland zone. Of the livestock reared, indigenous cattle accounted for 48.6% of the total livestock breeds in both lowland (23.3%) and riverine (25.3%) zones (Figure 3). Goats and cross-bred cattle accounted for 18.6% and 15.5% of the total livestock, respectively.

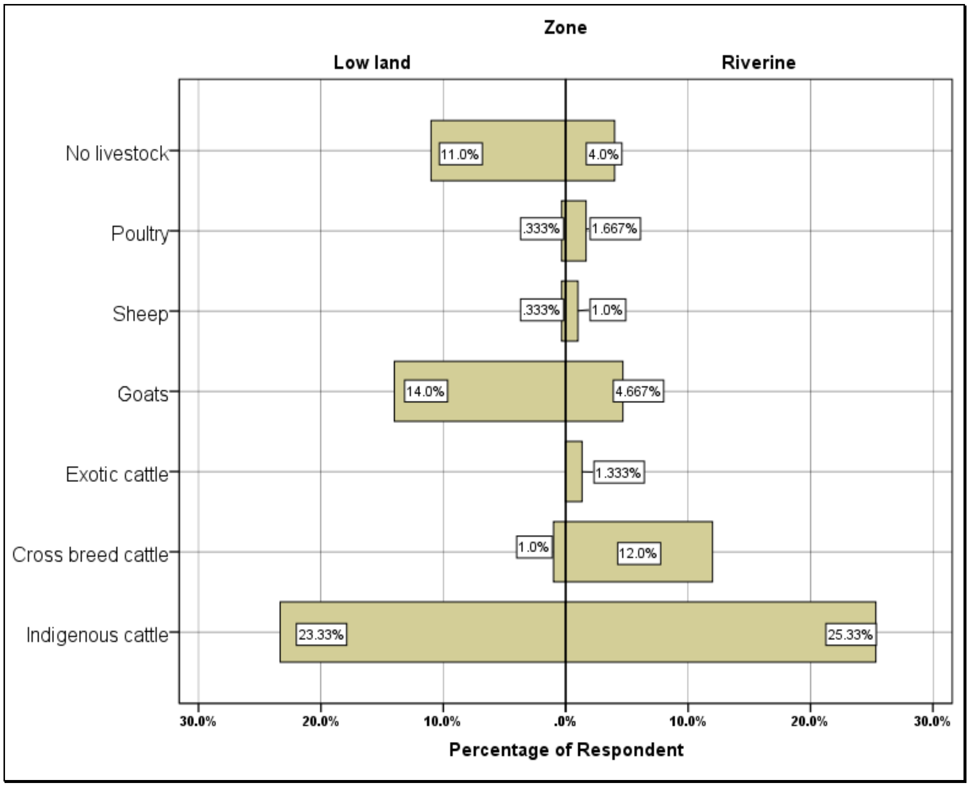

Figure 3: Types of livestock kept by communities living in Baringo County

4.2 Climate trend in Baringo County during 2003-2016 period

Results in sections 4.2 and 4.3 were published as ‘Amadi, J. A., Olago, D. O., Ong’amo, G. O., Oriaso, S. O., Nanyingi, M, Nyamongo, I, K. and Estambale, B. B. A. (2018). Sensitivity of vegetation to climate variability and its implications for malaria risk in Baringo, Kenya. *PLOS ONE*, **13**(7): e0199357. https://doi.org/10.1371/journal.pone.0199357’

4.2.1 Temperature

4.2.1.1 Annual trends

Temperature is the primary driver of global climate change. This study analysed the temperature changes in two ecological zones in Baringo County during the 2003 - 2016 period. The results show that during the 14-year period, significant increases in T_{min} and T_{max} trends were observed in the lowland zone ($p<0.05$) contrary to decreasing trends observed in the riverine zone (Table 5).

Table 5: Mean monthly temperature change (T_{min} and T_{max}) in the two zones during the 2003 -2016 period. Bold font indicate statistical significance at $p = 0.05$.

Months	**Lowland**				**Riverine**			
	$\mathbf{T_{min}}$		$\mathbf{T_{max}}$		$\mathbf{T_{min}}$		$\mathbf{T_{max}}$	
	tau	**p**	**tau**	**p**	**tau**	**p**	**tau**	**p**
January	-0.077	0.702	-0.077	0.702	-0.407	**0.043**	-0.385	0.056
February	0.121	0.547	0.143	0.477	-0.187	0.352	-0.165	0.412
March	0.319	0.112	0.319	0.112	0.209	0.298	0.253	0.208
April	0.077	0.702	0.077	0.702	-0.099	0.622	-0.143	0.477
May	0.253	0.208	0.407	**0.043**	0.011	0.956	0.165	0.412
June	0.132	0.511	0.165	0.412	0.121	0.547	0.319	0.112
July	0.560	**0.0052**	0.560	**0.0052**	0.066	0.742	-0.099	0.622
August	0.253	0.208	0.165	0.412	0.121	0.547	0.077	0.702
September	0.187	0.352	0.187	0.352	-0.165	0.411	0.077	0.702
October	0.143	0.477	0.121	0.547	-0.165	0.412	-0.187	0.352
November	0.231	0.250	0.231	0.250	-0.275	0.171	-0.187	0.352
December	0.319	0.112	0.231	0.250	-0.055	0.784	-0.077	0.702
Overall	0.210	**0.0003**	0.211	**0.0003**	-0.089	0.125	-0.029	0.613

Studies have shown that minimum and maximum air temperature trends are neither stable nor increasing but often depict fluctuations over varied temporal scales. For instance, while King'uyu *et al.* (2000) and Ageena *et al.* (2014) found decreasing T_{min} and T_{max} trends, warming trends were reported across different parts of Africa (Wandiga *et al.*, 2010; Jury and Funk, 2013; Omondi *et al.*, 2014). The short-term cooling episodes are not unique to this study as decreasing minimum temperature trends have been previously reported in Serbia (Gavrilov *et al.*, 2016) and Northeast Brazil (Lacerda *et al.*, 2015) during 2000 - 2010 and 1960 – 2011, respectively. Although the recent global warming has been largely attributed to anthropogenic effects (IPCC, 2014c), the cooling episodes are linked to short-term climate fluctuations and vegetation influences (Rangwala and Miller, 2012; Fyfe *et al.*, 2016). A study in San Juan Mountains, Colorado found a decrease in maximum temperature during 2006-2009, further suggesting that inter-annual variability in precipitation could be affecting T_{max} more than T_{min} (Rangwala and Miller, 2010).

In the FGDs, there were varied opinions among people living in riverine and lowland zones on whether climate had become hotter or cooler. Generally, 55% of the discussants believed that the temperature was warmer than it was 10 years earlier. These opinions were in agreement with those reported in Burkina Faso (Sanfo *et al.*, 2014) and Tanzania (Mwakalila *et al.*, 2011) where people believed that climate had become warmer over the last two decades. In this study, 39% of the discussants from the riverine zone had views that were consistent with climate observations. Discussants argued that, in the 1990s, during January - March period, they could sleep till morning without using a blanket as opposed to the year 2016 during which the temperatures were cooler. Contrary to the observed warming pattern, the locals in the lowland zone felt that the temperature was lower than it was a decade or more ago relative to the year (2016) when the survey was conducted. The locals attributed the cool conditions to the effect of vegetation cover change as a result of *Prosopis* invasion over the past three decades. This local perception is supported by scientific observations that reported local-scale thermal comfort due to vegetation-temperature feedback (Perini and Magliocco, 2014). The aforementioned short-term temperature variations influence communities' perceptions and responses to long-term temperature trends in the region.

4.2.1.2 Seasonal and monthly trends

Although there was no evidence of change in the seasonal temperature, Figure 4 shows a general increase in T_{min} and T_{max} across all seasons in the lowland zone. The JJA season warmed faster compared to other seasons. In the riverine zone, heterogeneous seasonal temperature trends were observed with decreases in T_{min} in the SON and DJF seasons and increases in the MAM and JJA seasons. The observed warming trend in the lowland zone was consistent with a study that found a warming T_{max} trend in all seasons in Kericho, Kenya during the 1978 - 2004 period (Wandiga *et al.*, 2010). Funk *et al.* (2012) also reported a warming trend during MAM and JJA seasons across Kenya.

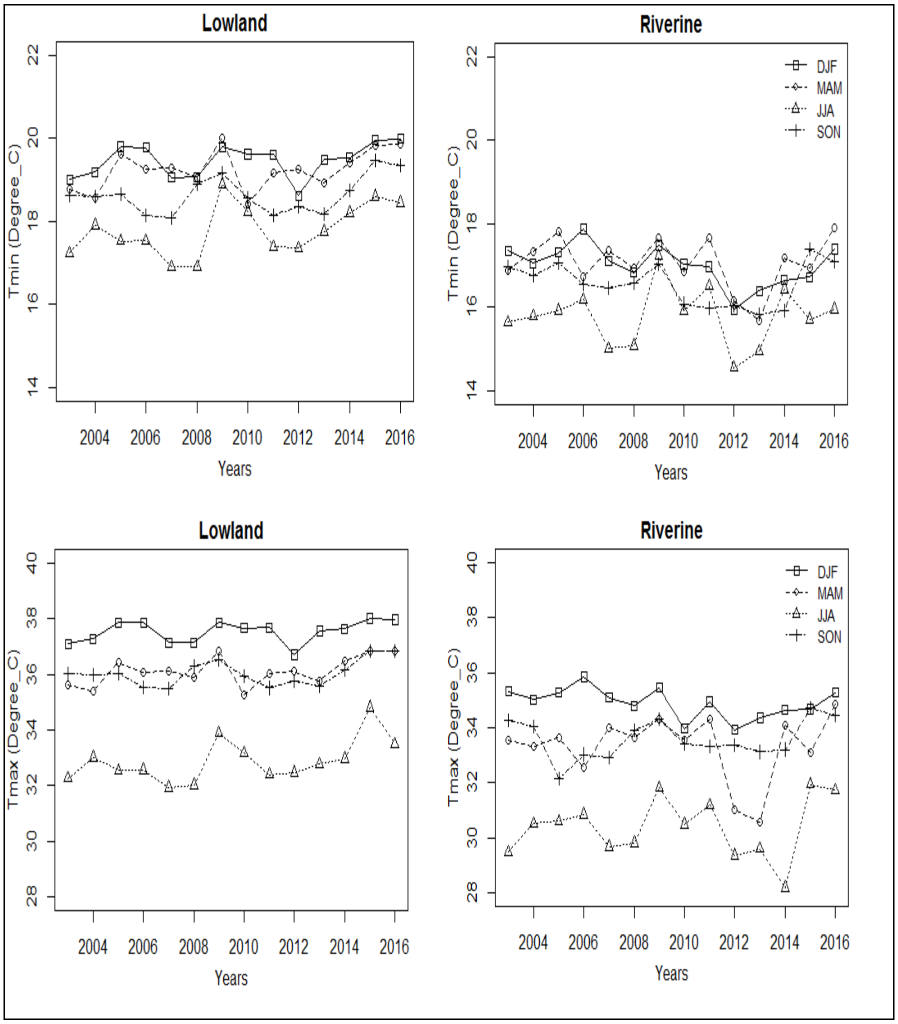

Figure 4: Seasonal T_{min} and T_{max} trends during the 2003 to 2016 period

Higher mean monthly T_{min} and T_{max} were recorded in the lowland zone compared to the riverine zone (Figure 5). January - March were the hottest months while June - August were the coolest, results that are in agreement with local opinion on monthly temperature pattern in the area. Despite being the coolest period, there was significant warming in T_{min} and T_{max} during the months of May and July in the lowland zone (Table 5). General warming trends were detected in all months in the lowland zone except during January where a decrease in both T_{min} and T_{max} trends was noted (tau = -0.077; $p > 0.05$). There was a significant decrease in T_{min} during the month of January in the riverine zone (tau = -0.407; $p < 0.05$). Generally in the riverine zone, some months showed increased temperature while others showed a decreasing trend. The warming pattern during May and July culminated in warmer MAM and JJA seasons in Baringo County.

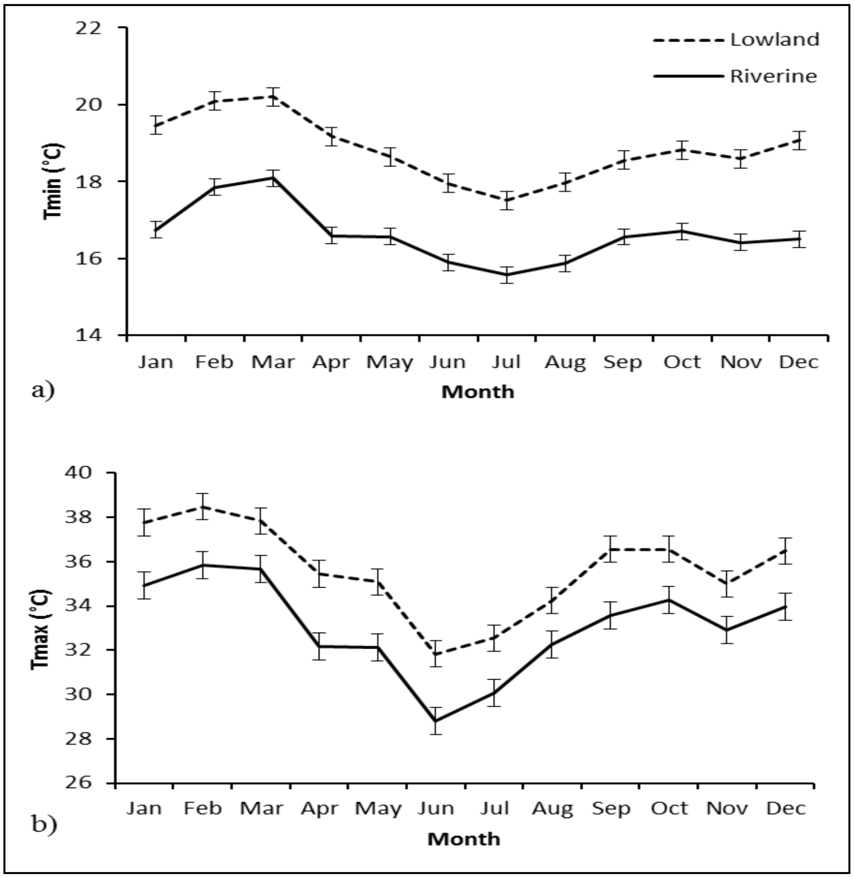

Figure 5: Mean monthly minimum (a) and maximum (b) temperature trends during the 2003 to 2016 period

In the FGDs, there was consensus in local opinion on MAM temperature increase. Discussants from the riverine zone reported extreme diurnal temperature with warmer days and cooler night. The increasing seasonal temperature trend was also reported among communities in Ruaha catchment in Tanzania (Mwakalila *et al.*, 2011).

4.2.2 Rainfall

4.2.2.1 Annual trends

There was no change in mean annual rainfall trend during the 2003 - 2016 period in both lowland (tau = 0.004, p = 0.936; Figure 6a) and riverine zones (tau = 0.037, p = 0.061; Figure 6b). This finding agreed with recent studies conducted in some parts of Africa (Hoscilo *et al.*, 2014; Mishra *et al.*, 2015). Conversely, declining mean annual rainfall trends linked to sea surface temperature (SST) anomalies have been reported in other parts of Kenya and the GHA (Funk *et al.*, 2012; Omondi *et al.*, 2012; Liebmann *et al.*, 2014). There was a high year-to-year rainfall variability (above means) in the riverine zone compared to the lowland zone, the wettest year being 2012 and 2009 the driest.

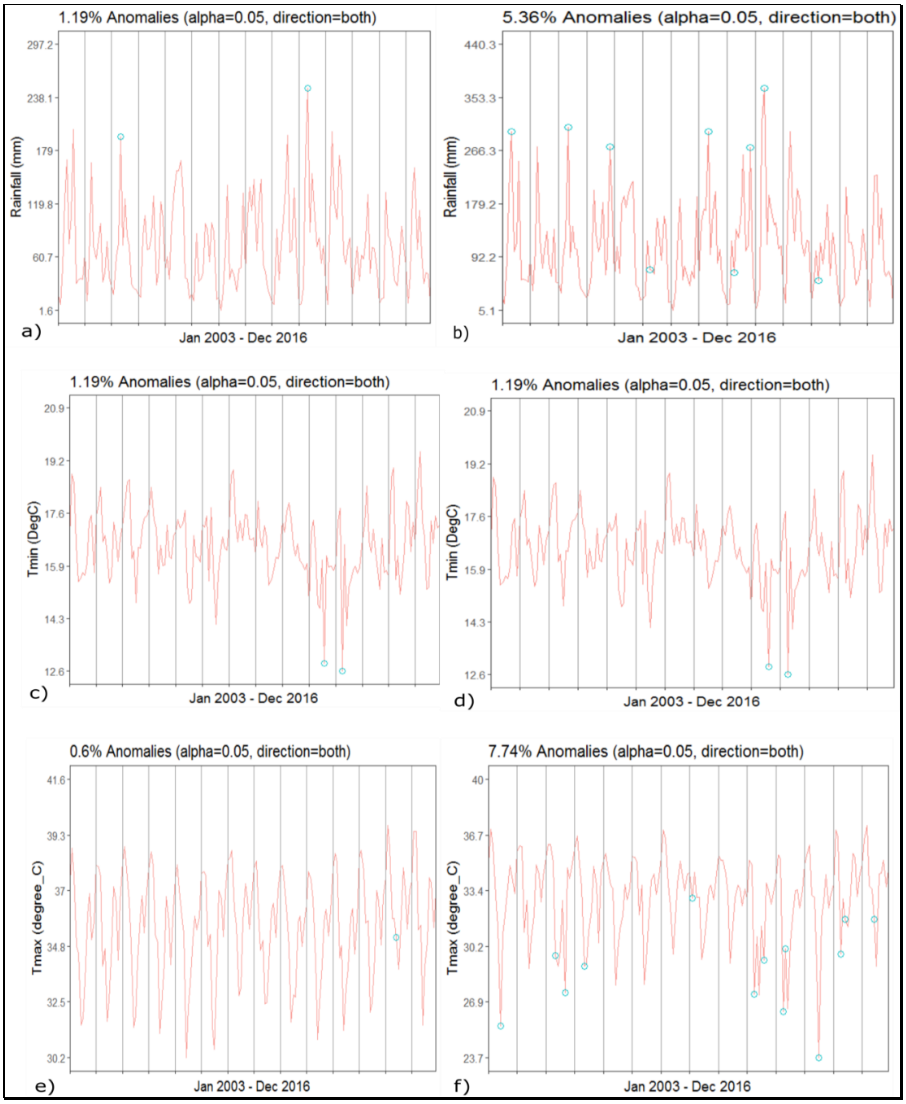

Figure 6: Trends in annual anomalies averaged for 2003 - 2016 period for rainfall (a and b), LST (night) (c and d), and inferred maximum temperature (day) (e and f) in the lowlands and riverine zones respectively.

Consistent with results shown in Figure 6, there was concurrence in all FGD on the year-to-year rainfall variability in Baringo County, 2016 was considered as a “good” year compared to 2015. The local communities considered the temporal distribution of rainfall as erratic and unpredictable. These observations were common in other studies on changing rainfall patterns in Tanzania (Mwakalila *et al.*, 2011), Burkina Faso (Sanfo *et al.*, 2014), Ghana (Yaro, 2013) and Indonesia (Boissière *et al.*, 2013). The observations were captured in the following statement:

> *'There are some years when we get good rains, others we don't. Some years we get much heavier rainfall, for example, this year (2016) is not bad.'* Male discussant, Salawa.

There was lack of consensus among the discussants on whether annual rainfall had increased or not. However, majority (five out of eight) of them felt that rainfall had declined over the past decade, findings similar to those in Ruaha catchment Tanzania (Mwakalila *et al.*, 2011) and Ghana (Yaro, 2013). In this study, the locals clearly recalled major climate events such as drought, floods and soil erosion. For example, there was a common conviction among discussants on a post-1984 rainfall decline similar to the climate observations by Omondi *et al.* (2014), Funk *et al.* (2012) and Williams *et al.* (2012) over East Africa. In their study on East African long rains, Yang *et al.* (2014) suggested that natural variability occurring at decadal time scale was the key driver causing the recent decreasing rainfall trends. A discussant stated the following:

> *'You see, in 1984 there was no rainfall. The crops were completely destroyed. Since then, it (rainfall) changed completely.'* Female discussant, Salawa.

In the lowland zone, discussants from Salabani had a contrary opinion, stating that rainfall had increased. They cited frequent flooding in the area as a sign of enhanced rainfall. The variations in local opinion on the rainfall trend in both lowland and riverine zones could be attributed to high rainfall variability (Cubasch *et al.*, 2013). Furthermore, there has been a lack of consensus among climate models and researchers on the evolution and future trend of the "paradoxical East African precipitation" (Yang *et al.*, 2014; Lyon and Vigaud, 2017). This increases vulnerability of the rainfall-dependent communities in Baringo to climate risks by affecting their livelihood resources such as pasture and crop production.

4.2.2.2 Seasonal and monthly trends

In both zones, there was no change in seasonal rainfall trend. However, MAM and JJA seasons showed a general decrease while SON and DJF seasons showed general increase ($p > 0.05$; Figure 7). These findings were in agreement with other studies such as Williams *et al.* (2012) and Liebmann *et al.* (2014) that reported a decrease in MAM rains in parts of East

Africa. Liebmann *et al.* (2014) suggested that the strength of seasonal changes in precipitation is often weakened by robust year-to-year rainfall variabilities. Generally, there was no evidence of variation in monthly rainfall trends in both lowland and riverine zones except during the month of October as shown in Table 6.

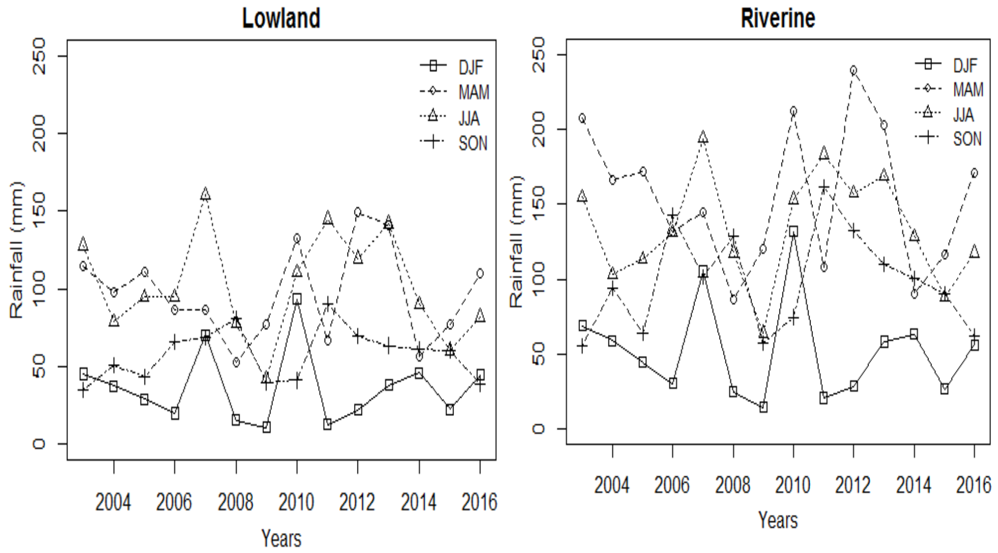

Figure 7: Seasonal rainfall trends in the lowland and riverine zones during the 2003 to 2016 period

Table 6: Monthly rainfall trend during the 2003-2016 period. Bold font indicate statistical significance at p = 0.05.

	Lowland zone		**Riverine zone**	
Month	**tau**	**p**	**tau**	**p**
January	-0.231	0.250	-0.275	0.171
February	0.011	0.956	-0.165	0.412
March	-0.011	0.956	-0.099	0.622
April	0.055	0.784	-0.055	0.784
May	-0.011	0.956	-0.099	0.622
June	0.033	0.870	0.187	0.352
July	0.077	0.702	0.275	0.171
August	-0.187	0.352	-0.209	0.298
September	-0.099	0.622	-0.055	0.784
October	0.385	**0.048**	0.275	**0.051**
November	0.143	0.477	0.077	0.702
December	0.033	0.870	0.033	0.870
Overall	0.016	0.776	-0.009	0.874

There was concurrence among all FGDs on decreasing amounts of rainfall during the long rains (MAM) as compared with the short rains (SON). These perceptions were in agreement with the results shown in Figure 7. Similar depressed rainy seasons were reported by communities in Tanzania (Mwakalila *et al.*, 2011). In all FGDs, discussants agreed that heavy rains that were a norm during the month of April were no longer experienced in the area. By the year 2016, the long rains received were erratic with intermittent breaks that negatively affect crop production, opinions captured in these excerpts:

> *'Nobody knows the onset of the rains. It is possible to plant in April, May, or June as opposed to the past when everyone knew that by mid-March it would be raining and everyone would be planting.'* Male discussant, Salawa.

> *'The rains are not consistent. It might start to rain then shortly the rains disappear. In the past when it started raining, it rained heavily such that even if it stopped raining for two weeks crops would not wither. But nowadays, if it stops raining for two weeks, if you go to the farm you will find your crops looking like onions.'* Male discussant, Salawa.

The locals explicitly described the changing seasonal rainfall pattern. All (four) FGDs conducted in the riverine zone concurred that a phenomenon locally referred as "*Sogek*" rains (Tugen) occurred during late February/early March. However, the said phenomenon was no longer experienced, a local indicator of a changing seasonal pattern. The month of March marked the onset of the long rains season. The rains would extend to May and a short break occurred in June followed by July-August rains. However, by the year 2016, the long rains were considered depressed and were received after March. The short rains season locally known as "*Cherobon*" (Tugen) occurred during October-December. The local opinion on seasonal rainfall patterns agreed with observed climatic patterns in the region (Omondi *et al.*, 2012; Yang *et al.*, 2014). Additionally, strong northern winds that occurred in March indicated the onset of the long rains season. These winds were reported to have disappeared as indicated in the following quote:

> *'Once those strong winds passed then it would not take one week before the rains start. We no longer have any signs of rains, even the clouds may cover the sky and still it might not rain.'* Female discussant, Salawa.

4.3. Influence of climate variability on ecohydrological systems

4.3.1 Vegetation trends during the 2003 - 2016 period

4.3.1.1 Annual trends

Annual vegetation trends are shown in Figure 8. Vegetation greenness substantially declined in 2009 and an increase occurred thereafter with peak greenness during 2012 - 2013. This study showed a statistically significant increase in NDVI in the riverine zone (tau= 0.103; p= 0.047) while there was no change in annual vegetation trend in the lowland zone (tau=0.051; p>0.05; Figure 8). The observed increase in vegetation in the riverine zone could be due to local-scale rainfall anomalies that alters the growth pattern of riparian forests and woodlands in the area. However, the presence of evergreen woody plant encroachment (mainly *Prosopis* species) could have contributed to the non-significant change in annual NDVI trends in the lowland zone. Consistent with this study, Zewdie *et al.* (2017) found a declining annual NDVI trend during 2009 with an increase during the post-2010 period in northwest Ethiopia.

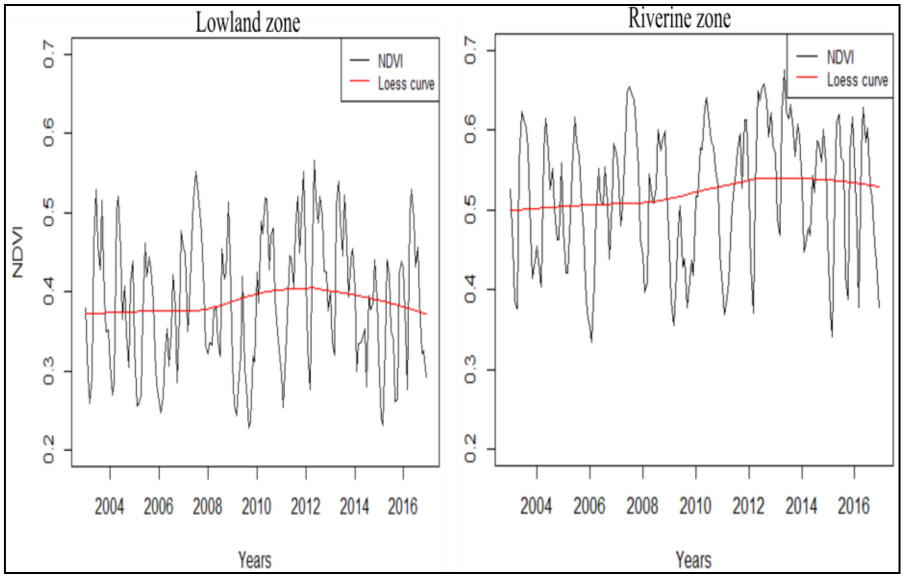

Figure 8: Annual NDVI trends observed during the 2003 to 2016 period

There was convergence of opinion among discussants in all FGDs on vegetation cover changes in Baringo County. In the riverine zone, discussants asserted that the region had become greener than it was over a decade ago. Similarly sentiments were reported in the lowland zone. In both zones, it was reported that the density of woody vegetation had increased replacing the once vast grasslands; *Terminalia kilimandscharica* and *Prosopis juliflora* dominating the riverine and lowland zones, respectively. The introduction of *Prosopis juliflora* by the Kenya government during the early 1980s led to an alteration of the vegetation composition in the Lake Baringo-Bogoria ecosystem as shown in the excerpt below:

> *'At around 1983, this place was like a desert, at some point people started complaining about dust storm... So, a certain District Commissioner (DC) advised them to plant trees. He (the DC) told some elders to get trees from Kenya Forest Service… He (the DC) sometimes encouraged people by giving them maize through "Food for Work" programme. So, Prosopis juliflora were planted in all fields in Meisori, Salabani, Ngambo, and Lamalok.'* Male discussant, Salabani.

Anomalous rainfall and increased density of invasive plants species may have had a synergistic effect on the overall vegetation greenness in Baringo County. The evergreen *Prosopis* forms impenetrable thickets that may have displaced dominant tree species like *Balanites aegyptiaca* and some *Acacia* species. It was reported that the *Prosopis juliflora* bushes covered waterways and channels of main rivers like Molo, Perkerra, and Waseges resulting in changes in river courses that displaced many families. Communities living along the shores of Lake Baringo (mainly Turgen and Ilchamus) believed that the *Prosopis juliflora* bushes influenced the microclimate causing increased rainfall, lower air temperature and reduced dust storms "Chebomo" (Tugen). This is illustrated in the following excerpt:

> *'Earlier, when there were no Prosopis you could see Marigat from here. The area was bare, so strong wind from Lake Baringo used to blow… If you could see it (dust storm) you would think it's really raining but it's nothing.'* Male discussant, Kapkuikui.

Land use change especially irrigation agriculture in areas near Perkerra, Salabani, Ngambo and Loboi may have contributed to increasing vegetation greenness in the lowland zone. This was captured in the following statement.

> *'Although we used to do farming, it was in small scale as opposed to recently (2016) where it is practiced in large scale.'* Male discussant, Salabani.

4.3.1.2 Seasonal and monthly trends

There was no change in seasonal NDVI values in the riverine and lowland zones during the 2003 – 2016 period. Similarly, monthly NDVI did not change in both zones. There was a decrease in NDVI between the months of January and March, followed by an increase during April and June (Figure 9). A subsequent decrease was observed between September and October, thereafter a recovery occurred during November and December.

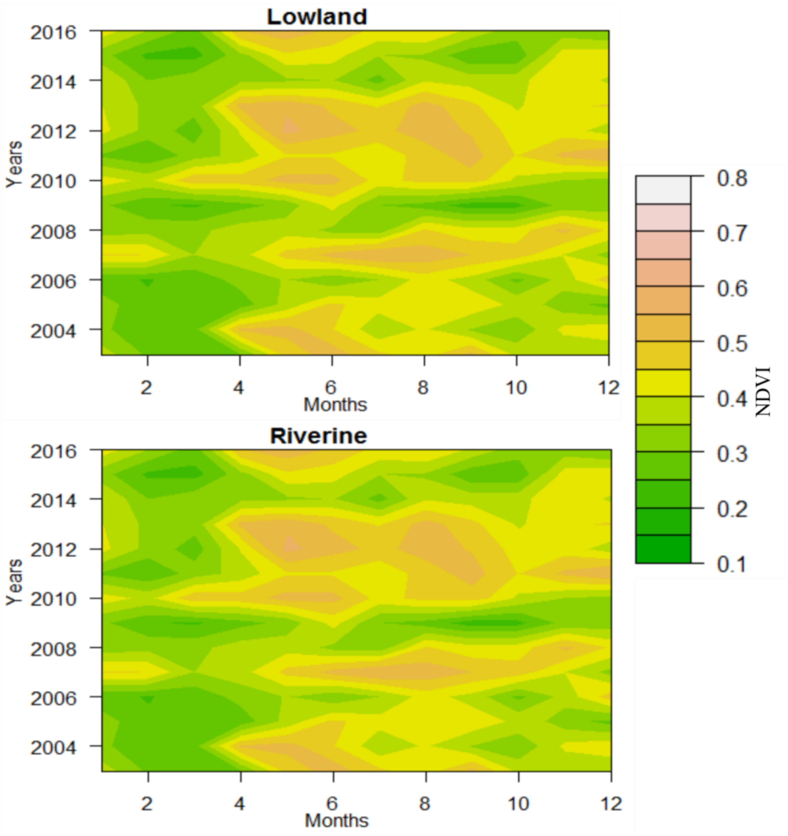

Figure 9: Annual trend in the Normalized Difference Vegetation Index (NDVI) observed during the 2003 - 2016 period. Values 2 and 12 correspond to February and December respectively. NDVI values close to 0.1 indicate low vegetation cover while 0.8 indicate dense vegetation.

Discussants concurred in their opinions that March had the lowest vegetation cover while May was the greenest. These opinions were consistent with observations in Figure 9 on peak vegetation in the area. The locals noted with concern the occurrence of extreme climate conditions including severe drought and excessive flooding that had effects on their livelihoods.

4.3.2 River discharge and lake levels during the 2011-2014 period

4.3.2.1 Annual trend

This study shows an increase in Lake Baringo water levels during the 2011 - 2014 period (tau = 0.569; $p < 0.001$; Figure 10). However, discharge in River Arror decreased significantly (tau = -0.412; $p < 0.001$) during the same period, while there was no change in discharge in rivers Kessup (tau = -0.078; $p > 0.05$) and Perkerra (tau = 0.196; $p = 0.051$; Figure 10). The cause of the observed increase in Lake Baringo water level is not yet known. However, factors such as tectonics, change in spatial distribution of rainfall, improved forest cover in the catchment and increased sedimentation have been speculated as possible causes of the increased lake levels. The increased lake levels may also be attributed to interdecadal variability that has not been captured by instrumental records. During the same study period, Bloszies and Forman (2015) found that Western Indian SST anomaly was a key factor that caused increased Lake Turkana water levels. Variations in the surface hydrology is governed by numerous factors whose interactions are poorly understood in Africa (Niang *et al.*, 2014). This may explain the variation in flow rates observed in the three gauged river in Baringo County. Regardless of the complexity of the surface hydrology, alterations in River Perkerra discharge could be partly due to withdrawals and hydrological modifications in the catchment areas (Kipkorir *et al.*, 2002)

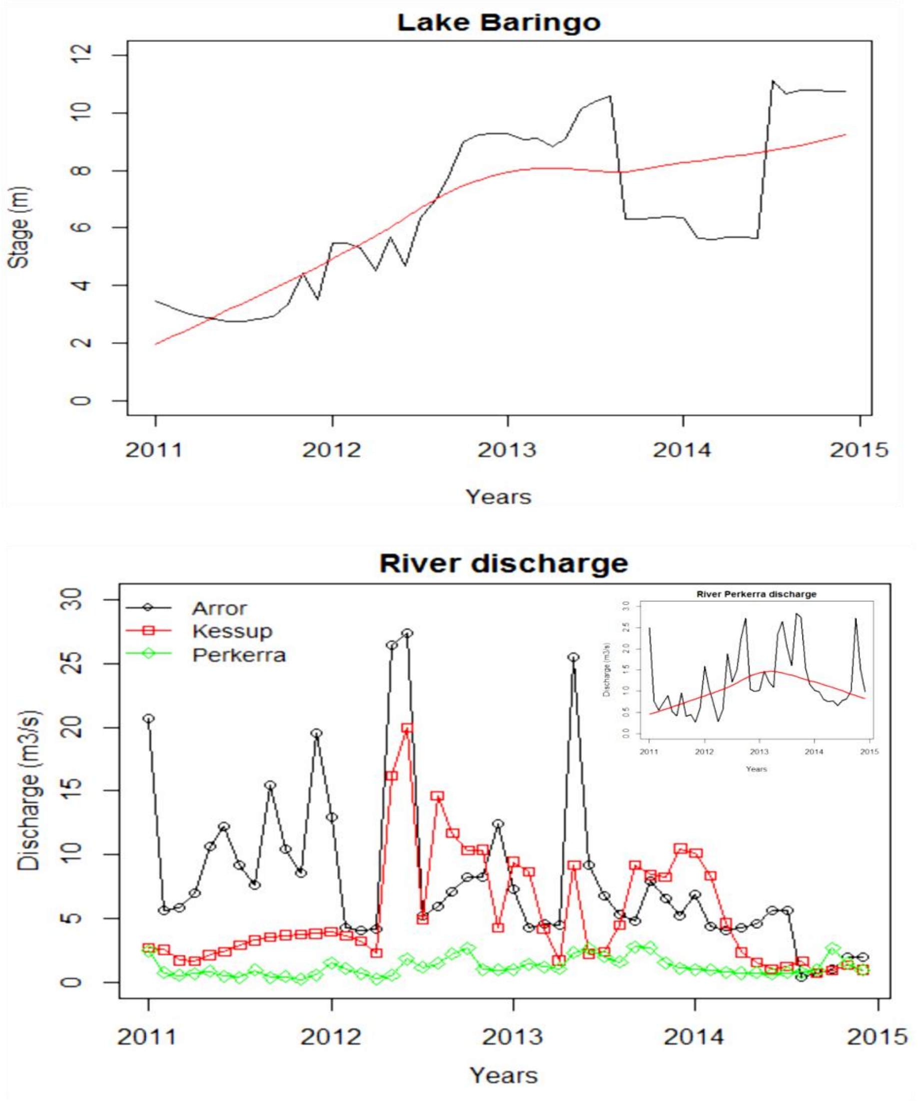

Figure 10: Lake Baringo water levels (m) and discharge (m^3/s) for rivers Perkerra (lowland zone), Arror and Kessup (riverine zone).

Discussants from the lowland zone reported that the increase in Lake Baringo water levels begun around 2010 culminating in the 2012/2013 floods that devastated local structures, submerged farms and displaced many families. In 2016, the locals reported that lake levels had not fully receded causing seasonal submergence of farms along the shores of the lake. There was divergence of opinion among discussants on the dynamics of the major rivers in the lowland zone. The divergent opinions could be attributed to the fact that communities in the lowland zone depend largely on irrigation canals as opposed to streams for livestock and domestic uses. In addition, Loboi swamp and Lake Baringo were additional water sources for the communities in the lowland areas. The discussants believed that expansion of irrigation activities to areas such as Ngambo, Eldume, Endao and Sandai contributed to the reduction in the swamp size. This opinion was consistent with the findings of Ashley *et al.* (2004) that attributed a 60% reduction in Loboi swamp primarily to intensive agriculture.

4.3.2.2 Seasonal and monthly trends

Lake Baringo water levels consistently increased across all seasons (tau = 0.55; p = 0.0034). However, there was no change in seasonal discharge in River Perkerra, a major inlet for Lake Baringo. In the riverine zone, there was a consistent decrease in discharge across all seasons for River Arror (tau = -0.6; p = 0.0014). In River Kessup, the decrease observed during MAM and JJA seasons may be associated with decreased seasonal rains (Figure 7). These findings corroborate results of an earlier study in the upper Mara river basin, Kenya where a decrease in river discharge was reported (Mango *et al.*, 2011).

The local opinions among the FGDs confirmed the decreasing trends in river flow. In the riverine zone, it was reported that some springs had recently dried. Discussants felt that decreased rains led to substantial decrease in stream flow between the months of February and March. It was reported that substantial decreases in rivers Endo, Eron (Salawa), and Kerio led to excavation of water pits "*Kosoke*" along dry river channels. These findings concurred with observations made by some communities in Tanzania (Mwakalila *et al.*, 2011) and Ghana (Gyampoh *et al.*, 2009). Rivers contribute significantly to socio-economic development of most communities. This is evident by activities in Perkerra irrigation scheme in Marigat and other small-scale irrigation activities in Baringo County. Nevertheless, these rivers are currently undergoing alterations due to human activities and climate change (Kipkorir *et al.*, 2002; Mango *et al.*, 2011). Changing seasonal discharge may cause decreased crop and livestock production and subsequent livelihood losses.

4.3.3 Association between climate and ecohydrological factors

4.3.3.1 Relationship between climatic factors and vegetation growth

There was a significant positive correlation between T_{min} and T_{max} ($r = 0.859$; $p < 0.001$; Table 7). A negative relationship existed between rainfall and temperature while a positive association occurred between NDVI and rainfall.

Table 7: Correlation matrix for predictor variables

Variable	NDVI	T_{min}	T_{max}	Rainfall
NDVI	1.000			
T_{min}	-0.609	1.000		
T_{max}	-0.520	0.859	1.000	
Rainfall	0.553	-0.540	-0.539	1.000

A strong positive correlation with a 1-month lag occurred between rainfall and NDVI in both lowland ($r^2 = 0.824$; Figure 11a) and riverine ($r^2 = 0.726$; Figure 11d) zones. These lagged correlations were consistent with observations made by (Sewe *et al.*, 2016) in western Kenya. The lag effects are used to account for the rate and direction of vegetation change (Lin *et al.*, 2015). The observed lag effects suggest that vegetation growth in dryland areas of Baringo County is not controlled by the rainfall within the current month, rather the preceding one. Studies have reported varied lag effects between rainfall and vegetation. For example, Barbosa *et al.* (2015) reported lags of three to six months between rainfall and vegetation density in semi-arid areas of South America while Cui *et al.* (2009) reported a 10-day delayed effect of rainfall on vegetation in Eastern China. The varied lag effects result from diverse responses of vegetation types to rainfall (Barbosa *et al.*, 2015). Notable exceptions to the lag effects were Lin *et al.* (2015) and Brandt *et al.* (2017) who found lack of a clear relationship between annual vegetation density and rainfall in China and West Africa, respectively.

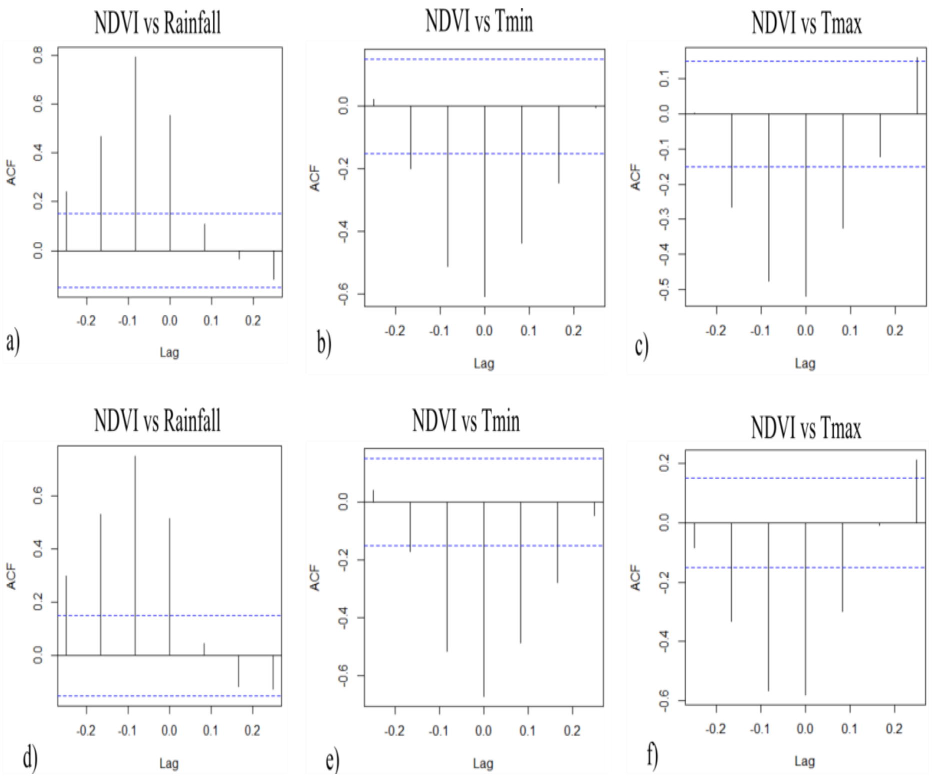

Figure 11: Estimates of autocorrelation function of NDVI and predictor variables (rainfall, minimum and maximum temperature) at lag of 0 - 3 months in the lowland (a-c) and riverine zones (d-f).

A strong negative relationship with 0-lag (direct response) was observed between T_{min} and NDVI (Figure 11b and e) as well as between T_{max} and NDVI (Figure 11c and f). This suggests that vegetation in these areas could be sensitive to temperature changes at time lags shorter than one month. According to Barbosa *et al.* (2015), the direct negative response of vegetation to temperature could be attributed to a reduction in evaporative demand that result in increased soil moisture for vegetation growth. Other studies have confirmed the observed rainfall-temperature feedback (Zhu *et al.*, 2005; Jain and Kumar, 2012).

Regression models were used assess the effect of predictor variables (rainfall, T_{min}, and T_{max}) on response variables (NDVI, discharge and lake levels). Rainfall and T_{min} were significant in predicting vegetation growth in both zones. An increase in rainfall was associated with significant increase in NDVI ($r^2 = 0.433$, $b = 0.083$, $t_{165} = 4.425$, $p < 0.001$) and ($r^2 = 0.538$, $b = 0.07$, $t_{165} = 5.985$, $p < 0.001$) in lowland and riverine zones, respectively (Table 8).

Table 8: Coefficients of regression analysis showing the effects of rainfall and temperature on vegetation in lowland and riverine zones

	Lowland zone				**Riverine zone**			
	Estimate	S. E	t	p	Estimate	S. E	t	p
Intercept	10.231	1.589	6.439	***	8.066	0.779	10.357	***
Rainfall	0.083	0.019	4.425	***	0.07	0.012	5.985	***
T_{min}	-1.8	0.291	-6.193	***	-1.351	0.145	-9.266	***

Note: p is the significance level, '***' = 0.001

A decrease in T_{min} was associated with significant increase in NDVI in lowland ($r^2 = 0.433$, $b = -1.80$, $t_{165} = -6.193$, $p < 0.001$) and riverine ($r^2 = 0.538$, $b = -1.351$, $t_{165} = -9.266$, $p < 0.001$) zones (Table 9). In dryland areas, the response of vegetation to temperature changes is often unpredictable and may be negative in nature (Liu *et al.*, 2015). In this study, decreasing temperature in the riverine zone coupled with rainfall anomalies may have provided optimal conditions for accelerated plant growth resulting in the observed increase in vegetation greenness. Studies by Lin *et al.* (2015) reported a direct positive response of vegetation to temperature increase. Rishmawi *et al.* (2016) emphasized that there are complex relationships between vegetation and climatic factors leading to heterogeneous responses that cannot be adequately formulated across a geographic region.

4.3.3.2 Relationship between river discharge and climatic factors

Lake water levels and stream discharge were not correlated with climatic factors except Perkerra discharge where a weak correlation with 1-month lag occurred between River Perkerra discharge and rainfall ($r^2 = 0.309$; $p > 0.05$; Figure 12). This lag is within the duration anticipated in hydrologic models of 3 to 43 days delay (Bloszies and Forman, 2015). The parsimonious model eliminated all predictor variables when modelling the lake water levels, and retained only rainfall when modelling Perkerra ($r^2 = 0.078$, $b = -7.156$, $t_{46} = -1.969$, $p > 0.05$) and Arror discharge ($r^2 = 0.049$ $b = 0.333$, $t_{46} = 1.535$, $p > 0.05$). In contrast, discharge in Kessup river had weak negative association with T_{min} ($r^2 = 0.129$, $b = -5.481$, $t_{165} = -2.224$, $p = 0.031$).

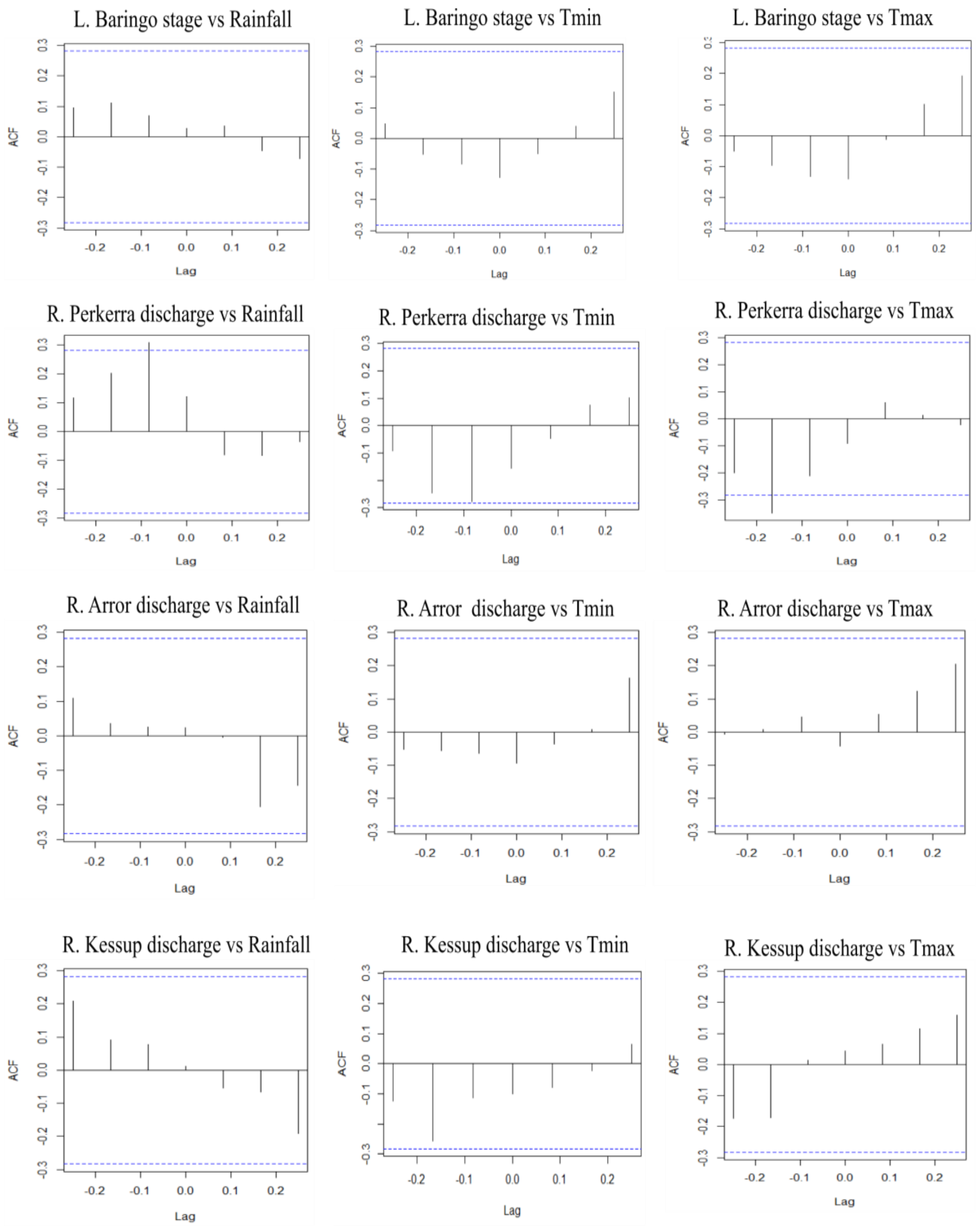

Figure 12: Estimates of autocorrelation functions of discharge and climate variables for L. Baringo, rivers Perkerra, Arror and Kessup at lags between 0 to 3 months.

4.4 Effects of ecohydrological factors on malaria vector abundance

Results in this section were published as ‘Amadi, J. A., Ong’amo, G. O., Olago, D. O., Oriaso, S. O., Nanyingi, M, Nyamongo, I, K. and Estambale, B. B. A. (2018) Mapping the potential *Anopheles gambiae s.l.* larval distribution using remotely sensed climatic and environmental variables in Baringo, Kenya. *Medical and Veterinary Entomology*. Doi: 10.1111/mve.12312’.

4.4.1 Entomological data

Two Anopheles species (*Anopheles gambiae s.l.* and *Anopheles pharoensis*) constituted thirty one percent (31%; 1,067) of all mosquitoes collected. *Culex quinquefasciatus*, *An. pharoensis*, *Culex annulioris* and *An. gambiae s.l.* were the dominant species constituting 39%, 34%, 14% and 9% respectively (Figure 13). Other species sampled were *Culex poicilipes*, *Culex dutoni*, *Culex tigripes*, *Culex univittatus*, *Mansonia uniformis*, *Culex pipiens* and *Aedes aegypti*. *Culex quinquefasciatus* dominated most aquatic habitats, findings that were similar to studies in Mwea (Muturi *et al.*, 2008) and Baringo Kenya (Arum *et al.*, 2010). The variation in species composition could be attributed to habitat dynamics such as seasonal variations in abiotic conditions (Muturi *et al.*, 2007) and changing predation and competition patterns (Koenraadt and Takken, 2003)

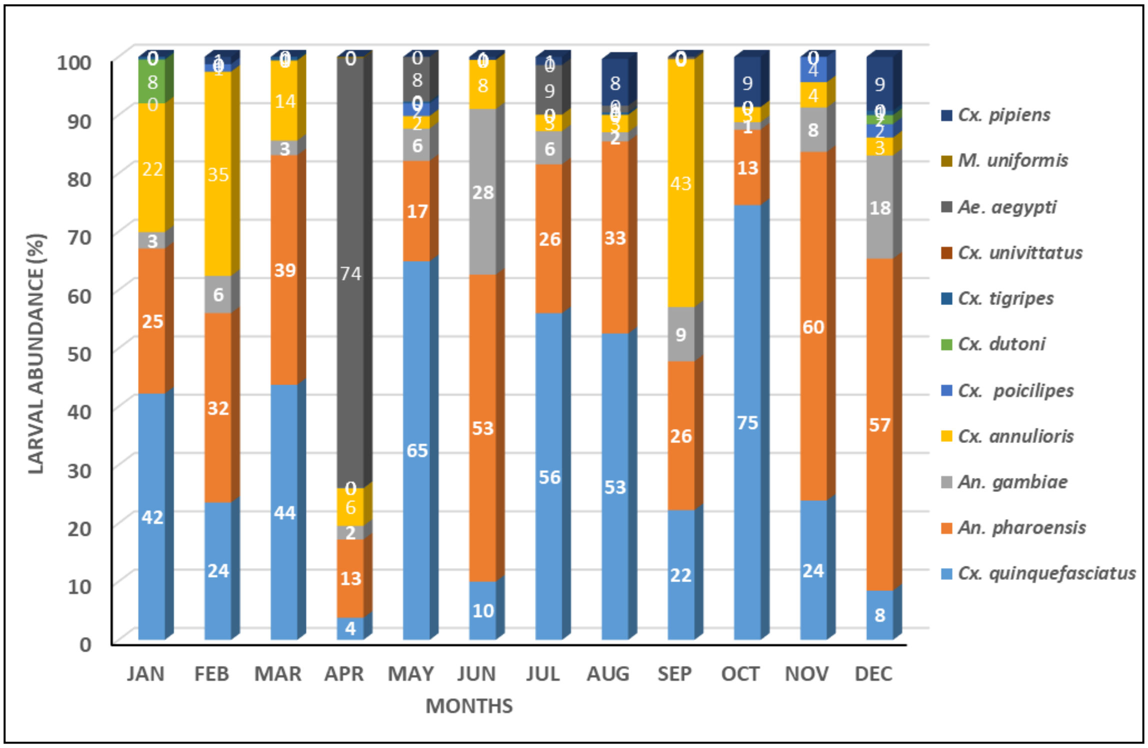

Figure 13: Monthly larval species diversity and their relative abundance during January December 2016.

Generally, *Cx. quinquefasciatus* and *An. pharoensis* were present all year round and ubiquitously distributed in both zones. *Culex quinquefasciatus* was abundant during May and October while *An. pharoensis* was abundant during the months of June, November and

December. *Aedes aegypti* was sampled only in April from a concrete water tank in the lowland zone. Domestic water storage vessels such as overhead tanks, pots, plastic containers and drums are the main *Ae. aegypti* breeding habitats (Lutomiah *et al.*, 2016; Nagpal *et al.*, 2016).

Anopheles gambiae s.l. was significantly higher in the riverine zone (W = 13; Z = -2.04; $p < 0.05$; r = 0.59; Figure 14). This implied high malaria risk in this region compared to the lowland zone. In the lowland zone, *An. gambiae s.l.* population showed a distinct seasonal pattern with peak population in May – July and December-January, coinciding with the end of long rains and start of the dry season.

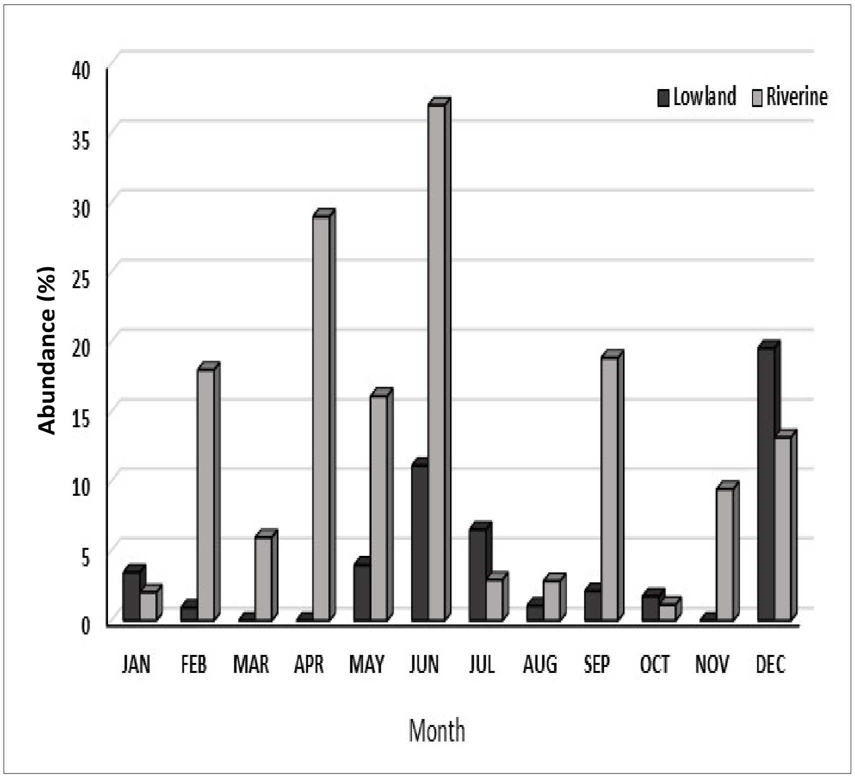

Figure 14: Monthly distribution of *An. gambiae s.l.* in the lowland and riverine zones during January - December 2016.

The occurrence of high vector abundance during dry season (DJF) relate to the persistence of suitable breeding sites during the early parts of the dry season. These findings were consistent with those of Arum *et al.* (2010) and Mala *et al.* (2011b) that showed high abundance of *An. arabiensis* (a congeneric species in *An. gambiae* complex) during dry seasons in the lowland areas in Baringo. However, in the riverine zone, *An. gambiae s.l.* was present throughout the year with peaks during April-June as well as during February, September November and December (Figure 14). This suggests year-round vector presence and possible malaria transmission. The presence of *An. gambiae s.l.* during the December-February period (dry season) in the riverine zone could be attributed to occurrence of spring-fed habitats as well as pools that exist along the channels of numerous seasonal and ephemeral rivers in the Kerio Valley. A recent study found high *Plasmodium* infections during the dry season in the riverine zone (Omondi *et al.*, 2017). This could be attributed to the dry season vector presence, a significant risk factor for malaria transmission.

Anopheles pharoensis and *An. gambiae s.l.* coexisted in 13 habitats including a marsh, river fringe, lake edge, canal, and pan dam (Table 9). *Anopheles pharoensis* occurred in isolation in two canals in the lowland zone while *An. gambiae s.l.* was found in isolation in a water pit in the riverine zone. High *An. gambiae s.l.* population is maintained by the availability of habitats such as marshes and leaking drainage canals that are less reliant on rainfall (Mala *et al.*, 2011a). Arum *et al.* (2010) found *An. gambiae s.l.* and *An. pharoensis* to be widely distributed in habitats such as marshes, canals and ditches in the lowlands of Baringo. *Anopheles gambiae s.l.* cohabited transient habitats such as rain pools and hoof prints. Similar to natural breeding habitats, human-made habitats such as brick making pits, pan dams, concrete tank and culverts support *An. gambiae s.l.* larvae populations (Carlson *et al.*, 2004; Arum *et al.*, 2010). A study in central Ethiopia found that waterlogged puddles, clogged irrigation canals and pools resulting from leaking canals were preferred habitats for *Anopheles* mosquitoes (Kibret *et al.*, 2014). In this study, *An. gambiae s.l.* was not found in an abandoned fish pond where *An. pharoensis* dominated. This could be explained by the presence of deep water levels, a condition that discourages *An. gambiae s.l.* production.

Table 9: Presence (+) or absence (-) of *An. gambiae s.l.* and *An. pharoensis* in different habitat types during the December 2015 - December 2016 period.

Habitat type	*An. gambiae s.l.*	*An. pharoensis*
Barwessa river	+	+
Barwessa secondary (water pit)	+	-
Mbakarpei river	+	+
Enot (Wandiga *et al.*)	+	+
Litein canal	+	+
Kamnarok (lake margin)	+	+
Ketiborok River	+	+
Tilalwa dam	+	+
Salawa River	+	+
Robert's Camp (lake margin)	+	+
Salabani (lake margin)	+	+
Nteppes (canal)	+	+
Eldume (canal)	-	+
Tirion (canal)	+	+
Kapkuikui (Wandiga *et al.*)	+	+
Loboi (canal)	-	+

4.4.2 Spatial distribution of climatic and ecohydrological factors

4.4.2.1 Vegetation cover

Landsat image classification generated eight land cover types including dense forest, sparse forest, wooded grassland, open grassland, annual crops, wetland, open water and bare land (Figure 15a). Wooded grassland was the dominant vegetation type found in Saimo Soi, Marigat, Koibos and Loboi locations (at 36.4%, 305,518 acres). Sparse forests, open grassland and dense forests covered 153,383 acres (18.3%), 97,897 acres (11.7%) and 88,296 acres (10.5%), respectively. Cropland (78,925 acres at 9.4%) was present in lowland and highland zones while wetland (29,989 acres, 3.6%) occurred in the riverine and lowland zones in Loboi, Mukutani, Njemps, and Kamnarok Soi locations. Open water at 7.1% includes major lakes such as L. Baringo, L. Bogoria, L. 94 and L. Kamnarok. Bare land together with settlement covered the least area at 3%. High NDVI values coincided with areas dominated by forest and cropland while low NDVI values were observed in areas with open grassland (Figure 15b).

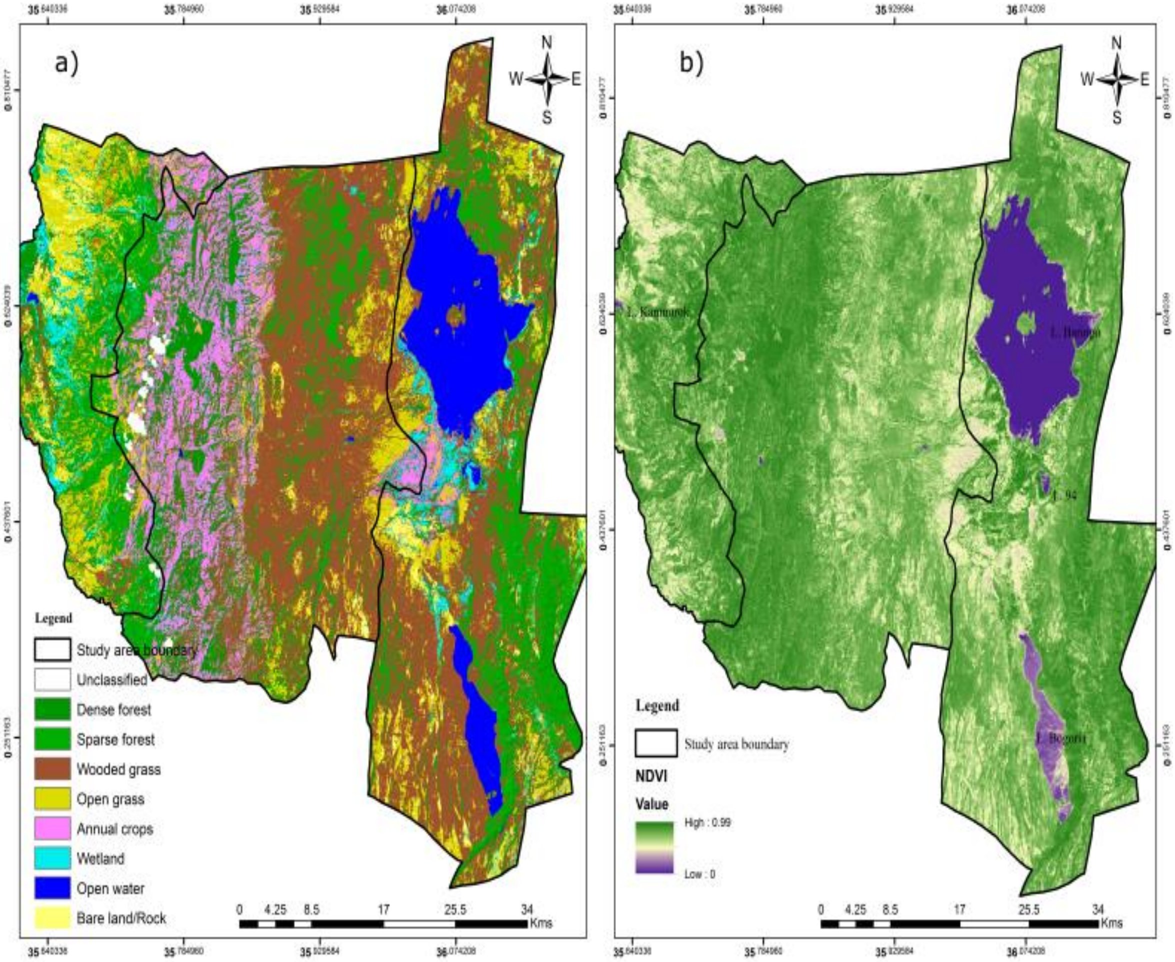

Figure 15: Land cover types (a) and vegetation health (b) of the study area interpreted from a Landsat image.

4.4.2.2 Climate and other ecohydrological factors

High rainfall was observed in the riverine zone while the lowland zone recorded the least. Low minimum temperature (Figure 16a and b) coincided with high rainfall amount. This indicates a negative association between rainfall and temperature. In this study, wetlands, croplands and forests had high TWI above 0.7 while open grass had TWI values lower than 0.5 (Figure 16c). Lower TWI values were observed in the riverine zone compared to lowland zone. High TWI values coincided with low temperatures suggesting low evaporative demand due to cooler conditions. The high TWI observed in areas with cropland and forests corroborates a study in Yangjuangou China that found high moisture levels in cropland compared to grassland (Wang *et al.*, 2013).

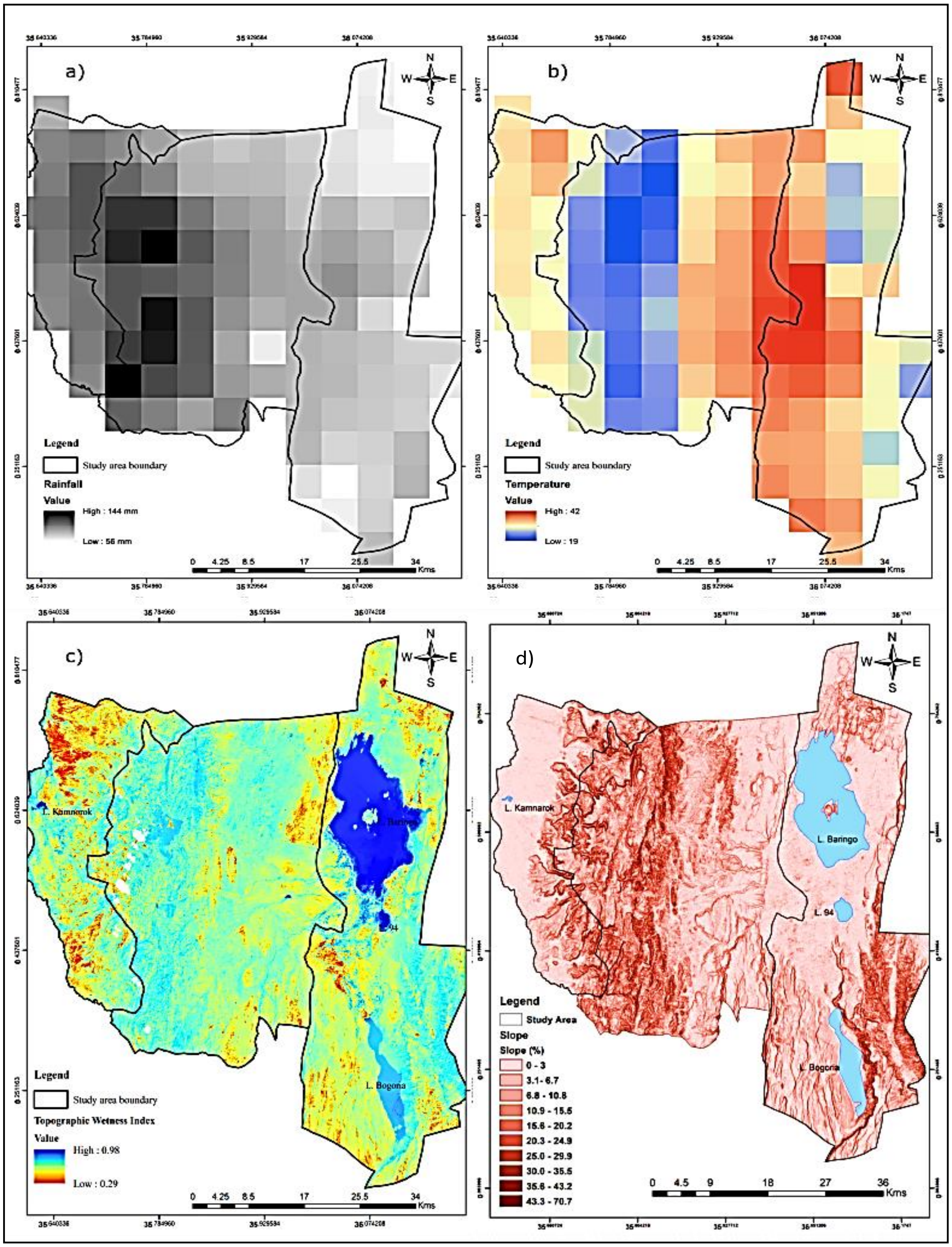

Figure 16: Spatial distribution of rainfall (a), temperature (b), TWI (c) and the study area slope (d).

Both lowland and riverine zones had area slope less than 7% (Figure 16d). This suggests high water accumulation potential and possibility of flooding. Hopp and McDonnell (2009) confirmed that low slope angle influences hydrologic response resulting in high flow accumulation. Area slope and TWI are correlated hydrological variables often associated with mosquito breeding habitats (Hanafi-Bojd *et al.*, 2012). Slope influences area drainage, water velocity and accumulation (Nmor *et al.*, 2013) while wetness index affects occurrence and duration of larval habitats (Mushinzimana *et al.*, 2006). Figure 17 shows *An. gambiae s.l.* suitability map based on three biophysical conditions (rainfall, temperature and slope). High mosquito densities occurred in areas located in both the lowland and riverine zones.

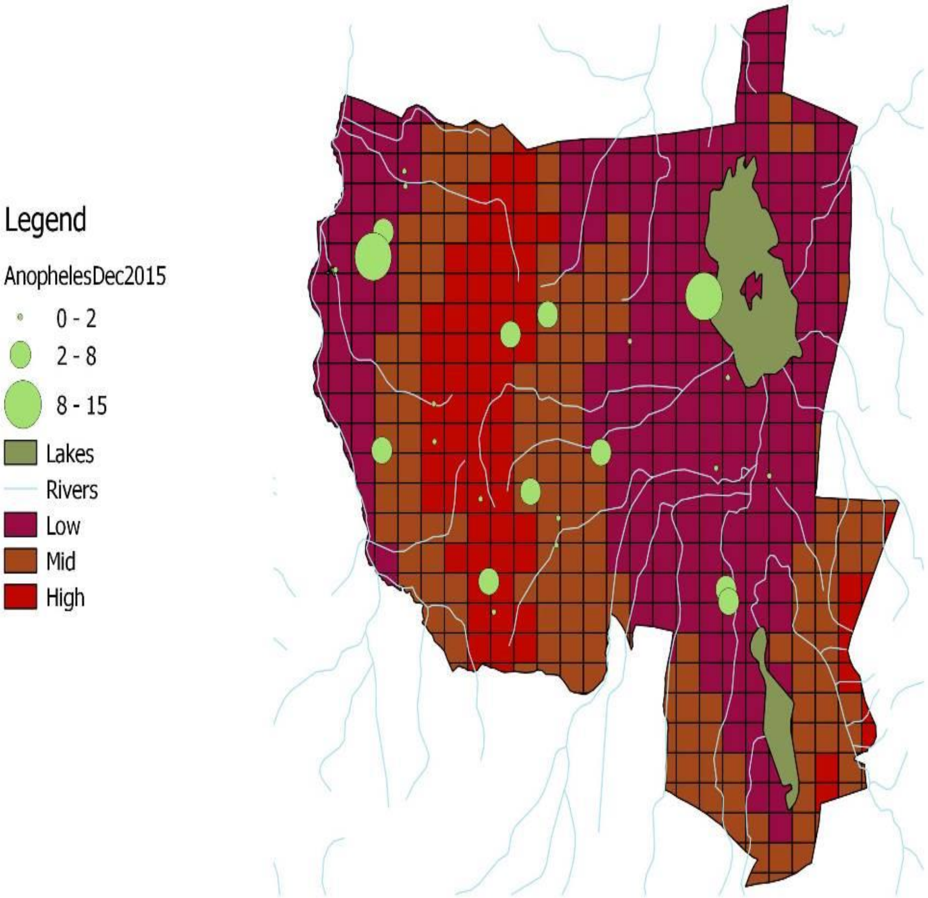

Figure 17: Suitability map of *An. gambiae s.l.* larvae. Low, mid and high correspond to slope attributes

4.4.3 Effects of ecohydrological factors on the distribution of An. gambiae s.l. larvae

A GLMM analysis showed that rainfall, slope and vegetation health were significant factors influencing the distribution of *An. gambiae s.l.* larvae in Baringo (Table 10). An increase in rainfall was associated with increased *An. gambiae s.l.* larvae (b = 6.22, p < 0.001, AIC: 180.7). This finding was consistent with studies in coastal parts of Kenya (Walker *et al.*, 2013) and in west Africa (Dambach *et al.*, 2012) that found significant association between rainfall events and *Anopheles* abundance.

Table 10: Ecohydrological factors affecting and *An. gambiae s.l.* occurrence.

Predictors	**Estimate**	**p**
Intercept	-0.85	0.86
Vegetation cover	0.29	0.67
Vegetation health	-5.60	0.038 *
Rainfall	6.22	0.00041 ***
Temperature	-0.58	0.68
TWI	2.15	0.76
Slope	-4.81	0.012 *

Note: p is the significance level: '*' 0.05, '**' 0.01, '***' 0.001

The presence of *Anopheles* larvae is governed by multiple interconnected factors such as temperature, rainfall, topography, and NDVI (Dambach *et al.*, 2012). Rainfall directly influences mosquito survival and densities (Mamai *et al.*, 2015) and may act as proxy for the presence of larval habitats (Wiebe *et al.*, 2017). Recently, Wiebe *et al.* (2017) developed predictive maps showing the distribution of *Anopheles* congeneric species in Africa. The model found temperature, wetness and slope as the best predictors for the presence of *An. gambiae s.l.* (Wiebe *et al.*, 2017). In the present study, slope was a significant environmental factor influencing occurrence of *Anopheles gambiae s.l.* larvae in Baringo (b = -4.81, p = 0.012, AIC: 180.7; Table 11). De Souza *et al.* (2010) reported a similar relationship between slope and *Anopheles gambiae s.s.* abundance in Ghana. Studies have shown that slope correlates strongly with wetness index as is vegetation index to temperature (Wiebe *et al.*, 2017). Steep slope have low wetness while flat terrain are associated with high wetness increasing chances of larval habitat occurrence (Nmor *et al.*, 2013).

There are inconsistencies in the relationship between ecohydrological variables and *Anopheles* abundance. This study found a negative association between vegetation health and *An. gambiae s.l.* larvae (b = -5.60, p = 0.038, AIC: 180.7; Table 10) contrary to the findings where vegetation health were positively associated with mosquito abundance (Ren *et al.*, 2015; Kabaria *et al.*, 2016). The negative association could be attributed to the fact that vegetation provides shade that does not favour *Anopheles* larvae abundance (Carlson *et al.*, 2004; Munga *et al.*, 2006; Dambach *et al.*, 2012). The present study finds a non-significant positive influence of TWI on *An. gambiae s.l.* larvae. Similarly, vegetation cover and minimum temperature were not significantly associated with *An. gambiae s.l.* larvae.

The spatial distribution of *An. gambiae s.l.* larval is shown in Figure 18. High abundance is observed in the riverine zone compared with the lowland zone. In the lowland zone, high larval abundance was observed in areas dominated by cropland and wetland in Marigat, Njemps and Loboi locations. Irrigation canals found in Perkerra, Salabani and Loboi may have provided permanent breeding habitats increasing *An. gambiae s.l.* larvae in areas dominated by irrigation farming. This is consistent with a study conducted in central Ethiopia that found high *Anopheles* larvae in irrigated cropland (Kibret *et al.*, 2014). Leakages from irrigation canals support high vector activity in irrigated areas (Arum *et al.*, 2010; Mala *et al.*, 2011a; Kibret *et al.*, 2014). In the highlands of Western Kenya, Kweka *et al.* 92015) found high larval abundance to be associated with pasture land compared to crop land. In this study, the presence of wetland and numerous river channels that form rock pools during dry seasons may have influenced the occurrence of *An. gambiae s.l.* larvae in the riverine zone.

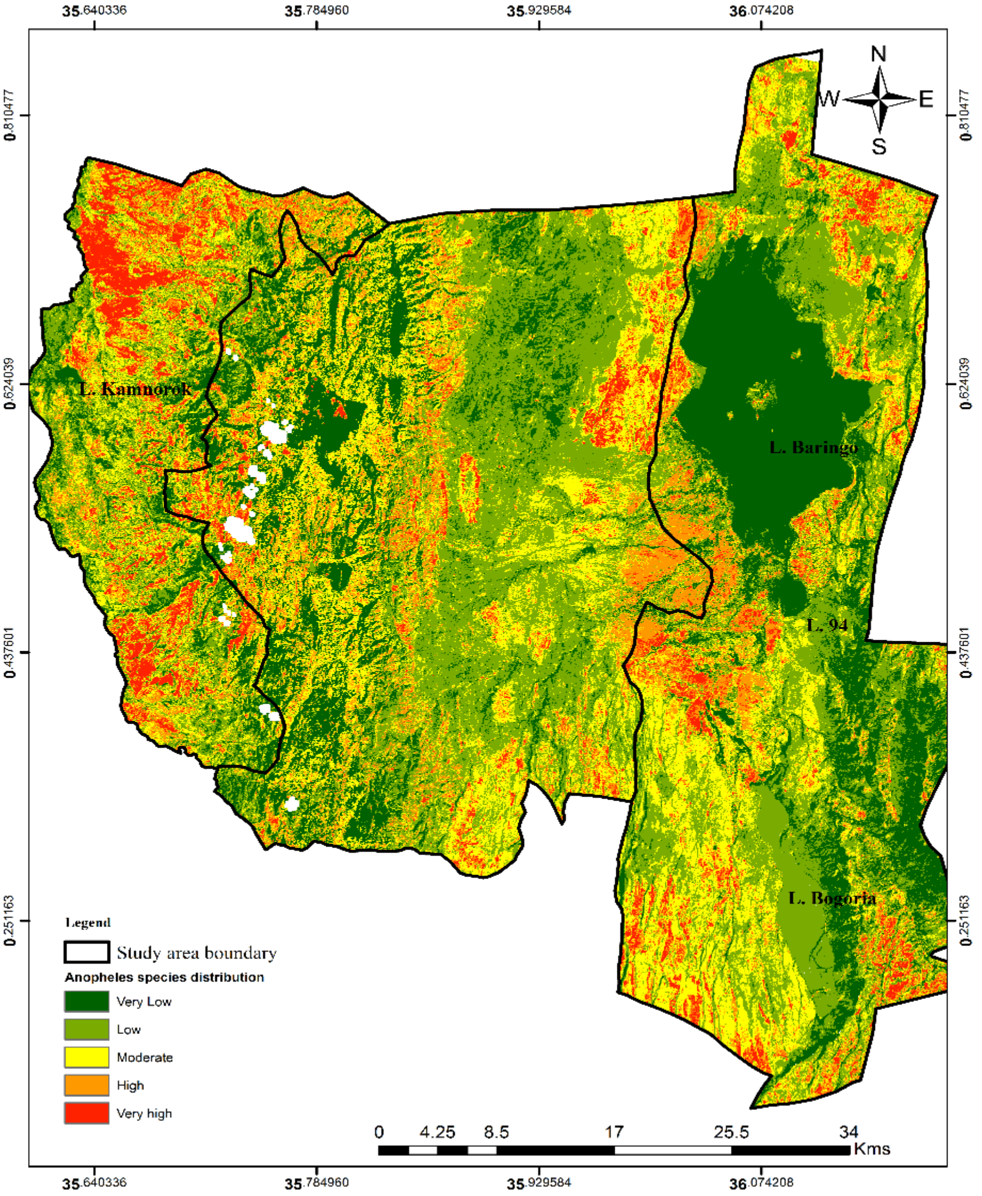

Figure 18: Spatial distribution of *Anopheles gambiae s.l.* larvae in the study area. White patches are areas with cloud cover.

4.5 Malaria trends in Baringo County

Section 4.5 was published as 'Amadi, J. A., Olago, D. O., Ong'amo, G. O., Oriaso, S. O., Nanyingi, M, Nyamongo, I, K. and Estambale, B. B. A. (2018) "We don't want our clothes to smell smoke": Changing malaria control practices and opportunities for integrated community-based management in Baringo, Kenya. *BMC Public Health*, **18**:609. Doi.org/10.1186/s12889-018-5513-7'.

According to the key informants, Malaria, locally known as "*Esee*" (Tugen), ranked second to Upper Respiratory Tract Infections (URTIs) in Baringo. In all FGDs, malaria was cited as a common illness that had persisted for decades in the region. A key informant from the Department of Disease Surveillance reported that confirmed malaria cases accounted for about five percent while suspected cases constituted nine percent of the total diseases in Baringo County.

4.5.1 Annual malaria trend

In the riverine zone, malaria cases increased steadily during the 2005 - 2014 period (tau = 0.352; $p < 0.001$) while an insignificant decrease was observed in the lowland zone (tau = -0.076; $p > 0.05$; Figure 19). Generally, high malaria cases were observed in Songor, Salawa, Kapkelelwo and Chesongo in the riverine zone as well as in Marigat and Njemps locations in the lowland zone in 2014 (Figure 20).

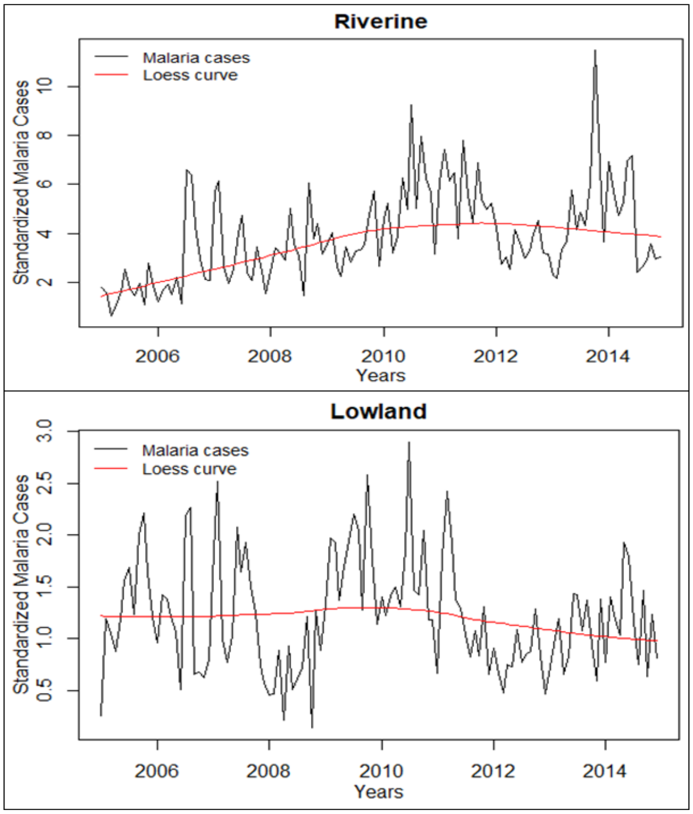

Figure 19: Trends in malaria cases (standardized using the total population) in the riverine and lowland zones during the 2005 - 2014 period.

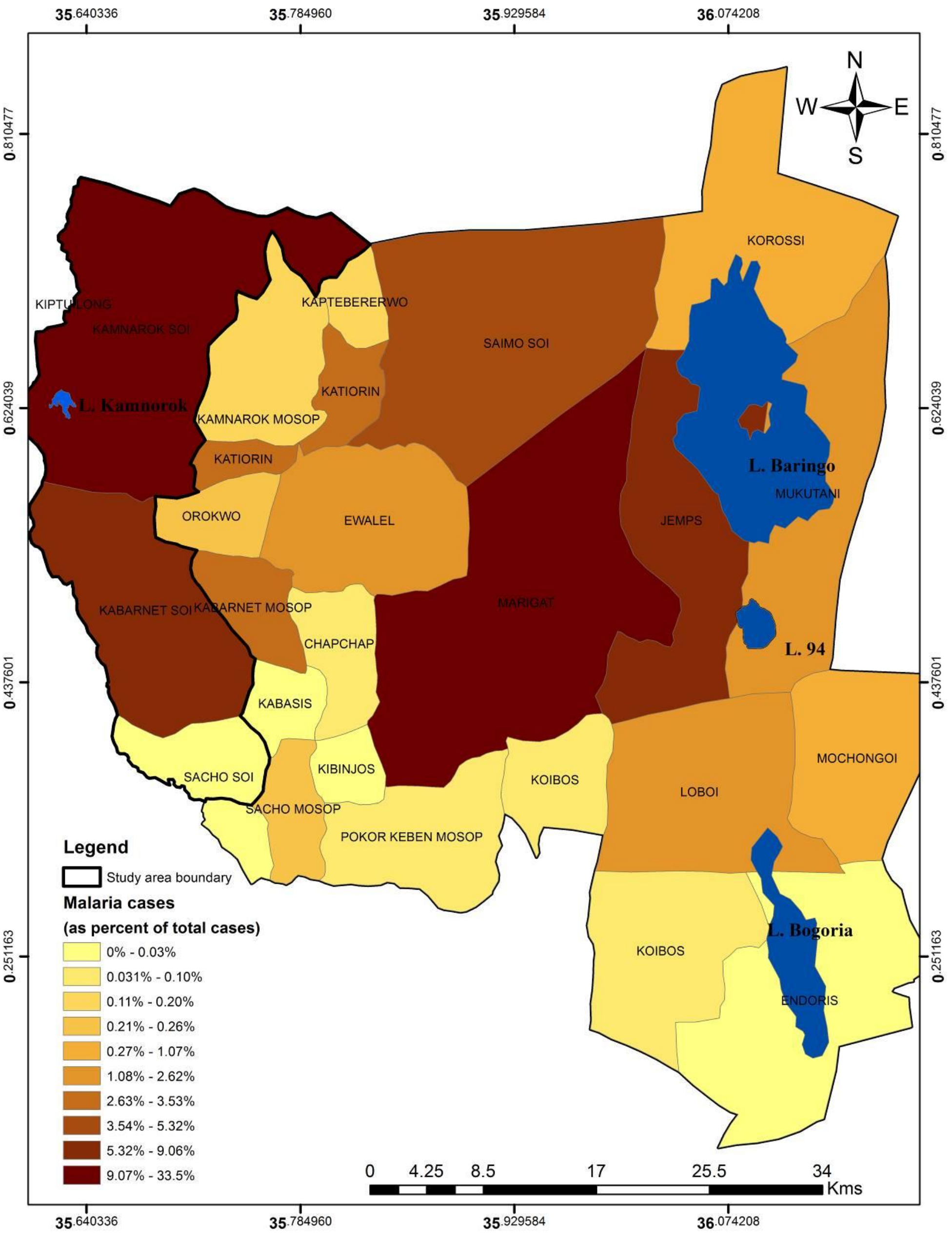

Figure 20: Total annual malaria cases per location for the year 2014.

The increased malaria trend in the riverine zone may be attributed to high abundance of *An. gambiae s.l.* as illustrated in Figure 14. The presence of numerous river channels could be additional geomorphological characteristics that favoured high vector abundance. High abundance of *An. gambiae s.l.* in the riverine zone could be the reason for high prevalence of *P. falciparum* in the riverine zone as reported by (Omondi *et al.*, 2017). There was concurrence between observed malaria cases in the riverine zone and a report from a key informant as shown in the following excerpt:

> *'Actually, malaria trends have been high in some areas in Kerio valley including Kabutiei, Kaboskei, and Lawan areas in Kamnarok Soi Location. When you look at it (malaria trends) it is actually continuous. It's not seasonal in areas such as Kapluk, Katibel, L. Kamnarok, Litein, Keturwo, Barwessa, Kiplolwon, Chemoso and Kuikui areas'* Key Informant 2

The observed decrease in malaria cases in the lowland zone could be attributed to vector control interventions. Long Lasting Insecticide-treated Nets (LLINs) have been used for malaria and Leishmaniasis control (Zollner, 2006) in the lowlands of Baringo. Prior to the observed decline, it was reported that mass net distributions were conducted in 2007 and 2012. Consequently, the sharp decreases (Figure 19) could be attributed to the period of community-wide malaria prevention using the mosquito nets.

4.5.2 Seasonal and monthly malaria trends

A significant increase in seasonal malaria cases was noted in the riverine zone (tau = 0.418; $p < 0.001$); the long rains (MAM) season showing significant increases compared to other seasons (tau = 0.733; $p < 0.01$; Figure 21). However, there was no change in seasonal malaria cases in the lowland zone. Monthly malaria cases did not change in the lowland zone compared to significant increases observed during March, April, May, June and October in the riverine zone as opposed to lowland zone (Table 11).

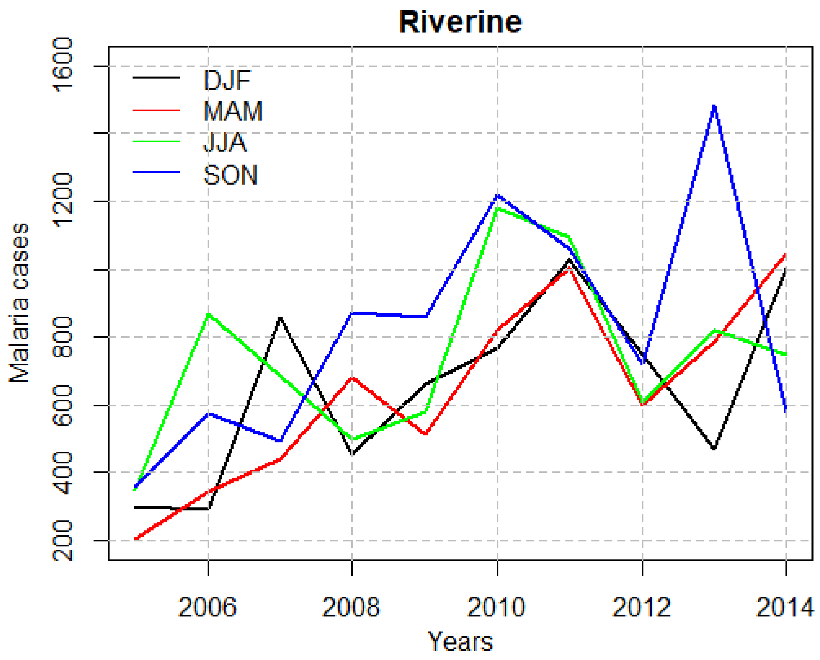

Figure 21: Seasonal malaria cases in the riverine zone during the 2005 – 2014. Significant trend observed during MAM season.

Table 11: Monthly malaria cases observed during the 2005-2014 period

	Lowland zone		**Riverine zone**	
Months	**Tau**	**p**	**tau**	**p**
January	0.02	1	0.42	0.11
February	-0.11	0.72	0.29	0.29
March	0.02	1	0.67	0.0092**
April	0.02	1	0.69	0.0073**
May	0.02	1	0.73	0.0042**
June	0.02	1	0.56	0.032*
July	-0.20	0.47	-0.07	0.866
August	-0.38	0.15	0.09	0.79
September	-0.07	0.86	0.2	0.47
October	-0.20	0.47	0.56	0.032*
November	-0.11	0.72	0.33	0.21
December	-0.02	1	0.49	0.059+

Note: p is the significance level: ‘+’ 0.1, ‘*’ 0.05, ‘**’ 0.01, ‘***’ 0.001

4.5.3 Association between climatic factors and malaria cases

Monthly malaria cases had a strong positive association with rainfall occurring at two-month lag in both riverine (r = 0.79) and lowland (r = 0.51; Figure 22) zones. Rainfall influences malaria epidemics by altering availability of larval habitats (Yé *et al.*, 2007). Minimum temperature was negatively associated with monthly malaria cases with similar lags as rainfall. In the lowland zone, peak malaria cases occurred during June – July and were associated with minimum temperatures of 18.5°C – 20°C. In the riverine zone, peak malaria cases occurred during September - November and May - July associated with minimum temperatures of 16°C - 17°C (Figure 22).

A strong positive association with a one-month lag was observed between monthly malaria cases and NDVI in riverine zone (r = 0.57) contrary to the lowland zone (r = -0.59) where the association was negative. Studies conducted in western Kenya (Sewe *et al.*, 2016) and in China (Bi *et al.*, 2003) found a lag of up to three months between NDVI and malaria cases. The time lags between environmental factors and peak malaria cases correspond to the period necessary for mosquito development and parasite transmission (Elissa *et al.*, 2003; Githeko *et al.*, 2014). Studies have shown that Anopheles development takes about 27 days at temperatures between 16°C - 32°C (Knols *et al.*, 2002; Afrane *et al.*, 2012) while parasite transmission takes about 32 days between 17 °C to 21°C (Githeko and Ndegwa, 2001; Tanser *et al.*, 2003).

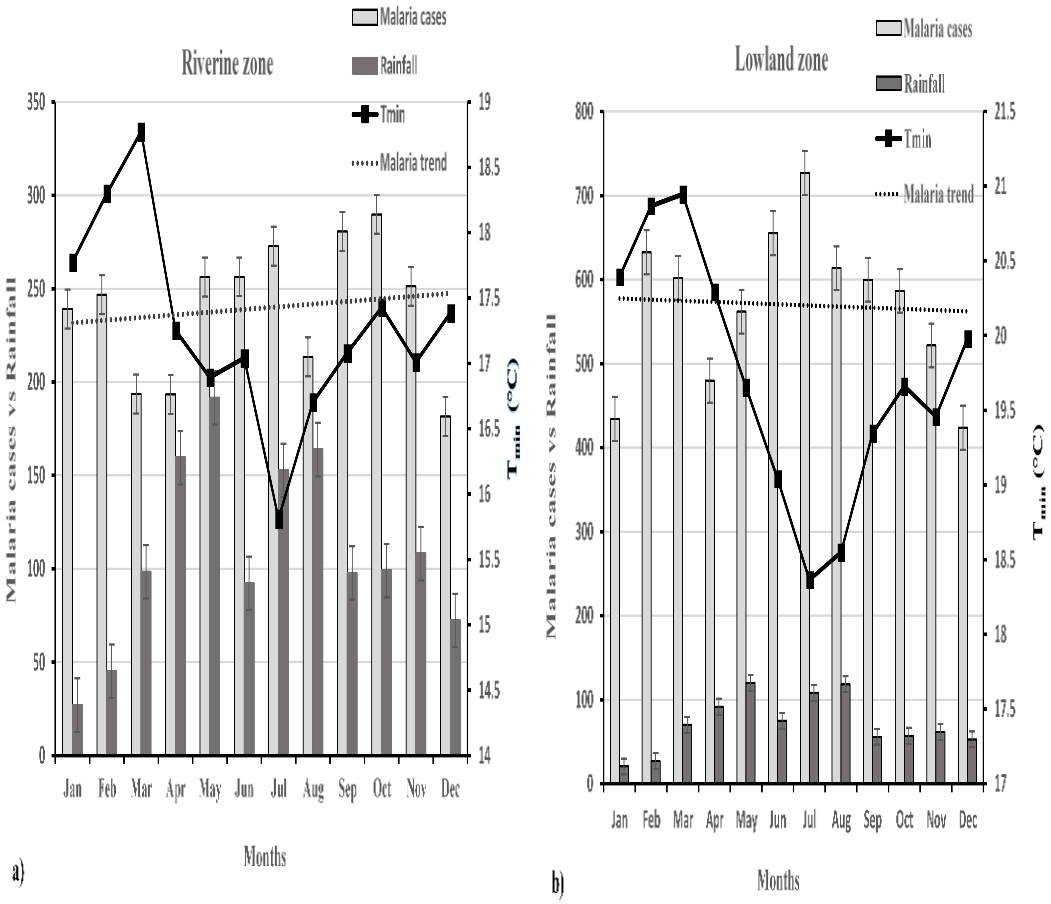

Figure 22: The relationship between mean monthly malaria cases and rainfall and minimum temperature during the 2005 - 2014 period.

4.5.4 Local knowledge on malaria transmission

Nearly all discussants were aware that malaria is transmitted by a mosquito bite. However, misconceptions on the causes of malaria existed (Figure 23). For example, some people believed that drinking muddy water, excess stomach acid "*nyongo*", eating sugary foods, or eating food cooked with conventional cooking oil, caused malaria. While detailing the causes of malaria, discussants expressed the following:

> *'Then we would drink that (muddy) water and be infected with malaria.'* Female discussant, Salawa.
>
> *'You clear off the green substance (algae) then fetch the water. It would take you a few hours to fall sick.'* Female discussant, Salawa.

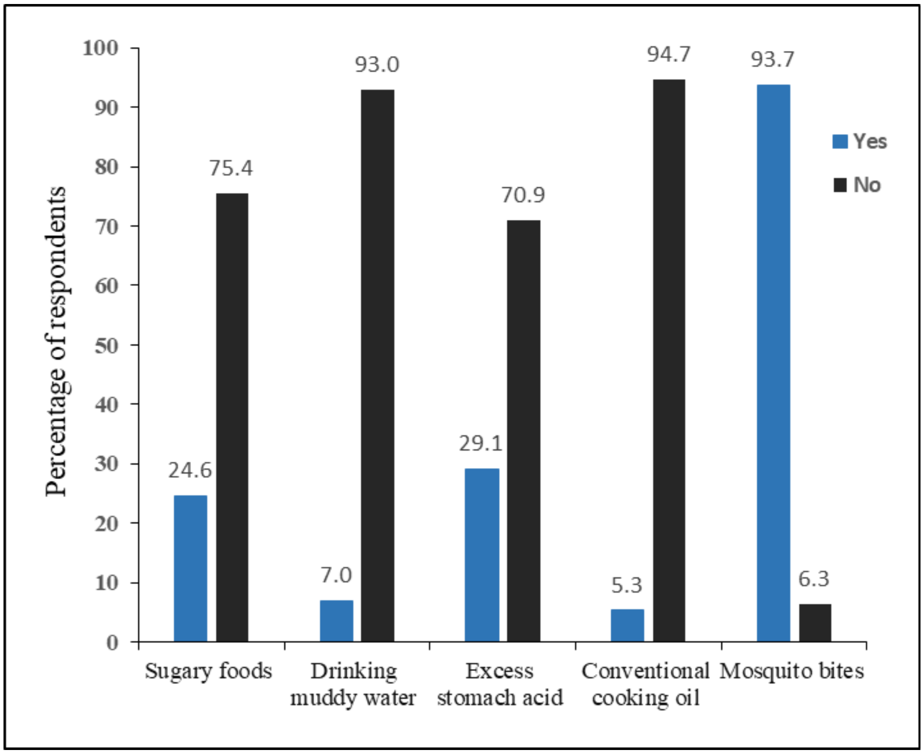

Figure 23: Causes of malaria

Such misconceptions were not unique to this study since similar perceptions were reported among communities in Western Kenya (Shuford *et al.*, 2016; Owek *et al.*, 2017), Tanzania (Moshi *et al.*, 2017) and in Swaziland (Dlamini *et al.*, 2017). Effective malaria control hinges on a community's level of knowledge. Thus, there is need for enhanced public awareness and education to dispel these misguided perceptions (Al-Adhroey *et al.*, 2010).

About 95% of respondent agreed with the opinion that staying outdoors after dark exposed someone to mosquito bites. Gender or age did not influence opinions on outdoors malaria transmission. However, the level of education was associated with the opinion that sitting outdoors increased risk of mosquito bite. People with higher education were more confident that sitting outdoors was a factor that exposed someone to malaria risk ($\chi^2 = 2.70$, df = 4, $p < 0.05$). In this study, older men were found to engage in politics and social drinking till late in the night. It was reported that open air traders stayed outdoors up to 10pm selling commodities. *Anopheles gambiae s.l.* and *An. funestus* feed outdoors as well as indoors (Kitau *et al.*, 2012; Kibret and Wilson, 2016; Meyers *et al.*, 2016), transmitting malaria during peak biting hours (between 1900-2200hrs) (Yohannes and Boelee, 2012) when most people were found outdoors. Community members engaging in outdoor chores and social activities found themselves at a greater risk of malaria infection because they would have been bitten before sleeping under the mosquito nets. Outdoor occupation was reported as a major risk factor responsible for malaria transmission in Tanzania (Moshi *et al.*, 2017) and Swaziland (Dlamini *et al.*, 2017).

Irrigated crop farming was identified as a risk factor for malaria transmission among people living in the lowland zone. Besides the fact that irrigated farming provides suitable breeding habitats, on farm activities increase the chances of getting in contact with malaria-transmitting mosquitoes. In Perkerra, Njemps, Eldume, and Loboi, men preferred watering their crops at night, prolonging their exposure to mosquito bites as indicated in the following statement:

> *'You know people do irrigation here. So they (locals) pump water in the farms until late. Mostly men do this at night… and women when they go fetching water and tending to their animals early in the morning as early as 5 am they may come in contact with mosquitoes.'* Key Informant 10

In the riverine zone, older boys and men stayed overnight in the farms protecting crops against wild animals such as elephants. This activity was common during the harvesting period from August to September when crop depredation cause immense loss and would be prevented at all cost:

> *'They (men) are forced to stay in the farms to protect their crops like maize because of these wild animals. So, people stay overnight in the farms even for 4 weeks, sleeping on trees.'* Key Informant 7

Other activities such as going to the farms early in the morning (0600hrs), circumcision ceremonies and livestock herding increased risks of malaria transmission. It has been shown that peak *Anopheles* mosquito activity occurs between 0500 - 0600hrs (Moiroux *et al.*, 2012). In the lowland zone, warm weather condition was an additional reason why people stayed longer outdoors during early evening. Similarly, women and girls conducted most of their cooking while outdoors. During circumcision ceremonies, boys aged between 13-18 years together with older men spent about four weeks in the wilderness. A key informant reported that during these ceremonies participants did not used any form of malaria prevention or treatment. Herders were additional high risk group since they spent most of their nights in remote areas away from homes or health facilities. Results show that about 59.6% of the respondents did not protect themselves while outdoors. There was a gender differentiation among those who protected themselves, 67% being women while 33% were men. About 40.4% of those who protected themselves while outdoors at night used additional clothing like socks, long pants and long-sleeved clothes.

4.5.5 Existing strategies for malaria control

4.5.5.1 Conventional methods

About 68% (204/300) of the respondents owned a mosquito net, majority being women, while 20% of respondents did not have mosquito nets. During in-depth interviews, it was reported that the national government routinely gave LLINs to expectant women and children under one year of age. In addition, discussants reported that there were mass net distributions in some parts of the lowland zone. Although the efficacy of LLIN has been repeatedly confirmed (Atieli *et al.*, 2011; Snow *et al.*, 2015; Machini *et al.*, 2016), the periodic mass net distribution (5 years) and challenges of outdoor malaria transmission may have weaken the effectiveness of this strategy in achieving substantial malaria reduction in Baringo. This study found that mass net distribution was carried out in areas perceived as malaria hotspots rather than the entire Baringo south sub-county. For example, mass net distribution was carried out in areas around Marigat yet communities living in Salabani, Mochongoi, and Loboi where irrigation activities were also carried out were excluded from the programme. This was reported by a key informant from the Department of Disease Surveillance, Baringo County as shown below:

> *'Recently, I was arguing in a certain meeting why Marigat had mass net distribution yet there are areas such as Salawa, Kuikui, Kapluk, Barwessa (in the riverine zone) that have malaria episodes almost year-round. But I was told the data from Kerio Valley does not support what I was saying.'* Key Informant 4

The aforesaid year-round malaria occurrence in the riverine zone was in agreement with observed malaria cases during the 2005 - 2014 period (Table 11). Unlike Marigat (in the lowland zone), the riverine zone lies within two sub-counties namely Baringo north and

Baringo central. According to a sub-county malaria control coordinator, the administrative divisions pose a great challenge in malaria control and distribution of resources in the riverine zone since Baringo central is considered a low risk sub-county with minimal malaria resource allocation.

Less than half (47%) of the respondents acquired their mosquito nets from government hospitals. Some locals purchased their bed nets while others got the nets from non-governmental organizations (NGOs) or during government distribution (Table 12). All respondents who benefitted from government or NGO supplies were mainly from the lowland zone. For instance, Perkerra irrigation area was considered a malaria hotspot thus residents benefited from government and NGOs support.

Table 12: Sources of bed nets

Sources of bed nets	**Respondents (%)**		
	Lowland	**Riverine**	**Total**
Don’t have	9.3	10.7	20.0
Gift	2.7	2.0	4.7
Purchase	8.0	10.0	18.0
Government hospital	20.3	26.3	46.7
Government distribution of nets in community	3.0	0.0	3.0
NGO distribution of nets in community	6.0	0.3	6.3
Other	0.7	0.7	1.3

More than half (63%) of the respondents expressed a good feeling of using a mosquito net. Results showed a significant relationship between convenience of the mosquito nets and education level of the respondents ($\chi^2 = 22.27$, df = 4, p = 0.00). Those who had no education tended to experience inconveniences while using mosquito nets. This could be as a result of the unmatched shape of the mosquito nets in relation to the size and design of beds or sleeping rooms. There was no significant relationship between gender and convenience of mosquito nets ($p > 0.05$). Some discussants felt that mosquito nets were uncomfortable especially during hot conditions arguing that the nets suffocated them. Four out of 12 key informants reported that some locals inappropriately used mosquito nets to fence kitchen gardens, cover animal sheds, and for fishing. In some instances, mosquito nets given to expectant women or children ended up being used by male household heads due to their perceived role as head of family. Similar perceptions and malpractices were reported in central Kenya (Ng'ang'a *et al.*, 2009), Tanzania (Tarimo, 2015), Rwanda (Ingabire *et al.*, 2015) and west Africa (Toé *et al.*, 2009) where bed net use was associated with irritation and uncomfortable sleep.

4.5.5.2 Traditional methods

Local communities have used herbal remedies for centuries. In Baringo County, herbal medicines were used to treat numerous ailments. In some instances, the herbal medicines were administered to the entire family as a preventive measure against diseases such as malaria and stomach infections. When an individual had malaria, vomiting and diarrhoea were induced using traditional medicines. Other people boiled roots, leaves or barks of some medicinal plants as a way of treating respiratory ailments and other infections. This is illustrated below:

> *'Long time ago people used to slaughter a goat, make soup and mix with herbs then every member of the family would drink and they would be okay. Nowadays, it is a bit difficult, our children are very rigid when it comes to drinking traditional herbs…'* Female discussant, Salabani.

Traditional mechanisms such as burning plant leaves or cow dung were used to control mosquitoes and other nuisance insects, findings similarly to those in Tanzania (Moshi *et al.*, 2017) and Guinea (Ruberto *et al.*, 2014). Burning of plant leaves was reported to be effective in the traditional house erected on stilts locally known as "*Bororiet*". It was easy to smoke out mosquitoes when fire was lit underneath the *Bororiet*. When the survey was conducted, only 8% of respondents burnt cow dung or plant leaves to repel mosquitoes. This could be due to changes in attitude towards these traditional mechanisms for prevention or treatment of malaria and other diseases as well as the adoption of other house types as shown in the quote below.

> *'We would climb into the* Bororiet, *and then light a fire beneath so as to smoke out the mosquitoes. When the bed nets were brought people became lazy to smoke leaves, in addition, we no longer want our clothes to smell smoke.'* Female discussant, Litein.

This study revealed that complementary malaria control measures were under-utilized, depicted by over 90% of the respondents denying having used these methods over the last one year. Ninety-three percent (93%) of survey respondents had not sprayed their compounds using chemical insecticides while less than nine percent reported having used repellents such as sprays, creams and mosquito coil. The under-utilization of complementary malaria prevention strategies could be attributed mainly to limited strategies available to the communities as well as generational change. During the FGDs, young children and youth were reported to reject the traditional herbs used to treat diseases such as malaria. Similar observations were reported in two FGDs where discussants considered the aforementioned methods as backward. Against the backdrop of inadequate mosquito nets and abandoned traditional methods, increased awareness and education among the locals is imperative to enhance adoption of locally available supplemental strategies for malaria reduction as illustrated below:

> *'Here at the health centre only if your wife delivers then she is given a net and that is just for the woman and her baby, the other children sleep without a net. It is also very difficult to find nets even in the shops in this area.'* Male discussant, Litein.
>
> *'People are educated and have become "digital", you will not find them in the bushes uprooting plants and using them to smoke out mosquitoes.'* Male discussant Salawa.

4.5.6 Barriers to effective malaria control in Baringo County

4.5.6.1 Devolution of health services

The enactment of the Kenya Constitution (2010) marked the devolution of healthcare services from national to county governments. County government became key actors in achieving objectives outlined in the revised Kenya Malaria Strategy 2009-2018. Established structures such as the Division of Malaria Control (DOMC) was transformed into National Malaria Control Programme (NMCP) and Malaria Control Unit (MCU) at the national and county levels, respectively. This transition resulted in new challenges such as weak linkage between the two malaria programs, low communication and inter-sector collaboration and inadequate funding of the county MCUs (National Malaria Control Programme, 2016b). These challenges may undermine achievements made in malaria control as shown in the excerpts:

> *'Although devolution is good, it seems it was done in a hurry. There were no proper structures in the counties. In addition, decision making at the county level is done by the politicians rather that technocrats. Under such system you find more financial allocation go to infrastructure rather than service delivery.'* Key Informant 4

> *'When we tell the county government to procure commodities for "malaria in pregnancy", they say that the partners are supposed to organize for that through the national government. It's not clear how to go about it in the county and when you go to national government whom do you talk to yet health is devolved.'* Key Informant 2

4.5.6.2 Financial constraints

A key informant reported that Baringo County government's health allocation was lower than the county's health requirements. This resulted in periodic shortages of malaria drugs and Rapid Diagnostic Test (RDT) kits. Inadequate supply of mosquito nets, shortage of anti-malarial drugs and RDT kits were cited as key reasons for sustained malaria prevalence in the riverine zone as seen in the following statements:

> *'Now you find that second line antimalarial drugs like quinine injections and cortexin are not available. Right now, I am conducting malaria supervision survey and most facilities do not have first line drugs for malaria and even for treating severe malaria cases.'* Key Informant 3

> *'Mosquito nets are only given to infants and expectant women but adults like us are not protected and we are the ones left to suffer from malaria.'* Male discussant, Salawa.

All (12) key informants concurred that most health facilities had inadequate staff. For instance, most dispensaries had only one nurse while health centres operated with two nurses. Further, some dispensaries remained closed when a nurse in-charge was away on official duty or when he/she went for an annual leave. This is expressed in the excerpt below:

> *'For us that is the norm… In fact having one (nurse) is far much better. You would rather have that one even if she (nurse) will close for some time, during the months that she is present she assists. It has been a challenge though…..'* Key Informant 5

4.5.6.3 Limited research

This study found that malaria research was restricted to lowland areas as compared to the riverine zone. This could be due to accessibility and the fact that some parts of the lowland zone were considered as malaria hotspots. Evidence-based decision making is a key pillar in malaria control. Thus, up-to-date research is needed to support decisions on appropriate intervention measures and resource distributions in these two vulnerable zones. Existence of limited research was captured in the quote below:

> *'The data we have is not convincing enough to allow other parts Baringo County to get some supplies like the mass nets. This might call for another scientific study to help classify Baringo accordingly since the last study was done in 2004/2005.'* Key Informant 4

4.5.7 Mechanisms for communication and information exchange

Accurate information about the cause, mode of transmission and prevention of malaria is crucial in any malaria control activity. Thirty four percent (34%) of survey respondents mentioned family as their main source of malaria information (Table 13). Other noticeable sources of malarial information were radio and health facility, each at 16%. Most male respondents received malaria information from radio while most women relied on family members. Although female respondents depended on their family members for information, statistics confirmed that no gender was advantaged in terms of malaria information ($\chi^2 = 2.475$, df = 2, $p > 0.05$). According to the Kenya Malaria Indicator Survey (KMIS) 2015, household ownership of radios, televisions and mobile phones was at 70%, 36% and 90%, respectively (National Malaria Control Programme, 2016b). Most rural communities rely on radio and their kin for malaria information (Kimbi *et al.*, 2014; Mutua *et al.*, 2016) as opposed to television and internet (Salami and Onuegbu, 2016; Tobgay *et al.*, 2016).

Table 13: Sources of malaria information

Source	**Respondents**	
	n	**(%)**
Family	46	33.8
Other	7	5.1
Friends	12	8.8
Radio (national)	22	16.2
Television	6	4.4
Posters/pamphlets	6	4.4
School textbooks	2	1.5
Health facility	22	16.2
Community health worker/public health official	13	9.6
Total	136	100

Most respondents (76%) had not received any formal malaria preventive advice or education during the past one year when the study was conducted. This finding is supported by in-depth interviews where nine out of 12 key informants asserted that community education and training were rare and conducted only during immunization campaigns, or when there was an imminent disease outbreak such as Cholera or Rift Valley Fever. This is illustrated below:

> *'We haven't had community education or trainings for quite some time now. So if we do not get regular information on how to protect ourselves against malaria then it becomes a bit difficult. I can say there is a problem... If our people could get that (information), I know they would help pass the information to other community members.'* Key Informant 10

Community training and awareness campaigns were primarily supported by health partners and conducted during *Baraza*. *Baraza* is a public meeting where local administrators pass news and information from the government. During a *Baraza* health officials and representatives of aid/development agencies often get opportunities to speak to the masses. In the riverine zone, there were structured *Barazas* scheduled every fortnight while in the lowland zone they were *ad hoc*. Irrespective of the nature, a *Baraza* was reported as an effective platform for communication and information exchange among communities in Baringo County. Other avenues for communication included community action days that were used to convey information on issues ranging from bed-net use, compliance to medication, and general public health matters. Community health volunteers together with the Ministry of Health officials spearhead activities during community action days. According to a key informant from the Department of Public Health, Baringo County, the action days were not routinely organized. In some areas, information was delivered by word of mouth from friends or trusted community members. Such social mobilization mechanisms are critical for a successful community approach to malaria control. Mutero *et al.* (2015) reported that mosquito scouts, school health clubs, school competitions and community educators contributed to the success of an IVM program in Malindi, Kenya. Elsewhere, a study indicated that mass media and interpersonal communications were used to publicize information and behaviour change messages for malaria control (Chanda *et al.*, 2016).

4.5.8 Complementary strategies needed

This study revealed that communities in Baringo County have limited options for malaria control and prevention, yet numerous supplementary IVM strategies have been documented for malaria control in Kenya (Division of Malaria Control, 2011). Further, considering the challenges facing the LLINs and IRS interventions in Kenya (Wanjala *et al.*, 2015), cost effective community-driven approaches have the potential to reduce malaria transmission in remote areas like Baringo. From 92% of survey respondents, and in all FGDs, it was apparent that the locals were willing to adopt complementary mechanisms for malaria control. These sentiments were captured in the following quotes:

> *'If these researches can discover new methods of killing the mosquitoes, then that is what we want. As long as the mosquito is dead, even if we don't sleep under a net we will be alright.'* Male discussant, Salawa.
>
> *'Nets helps us only when sleeping and all other times before we retire to bed we are outside doing other businesses, so, if the government has other ways we are ready to receive.'* Female discussant, Salabani.
>
> *'More methods should be added because each day is different; today differs from tomorrow so we need more (options). If there is information then we need to be given,*

> *then we will know how climate is changing and the world is moving. We used to sleep up there (in the Bororiet), then we descended to the beds and we don't know where we will be tomorrow…'* Male discussant, Kapkuikui.

4.5.9 The framework for malaria control for communities in Baringo County

Malaria control in Kenya has been a top-down initiative primarily by use of LLINs, IRS and case management strategies (Division of Malaria Control, 2009). These strategies are ineffective in reducing malaria prevalence (Benelli and Beier, 2017) since outdoor malaria transmission remains largely unabated. In light of challenges such as insecticide resistance, financial constraints, and inadequate LLINs, community-driven integrated approaches to malaria control should be explored (Zhou *et al.*, 2013; WHO, 2016). Achieving 80% utilization of malaria control interventions by 2018 as stipulated in the KMS 2009 - 2018 requires the development of a community-focused malaria reduction plan. The malaria reduction plan is attainable through implementation of IVM interventions since the 'one size fits all' strategy of LLINs use cannot effectively reduce malaria prevalence in Baringo County. Thus, this study presents a community-focused approach that is less expensive, and if implemented would result in substantial reduction in malaria cases among communities in Baringo. The malaria risk reduction plan for communities in Baringo was developed based on the processes outlined in the CBDRM framework (Abarquez and Murshed, 2004), the Kenya Malaria Strategy (NMS) 2009-2018 (National Malaria Control Programme, 2015) and Malaria Communication Strategy (MCS) 2016-2021 (National Malaria Control Programme, 2016a).

4.5.9.1 Participatory malaria risk assessment

4.5.9.1.1 Hazard analysis and indicators

Rainfall, rainy season, warm weather conditions and floods were key climate hazards linked to malaria epidemics in Baringo County (Figure 24). Erratic rains, rainy season, frequent floods especially in the lowland zone were hazard indicators of significant concern to the stakeholders. Biological hazards identified were high mosquito abundance and the presence of *Plasmodium falciparum*. This is illustrated below

> *'Long time ago the only place you could find a mosquito was at the shores of the lake (L. Baringo) but today we see them around even during the day.'* Community resource person, Salabani.

4.5.9.1.2 Vulnerability analysis and indicators

Community vulnerabilities were categorized into socio-economic, physical and environmental, biological and institutional (Figure 24). The socio-economic vulnerabilities outlined comprised of poverty, education level, household size, population density, and number of people affected by floods. The total number of children under 5 years and the number of women in reproductive age were the most vulnerable within biological category. Mosquito net ownership, house type and condition, and irrigation activities were the physical and environmental vulnerabilities named. Institutional vulnerabilities included proximity to health facilities and nurse-patient ratio.

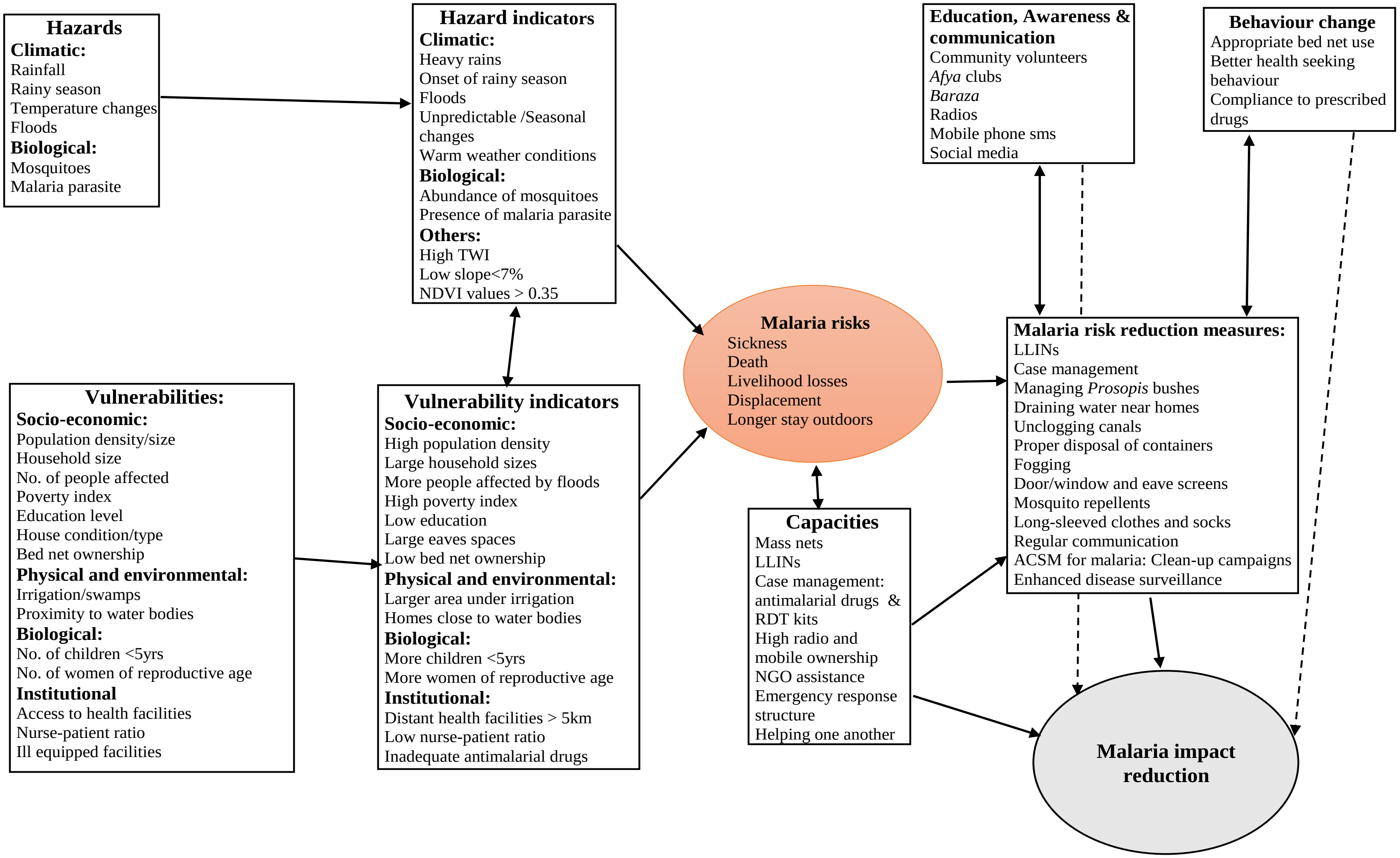

Figure 24: Malaria risk reduction framework developed by communities in Baringo County

Large household sizes, number of people exposed to malaria (such as older children and other family members) were among the social indicators cited (Figure 24). This study found an average of four children per household and only one child had the privilege of sleeping under a mosquito net. This shows that more than half of family members were exposed to mosquito bite every night.

Other indicators were high population density especially in the lowland, low-levels of education (the majority having primary education), high poverty index at 58.5% (KNBS, 2015), low bed net ownership, large eave spaces, and irrigation activities. In this study, mosquito net ownership seemed to be influenced by a combination of accessibility and cost since 47% of those who owned the nets got them from government facilities while 91% of those who bought the nets felt that they were not cheap. Other vulnerabilities were associated with community health seeking behaviour and non-compliance to malaria medication. Long distance travelled to health facilities (on average 7km) and long waiting hours at the health facility were the main reasons for delay by some people to seek health services. In addition, the low nurse-patient ratio was of concern to many stakeholders.

4.5.9.1.3 Participatory malaria risk assessment and analysis

Figure 24 illustrates the process for malaria risk analysis and risk reduction measures suggested during a participatory stakeholders' forums. Risks identified were ranked as death, sickness, loss of working hours and livelihoods, displacement and long stay outdoor due to warm weather conditions. The risk of death was greatest among children and women living in distant or inaccessible villages. It was also mentioned that school going children spent a lot of time out of class either seeking medical service or due to ill-health. A discussant from Kapkuikui accounted that if an individual became sick it took about five days to recover. During this period, a sick person could not carry out their day-to-day activities.

4.5.9.2 Capacities to deal with malaria epidemics

During participatory stakeholders' discussions, the discussants cited malaria treatment services, vector control interventions, and communication and information exchange as capacities for malaria control in Baringo. Anti-malaria drugs and LLINs were the major strategies for malaria control. When there was a shortage of anti-malaria drugs, the sub-county malaria coordinators redistributed medicines from low to high consumption facilities. This minimized chances of patients missing crucial medication. Availability of medicines for emergency response was an additional assurance from the medical practitioners to deal with imminent malaria outbreaks as illustrated below:

> *"It's (supply of antimalarial drugs) not adequate but we supplement by collecting from other facilities" If there is a shortage we request from other low volume facilities from the highlands areas."* Malaria coordinator, Baringo north sub-county

Radios and mobile phones are effective for communication in rural areas where electricity or internet may be lacking. Kass FM and Radio Jambo were the preferred radio stations among the Tugen and Ilchamus speaking communities, respectively. The discussants suggested the use of radios since they could support timely and effective communication among community members. The used of radios for communicating health information has been present for decades. However, mobile phone messages and internet, particularly the social media, was still at its infancy. A study showed that the use of mobile phone text messages for malaria surveillance was feasible in remote districts in Kenya (Githinji *et al.*, 2014). In Tanzania, Mushi and Chilimo (2013) demonstrated that mobile technology can significantly increase access to information among individuals or groups unaware of malaria. Thus, these new mechanisms could be tapped into for communication and disease surveillance (Kass-Hout and Alhinnawi, 2013). For instance, despite the riverine zone being remote, the stakeholders suggested the use of social media such as Twitter, WhatsApp and Facebook for communication. This was captured in the following statement:

> *'But now, we are in a digital world, we do Twitter, WhatsApp… Only a few people are not conversant with the social media.'* Assistant-Chief, Salawa.

The government's mass nets and the NGO assistance were capacities unique to communities in the lowland zone. Further, it was reported that women support groups were common in the lowland zone where members assisted each other in the farms and other entrepreneurial activities. The stakeholders suggested that such support groups could be strengthened to act as community organizations during implementation of malaria reduction strategies.

4.5.9.3 Malaria risk reduction measures

Proposed strategies were LLINs and case management supplemented with community-based vector control measures such as environmental management mechanisms (Figure 24). These measures included clearing bushes close to home, schools and market centres, opening blocked canals, recycling and proper disposal of containers. Other strategies comprised the use of repellents such as mosquito coil, cream and indoor aerosols that locals were willing to purchase and use. Discussants agreed that while outdoors, wearing long sleeved clothes, long pants and socks were simple yet effective ways that minimize mosquito bites. The stakeholders concurred that locally available materials such as wall decorations could be used as screens for doors, window, and eave spaces. The use of screens was not new to the people living in the lowland zone since some households had earlier benefited from screens donated by a research team working on Leishmaniasis.

The MCU through the sub-county malaria coordinators suggested that they could conduct strategic fogging in the lowlands where *Prosopis* bushes sustained high mosquito abundance. Local leaders concurred that they would encourage the people to continue with their cultural practices such as burning cow dung and plant leaves to kill or repel mosquitoes. Officials from the county MCU informed other stakeholders that the traditional remedies were locally available, less costly and effective in repelling biting insects. Studies documented numerous Kenyan plants to have toxicological effects against adult mosquitoes as well as for malaria management (Mukungu *et al.*, 2016; Musau *et al.*, 2016). This suggests that local plants used by communities in Baringo could provide some level of protection against mosquitoes and other biting insects. Leaders from the lowland zone agreed to encourage the residents to rid their dwellings of *Prosopis* as a measure to reduce contact with mosquitoes. Discussants were informed and encouraged to take actions that would ensure they had good health rather than wait for the government to initiate such actions. It was agreed that the local administrators would encourage residents to reduce bushes around their dwellings by organizing periodic community *Prosopis* management days as a way of keeping the vectors at bay.

In both consultative forums, a consensus was reached on using Advocacy Communication and Social Mobilization (ACSM) for malaria control. The use of ACSM was proposed by community resource persons arguing that such a strategy would be effective in spreading health messages especially in remote areas in the county. This would be achieved through *Barazas*, radios or mobile phone short message service (SMS) that were at the disposal of most community members. Vernacular radio stations could be exploited to reach the rural communities with malaria messages. Discussants were eager about using social media such as WhatsApp or Facebook platform for community communication arguing that these platforms provided explicit, graphical information that were easily understood. The ACSM was an appropriate platform for adoption of a multi-pronged approach to malaria control as illustrated by a study conducted in Malindi Kenya (Mutero *et al.*, 2015). Further, the social media platform is a new and rapidly developing avenue for malaria content distribution and communication among target groups (National Malaria Control Programme, 2016a).

The MCU together with County Disease Surveillance and Public Health departments committed to strengthening participation and collaboration with other institutions for efficient service provision in the county. The MCU officers affirmed that in collaboration with NMCP and other partners, they would minimize delays in procurement and service delivery. Consultative deliberations with the county health executive led to the resolution that community health volunteers were to be recruited and trained in order to enhance community education and awareness in the inaccessible areas in the county. Once trained, volunteers would act as community malaria ambassadors to spearhead social behaviour change activities at household and community levels. School teachers were urged to initiate "*Afya*" (health) clubs in order to increase awareness amongst schoolchildren and the entire community. Once equipped with information, the said groups would clarify existing misconceptions among families and community members. Studies have shown that school children acting as health messengers led to improved knowledge and practices among communities in Ghana (Ayi *et al.*, 2010) and India (Deepthi *et al.*, 2014). An integrated approach was applied in controlling malaria in the coastal parts of Kenya (Mutero *et al.*, 2015), Congo (Swana *et al.*, 2016) and Namibia (Chanda *et al.*, 2015).

4.5.10 A gendered perspective

This study revealed gender differentiation with regard to exposure to and control of malaria epidemics. The gendered disaggregation was reported during outdoor occupation, in mosquito net ownership, use and access to correct malaria messages. Both men and women spent long hours outdoors either as part of their daily chores or during social engagements. Men engaged in myriad outdoor occupations especially after dark. The activities included guarding crops against wild animals, watering crops, during circumcision rites, herding and social drinking. Women spent longer hours outdoors while cooking, selling in the market centres, in the farms, fetching water and cleaning. While a majority of respondents who owned and used mosquito nets were women, men had the advantage of sleeping under the nets due to their perceived role as household heads. Men relied on radios as their major source of malaria information while women depended on the information from their family. This shows that women were more likely to receive and perpetuate misguided perceptions about malaria transmission as revealed among the FGDs. The gendered aspect in malaria epidemiology should be considered when coming up with malaria control interventions in Baringo County.

CHAPTER FIVE: SYNTHESIS AND DISCUSSION

Climate change has strong societal impacts especially in Africa where communities have low adaptive capacity. In many regions in Africa, the impacts of climate change are likely to be significant in sectors such as agriculture, water and health. This study begun by analysing the rainfall and temperature trends in Baringo County. The study explored the relationship between the said climatic factors and ecohydrological alterations and the influence of these alterations on *Anopheles gambiae s.l.* distribution and malaria risk. This study showed that despite variations in climate trends, actionable adaptations by communities can be formulated to mitigate impacts of climate change such as increased malaria risks in this region and other areas with similar climatic and ecohydrological conditions.

Over the last five decades, there has been a rapid increase in near surface temperature in Africa at a rate faster than the global temperature increase (James and Washington, 2013; Engelbrecht *et al.*, 2015). However, this increase was not uniform since some regions experienced increasing (Omondi *et al.*, 2014) while others decreasing (MacKellar *et al.*, 2014) temperature trends. This study found spatial variation in minimum and maximum temperatures in Baringo, Kenya. While increasing temperatures occurred in the lowland zone, a decrease in temperature was observed in the riverine zone during the 2003-2016 period. The observed variation in temperature trends were consistent with findings of studies in different parts of Africa where significant increases in both minimum and maximum temperatures have been reported amidst local-scale decreases in minimum temperature (Wandiga *et al.*, 2010; Collins, 2011; Jury and Funk, 2013; MacKellar *et al.*, 2014). Elsewhere short-term cooling episodes have also been reported in Colorado USA (Rangwala and Miller, 2010), and in global scale analysis (Kaufmann *et al.*, 2011; Fyfe *et al.*, 2016). Increasing temperature trends have been largely linked to anthropogenic forcing (IPCC, 2014b); however, the temperature slowdown, often referred as ‘global warming hiatus’ have been attributed to the highly uncertain internal climate variability (Rangwala and Miller, 2010; Collins, 2011; Deser *et al.*, 2012).

There were varied perceptions among the local communities on temperature change over the past decade. In both zones, while some people had opinions contrary to climate observations, others had opinions that were consistent with observed climate trends. The aforementioned temperature variability and subsequent local scale vegetation-temperature feedbacks (Perini and Magliocco, 2014) may have been the reason why there were conflicting opinions. The contradiction between observed temperature trends and local perceptions may have serious ramifications such as maladaptation to climate change among the agro-pastoral communities in Baringo County.

A general increase in T_{min} and T_{max} observed across all seasons in the lowland zone was in agreement with studies over different parts of Kenya (Wandiga *et al.*, 2010; Funk *et al.*, 2012; Omondi *et al.*, 2014). Consistent with this study, James and Washington (2013) reported rapid warming during JJA season compared to other seasons. Similarly, there was a mix of increasing and decreasing mean monthly T_{min} and T_{max} trends in both zones. For instance, while a significant decrease in T_{min} was observed during January in the riverine zone, a significant increase in both T_{min} and T_{max} was observed during July in the lowland zone. Local perceptions on seasonal temperature trends were consistent with the observed temperature increase especially for the MAM season. Similar perceptions on warming during the long rains season have been reported among communities living in Tanzania (Mwakalila *et al.*, 2011) and West Africa (Yaro, 2013).

These was no change in rainfall trends in Baringo County during the 2003-2016 period. Although models project a wetter East African climate (Shongwe *et al.*, 2011; Yang *et al.*, 2014), observations have shown declining rainfall trends over some parts of Kenya and the GHA (Lyon and DeWitt, 2012; Omondi *et al.*, 2012; Liebmann *et al.*, 2014; Rowell *et al.*, 2015). The paradoxical East African rainfall pattern is attributed to high spatial, seasonal and inter-annual rainfall variability (James and Washington, 2013; Maidment *et al.*, 2015) as well as uncertainties linked to precipitation prediction (Christensen *et al.*, 2007). Local opinion agreed with climate observations on the erratic and unpredictable nature of the annual rainfall trend in Baringo. Similar spatially variable rainfall was reported by Funk *et al.* (2012) in their study over East Africa region.

Generally, decreasing MAM rains and increasing SON rains was observed in both zones during the 2003-2016 period. Pacific Ocean SST anomalies have been linked to decreasing MAM rains in East Africa (Liebmann *et al.*, 2014; Yang *et al.*, 2014; Maidment *et al.*, 2015; Rowell *et al.*, 2015). However, enhanced SON rains have been associated with the warming of the western

Indian Ocean (Omondi *et al.*, 2012; Williams *et al.*, 2012; James and Washington, 2013; Bahaga *et al.*, 2014). The local perceptions on seasonal rainfall patterns corroborated climatic observations. The explicit description of seasonal rainfall patterns by the discussants may be due to the fact that local livelihoods such as crop farming and pastoralism are rainfall dependent.

A significant increase in NDVI in the riverine zone may be attributed to the rainfall anomalies observed in the area. Consistent with these findings, a study in Ethiopia showed increased vegetation greenness during same study period (Zewdie *et al.*, 2017). The presence of evergreen *Prosopis* thickets could be the reason for insignificant changes in NDVI in the lowland zone. There was no evidence of change in monthly and seasonal NDVI trend in both zones. The annual NDVI cycle showed peaks during the month of May at the end of the long rains season whereas low NDVI was observed in March at the end of the dry season. The discussants concurred on 'post-1984 vegetation alteration' where plant species such as *Terminalia kilimandscharica* and *Prosopis juliflora* were reported to dominate the once vast grasslands in the riverine and lowland zones, respectively. The observed increase in vegetation greenness could also be attributed to land use change especially in the lowland areas where substantial increase in irrigated crop farming had been witnessed.

Rainfall and minimum temperature were significant predictors of vegetation change. An increase in rainfall was associated with a one month lag in peak vegetation greenness. The positive influence of rainfall on vegetation greenness has been reported in other studies in western Kenya (Sewe *et al.*, 2016), and in China (Cui *et al.*, 2009). In addition, a decrease in temperature was associated with significant increase in vegetation greenness. According to Rishmawi *et al.* (2016), the complexity of the relationship between vegetation and climatic factors result in heterogeneous responses that are not easily quantifiable in spatial scales. A strong association with 2-months lag occurred between both rainfall and temperature and malaria cases where peak malaria cases were associated with lower minimum temperature.

High rainfall amounts coincided with low temperatures. This finding is consistent with previous studies that suggested that the negative relationship between rainfall and temperature could be due to the cooling effects of rainfall (Zhu *et al.*, 2005; Jain and Kumar, 2012). Comparatively, the lowland zone had higher TWI than the riverine zone. High TWI was observed in areas dominated by wetlands, croplands and forests while low TWI was recorded in areas with open grassland. This is in agreement with a study conducted in China that found high soil moisture in croplands compared to grassland (Wang *et al.*, 2013).

Lake Baringo water levels rose considerably across all seasons during the study period. According to (Siebert, 2014), lake levels and stream flow changes are strongly associated with anomalous precipitation and temperature events. Siebert (2014) reported that a decline in surface water is likely under global warming even in areas where an increase in rainfall is currently experienced. Against this backdrop, several factors have been speculated to have caused the increased Lake Baringo water levels. Besides climate forcing, other extraneous factors including tectonics, improved forest cover in the catchment and increased sedimentation have been suggested. During the same study period, there was a significant decrease in River Arror discharge across all seasons. This is in agreement with finding of a study conducted in Mara River Basin, Kenya that linked decreasing river flow to land use and climate change (Mango *et al.*, 2011). However, there was no change in discharge in rivers Perkerra and Kessup. Withdrawal in the catchment areas could be the reason for non-significant change in River Perkerra stream flow (Kipkorir *et al.*, 2002). Changing surface water availability have profound consequences for communities especially in the lowland zone where irrigation is rainfall dependent.

Slope is a hydrological factor associated with mosquito habitat formation. Area slope affects drainage and water accumulation thus impacting the occurrence and duration of breeding habitats (Mushinzimana *et al.*, 2006; Nmor *et al.*, 2013). In this study, both lowland and riverine zones had slope lower than 7%. This implies high potential for water accumulation and pool formation, conditions that promote high *Anopheles* productivity.

Thirty one percent (31%) of the mosquito larvae sampled belonged to *An. gambiae s.l.* and *An. pharoensis* species. *Anopheles gambiae s.l.* were abundant in the riverine zone compared to the lowland zone suggesting a higher malaria risk in the riverine zone. In both zones, there was a tendency towards dry season mosquito occurrence. High *An. gambiae s.l.* abundance was also observed during December, January, February and September. This implies that malaria transmission in Baringo County occurs mainly at the end of the rainy season and at the beginning of the dry season. Areas where irrigation activities occur may have year-round vector abundance and malaria transmission risks. Thus, effective malaria control will require zone specific interventions such as a focus towards dry season vector reduction in the riverine zone.

This study showed high *An. gambiae s.l.* in areas dominated by cropland and wetlands suggesting that irrigation activities could be feeding habitats that support year-round mosquito presence in the lowland zone. According to Kibret *et al.* (2014), pools and leakages from irrigation canals promote high *An. gambiae s.l.* densities. In western Kenya, Munga *et al.* (2006) found high *An. gambiae s.l.* in farmland. Contrary to this study, Kweka *et al.* (2015) found high larval abundance in pastureland as opposed to cropland. In the riverine zone, high *Anopheles gambiae s.l.* abundance could be associated with the existence of wetlands and numerous river channels. According to Ageep *et al.* (2009) these habitats support high vector abundance.

The distribution of *Anopheles* mosquitoes is influenced by multiple interconnected factors (Dambach *et al.*, 2012) that vary in space. In this study, rainfall, slope and vegetation health had significant influence on *Anopheles gambiae s.l.* larvae distribution. An increase in rainfall was associated with increased larval abundance consistent with earlier studies in Kenya (Mushinzimana *et al.*, 2006; Walker *et al.*, 2013) and West Africa (Dambach *et al.*, 2012). Similar to the present study, a study conducted in Ghana (De Souza *et al.*, 2010) found that slope was negatively associated with *Anopheles* larvae distribution. Wiebe *et al.* (2017) cited temperature, wetness and slope as top predictors for mosquito distribution in Africa. Vegetation cover influences malaria transmission in diverse ways. Vegetation health acts as an indicator of surface water availability and near surface humidity conditions that promote vector survival (Midekisa *et al.*, 2012; Ren *et al.*, 2015; Kabaria *et al.*, 2016). On the contrary, vegetation cover may signify the presence of shade and aquatic macrophytes that inhibit mosquito production

(Carlson *et al.*, 2004; Munga *et al.*, 2006). This study revealed that vegetation health negatively influenced *Anopheles gambiae s.l.* occurrence. The negative association between vegetation and *Anopheles gambiae s.l.* larvae suggest that vegetation may have provided shade that negatively affects larval production (Carlson *et al.*, 2004; Munga *et al.*, 2006).

During the 2005 - 2014 period, there was a significant increase in malaria cases in the riverine zone. According to key informants, malaria transmission occurred year-round in many areas in the riverine zone. This study found significant increases in malaria cases during March, April, May, June and October in the riverine zone. In the lowland zone, non-significant decrease in malaria trends could be attributed to interventions especially the mass net distributions in some areas in the lowland zone.

Misconceptions coexisted with correct medical knowledge on the cause and mode of malaria transmission. The misconceptions about malaria etiology were not unique to this study since similar perceptions have been reported among communities in different parts of Africa (Shuford *et al.*, 2016; Dlamini *et al.*, 2017; Moshi *et al.*, 2017; Owek *et al.*, 2017). These misguided perceptions indicate a knowledge gap that potentially influences choices of malaria prevention or treatment patterns (Mutua *et al.*, 2016). Thus, there is need for enhanced community knowledge though public education and awareness in order to increase uptake of malaria control measures. According to Al-Adhroey *et al.* (2010), improved public awareness resulted in substantial reduction in malaria cases among rural communities in Malaysia.

This study identified several factors predisposing Baringo residents to malaria risk. Most of these activities were gender-oriented and resulted in longer stays outdoors by both men and women especially after dark. These activities increased chances of contact with mosquitoes since *Anopheles* peak biting hours (Moiroux *et al.*, 2012; Yohannes and Boelee, 2012) coincide with the duration when most people were still outdoors. Outdoor occupation was reported to increase malaria transmission in Tanzania (Moshi *et al.*, 2017) and Swaziland (Dlamini *et al.*, 2017). This study showed that very few people used protective measures such as long pants and socks while outdoors. Mosquito net was the dominant malaria prevention tool for indoors malaria control. Nevertheless, prolonged outdoor stays may have decreased the effectiveness of mosquito nets since most people were likely to be bitten by mosquito before sleeping under the nets. Inappropriate utilization of mosquito nets further compromised the efficacy of LLINs as has been reported in other studies (Ng'ang'a *et al.*, 2009; Toé *et al.*, 2009; Ingabire *et al.*, 2015; Tarimo, 2015).

Consistent with the current study, burning of cow dung and local plant leaves were reported in Tanzania (Moshi *et al.*, 2017) and West Africa (Ruberto *et al.*, 2014) as traditional mechanisms for repelling mosquitoes and other biting insects. The majority of community members had not used any mosquito repellents or chemical sprays, implying suboptimal utilization of complementary interventions for malaria prevention among communities in Baringo County. This could be attributed to over-reliance on mosquito nets and cultural transformation since those who used traditional mechanisms were considered retrogressive.

From this study, challenges stemming from the devolved healthcare system were found to hinder effective malaria control in Baringo County. These challenges included weak linkages between county and national malaria programs, inadequate funding, shortage of staff and malaria commodities (such as RDT kits and anti-malarial drugs), poor inter-sector collaboration, and lack of up-to-date research especially in the riverine zone. This was consistent with the gaps identified in the Malaria Communication Strategy 2016-2021 that further elucidated directions and approaches to address those issues (National Malaria Control Programme, 2016a).

Operational communication and information exchange platforms are essential in enhancing community health education and awareness. This study revealed low community engagement on public health issues depicted by lack of community malaria awareness. Women relied on family members and health workers while men depended on radio for information about malaria. Similar to these findings, Kimbi *et al.* (2014) and Mutua *et al.* (2016) established that most rural communities depended on kin and radios for malaria information.

Baraza was identified as an effective platform for communication and information exchange between the local communities and other stakeholders in Baringo County. *Baraza* was lauded as an efficient and community-friendly platform for communication since the messages were in vernacular and potentially reached a large number of people. If strengthened and properly utilized, *Barazas* could help achieve significant community awareness not only for malaria control but general public health awareness and education.

Despite having numerous strategies for malaria control and prevention in Kenya (Division of Malaria Control, 2011), this study showed that these strategies were underutilized in Baringo County. Taking into consideration the challenges associated with LLINs and case management strategies, community-driven supplementary approaches need to be embraced in order to reduce the malaria burden and achieve a malaria-free Kenya. This study revealed that locals were eager to adopt complementary strategies that would lessen the malaria burden. Concerns over inadequate mosquito nets as well as possibility of outdoor malaria transmissions fuelled the quest to adopt additional methods in reducing malaria transmission. Evidently, this called for diversification and adoption of complementary malaria control interventions.

This study presents for the first time a framework of malaria control for communities living in Baringo, Kenya (Figure 24, page 80). If implemented, the measures identified would help meet the strategic objectives outlined in the KMS 2009-2018. Local structures for implementation include ACSM platforms and local organizations. Enhanced utilization of local malaria preventive measures can significantly contribute to closing the gaps associated with primary intervention strategies. Several complementary mechanisms were identified and proposed for adoption in order to reduce malaria risk in Baringo. Besides the LLINs and case management mechanisms, complementary strategies such as social mobilization for environmental management were recommended. These activities included bush clearing, unclogging drainage canals and proper disposal of empty containers. Outdoor protection against mosquito bites using long-sleeved clothes, long pants and socks were cited as simple strategies that could effectively minimize outdoor malaria transmission. A study found that insecticide-treated clothing were effective in controlling the vector of Dengu and Zika Virus (Orsborne *et al.,* 2016). Using locally accessible materials as screens for doors, windows and eave spaces would minimize indoor mosquito densities. Additional vector control strategies include the use of repellents such as mosquito coils, and indoor sprays. Window and door screens were used to control *Aedes albopictus* in New Jersey (Shepard *et al.*, 2014). Similar mechanisms were suggested for control of malaria transmission in Tanzania (Namango, 2013), India (Van Eijk *et al.*, 2016) and Sri Lanka (Gunathilaka *et al.*, 2016) .

Individual and community-based activities and practices that potentially reduce mosquito densities were emphasized by the MCU officers. The stakeholders agreed to encourage the locals to continue with the safe traditional practices like burning cow dung or plant leaves within their compounds to repel mosquitoes and biting insects that transmit many vector-borne diseases. Such practices were to be emphasized during *Barazas*. The public health officers encouraged the people living in the lowland zone to clear *Prosopis* bushes that grew within their compounds as a way of keeping mosquitoes at bay. Chiefs and Assistant Chiefs concurred that they would initiate periodic *Prosopis* clearing activities around schools, market centres, and other public spaces.

The ACSM mechanism is a key component of any integrated vector control approach. The ACSM for malaria control is an indispensable tool for community-based approaches (Division of Malaria Control, 2009). In this framework, ACSM platforms identified by the stakeholders were *Barazas*, radios and mobile phone short message service (SMS). In addition, the fast-growing social media platforms such as Facebook, Twitter or WhatsApp could be exploited to pass malaria messages and information to individuals and groups. Radio, television and cell phones have been used for social mobilization campaigns for diseases like tuberculosis (Turk *et al.*, 2013), diabetes (Mshunqane, 2013) and malaria (Githinji *et al.*, 2014). A study showed that together with LLINs and diagnostic treatment, ACSM contributed significantly to malaria reduction in Bangladesh (Adediran *et al.*, 2017). The Kenya Malaria Communication Strategy 2016-2021 recommended that these social media spaces be taken up by county governments as potential social mobilization and interpersonal communication mechanisms for malaria communication (National Malaria Control Programme, 2016a).

Community health volunteers and school health "*Afya*" clubs could spearhead social mobilization for behaviour change, consequently demystifying existing myths and misconceptions. Studies have shown that the use of school children as health messengers led to improved knowledge and practices among communities in Ghana (Ayi *et al.*, 2010) and India (Deepthi *et al.*, 2014). A malaria-free Kenya will require implementation of community-driven integrated approaches for malaria reduction. These approaches have been applied at the Kenyan coast (Mutero *et al.*, 2015) and in other parts of the world for malaria (Swana *et al.*, 2016) and dengue control (Chanda *et al.*, 2015; Zahir *et al.*, 2016; Andersson *et al.*, 2017). Community-driven malaria prevention and control interventions would minimize outdoor malaria transmission, and ameliorate the challenges of LLINs and case management currently experienced in Baringo County. Collectively, these interventions would result in substantial reduction of the malaria burden and lead to healthier and productive communities.

CHAPTER SIX:CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Mean annual minimum and maximum temperatures increased during the 2003-2016 period in the lowland zone. Cooling occurred during the month of January in both zones. There was no change in annual rainfall trend during the 2003-2016 period contrary to the local perception that rainfall had decreased. Erratic and unpredictable MAM rains present climate adaptation challenges and threatens local livelihoods. During the 2003-2016 period, the annual vegetation greenness increased in both riverine and lowland zones. Although there was no change in discharge in River Perkerra, a key inlet of Lake Baringo, a significant increase in the Lake Baringo water levels was observed during the 2011-2014 period. In the riverine zone, there was a decrease in discharge in rivers Arror and Kessup. From the findings of this study, there were relationships between rainfall and temperature trends and the assessed ecohydrological factors in Baringo County. Rainfall and minimum temperature were significant predictors of vegetation change. During the 2011-2014 period, there was no evidence of association between assessed climatic factors and river discharge or lake levels.

Anopheles gambiae s.l. abundance was higher in the riverine zone compared with the lowland zone. While the lowland zone showed a seasonal pattern in *An. gambiae s.l.* abundance, there was a sustained mosquito presence in the riverine zone. High abundance of *An. gambiae s.l.* mosquitoes was found to be closely associated with cropland and wetland, suggesting the contribution of these land use types to malaria transmission. The occurrence of malaria vectors was influenced by various ecohydrological factors that exhibited heterogeneous relationships. For instance, rainfall, slope and vegetation health had significant influence on the occurrence of *An. gambiae s.l.* larvae. Malaria control in these zones will require adoption of environmental management interventions in addition to the LLINs currently used.

During the 2005-2014 period, malaria cases increased in the riverine zone while there was no change in malaria cases in the lowland zone. Malaria cases lagged rainfall and minimum temperature by two months and NDVI by one month. The lagged relationships can inform a timely distribution of resources to minimize malaria transmission. Misconceptions coexisted with correct medical knowledge on causes and modes of malaria transmission. This implied existence of a knowledge gap that may negatively influence choices on malaria prevention strategies and treatment regimes. There was over-reliance on mosquito nets for malaria prevention. The nets were, however, inadequate and not easily accessed by the locals. Activities conducted after dusk increased the likelihood of the locals getting into contact with mosquitoes consequently increasing outdoor malaria transmission risks. Challenges in the implementation of devolved healthcare system seemed to counter achievements made in malaria control. Malaria risk reduction strategies by and for communities in Baringo County would result in substantial reduction in malaria burden in the region.

In Baringo County, rainfall and temperature variability during the 2003- 2016 period influenced vegetation conditions with lags ranging from zero to one month. During the same study period, this study found lack of a relationship between the said climate factors and Lake Baringo levels and assessed river discharge. This study showed that heterogeneous relationships occurred between *Anopheles gambiae s.l.* and the ecohydrological factors, conditions that potentially promote malaria transmission. Thus, community-specific malaria risk reduction strategies identified during this study should be implemented to minimize malaria epidemics in Baringo County.

6.2 Recommendations

The key recommendations arising from this study are as follows:

- Local perceptions and climate observations should be integrated when developing climate change adaptation strategies.

- Climate and ecohydrological modelling should be conducted to inform climate adaptation and prediction of malaria outbreaks. These models would also support the development of malaria early warning system for the county.

- The Department of Health, Baringo County should revise malaria hotspots and interventions measures to capture the isolated yet critical riverine zone. This would inform the county government's procurement and distribution of malaria commodities.

- The MCU though the local administrators should initiate and mobilize communities to adopt environmental management strategies such as periodic environmental clean-ups geared towards reducing *Prosopis* within homes, schools and market centres.

- The MCU should recruit and effectively engage community health volunteers to reach out to the people in remote areas with messages to dispel myths associated with malaria and increase awareness among community members.

- Existing platforms such as *Barazas* and radios should be exploited for malaria information and communication.

- The county MCU with support of the local communities should adopt and implement the framework for effective malaria risk reduction in Baringo County.

REFERENCES

Abarquez, I. and Murshed, Z. (2004) *Community-based disaster risk management: Field Practitioners' Handbook*. Bangkok: Asian Disaster Preparedness Center (ADPC).

Adediran, M. B., Olabode, O. O. and Kayode, G. F. (2017) Improving Africa economy through efficient and effective malaria management and prevention programs. *Medical Science*, **21**(83): 39-47.

Afrane, Y. A., Githeko, A. K. and Yan, G. (2012) The ecology of Anopheles mosquitoes under climate change: Case studies from the effects of deforestation in East African highlands. *Ann N Y Acad Sci*, **1249**: 204-10.

Ageena, I., Macdonald, N. and Morse, A. (2014) Variability of maximum and mean average temperature across Libya (1945–2009). *Theoretical and Applied Climatology*, **117**(3-4): 549-63.

Ageep, T. B., Cox, J., M'oawia, M. H., Knols, B. G., Benedict, M. Q., Malcolm, C. A., Babiker, A. and El Sayed, B. B. (2009) Spatial and temporal distribution of the malaria mosquito *Anopheles arabiensis* in northern Sudan: Influence of environmental factors and implications for vector control. *Malaria Journal*, **8**(1): 123.

Al-Adhroey, A. H., Nor, Z. M., Al-Mekhlafi, H. M. and Mahmud, R. (2010) Opportunities and obstacles to the elimination of malaria from Peninsular Malaysia: Knowledge, attitudes and practices on malaria among aboriginal and rural communities. *Malaria Journal*, **9**(1): 137.

Albertson, J. D., Williams, C. A., Scanlon, T. M. and Montaldo, N. (2006) *Soil moisture controls on water vapor and carbon fluxes in semi-arid regions. In Dryland Ecohydrology* (Eds P. D'Odorico and A. Porporato). Dordrecht: Springer Netherlands, 67-83.

Andersson, N., Arostegui, J., Nava-Aguilera, E., Harris, E. and Ledogar, R. J. (2017) Camino Verde (The Green Way): Evidence-based community mobilisation for dengue control in Nicaragua and Mexico: Feasibility study and study protocol for a randomised controlled trial. *BMC Public Health*, **17**(1): 407.

Arum, S., Kokwaro, E. and Mulwa, F. (2010) *Diversity and colonization of permanent and semi-permanent breeding habitats by Anopheles mosquitoes in a semi-arid ecosystem of Baringo district in Kenya.* In Second RUFORUM Biennial Meeting, Conference proceedings; Entebbe: RUFORUM, 349-54.

Ashley, G. M., Maitima Mworia, J., Muasya, A., Owen, R. B., Driese, S., Hover, V., Renaut, R. W., Goman, M., Mathai, S. and Blatt, S. (2004) Sedimentation and recent history of a freshwater wetland in a semi-arid environment: Loboi Swamp, Kenya, East Africa. *Sedimentology*, **51**(6): 1301-21.

Atieli, H. E., Zhou, G., Afrane, Y., Lee, M.-C., Mwanzo, I., Githeko, A. K. and Yan, G. (2011) Insecticide-treated net (ITN) ownership, usage, and malaria transmission in the highlands of western Kenya. *Parasites & Vectors*, **4**(1): 113.

Atkinson, P. W. (2009) *Vector Biology, Ecology and Control*. Springer Netherlands.

Ayi, I., Nonaka, D., Adjovu, J. K., Hanafusa, S., Jimba, M., Bosompem, K. M., Mizoue, T., Takeuchi, T., Boakye, D. A. and Kobayashi, J. (2010) School-based participatory health education for malaria control in Ghana: Engaging children as health messengers. *Malaria Journal*, **9**(98).

Bahaga, T. K., Mengistu Tsidu, G., Kucharski, F. and Diro, G. T. (2014) Potential predictability of the sea-surface temperature forced equatorial East African short rains interannual variability in the 20th century. *Quarterly Journal of the Royal Meteorological Society*, **141**(686): 16-26.

Barbosa, H. A., Lakshmi Kumar, T. V. and Silva, L. R. M. (2015) Recent trends in vegetation dynamics in the South America and their relationship to rainfall. *Natural Hazards*, **77**(2): 883-99.

Baringo County Government (2014) County Integrated Development Plan 2013-2017. Kabarnet.

Baudena, M., D'Andrea, F. and Provenzale, A. (2008) A model for soil-vegetation-atmosphere interactions in water-limited ecosystems. *Water Resources Research*, **44**(12).

Bayoh, M. N. and Lindsay, S. W. (2003) Effect of temperature on the development of the aquatic stages of *Anopheles gambiae* sensu stricto (Diptera: Culicidae). *Bull Entomol Res*, **93**(5): 375-81.

Beier, J. C., Keating, J., Githure, J. I., Macdonald, M. B., Impoinvil, D. E. and Novak, R. J. (2008) Integrated vector management for malaria control. *Malaria Journal*, **7**(1).

Benedict, M. Q., Sandve, S. R., Wilkins, E. E. and Roberts, J. M. (2010) Relationship of larval desiccation to *Anopheles gambiae* Giles and *An. arabiensis* Patton survival. *Journal of Vector Ecology*, **35**(1): 116-23.

Benelli, G. and Beier, J. C. (2017) Current vector control challenges in the fight against malaria. *Acta Tropica*, **174**: 91-6.

Berdud, M., Towse, A. and Kettler, H. (2016) Fostering incentives for research, development, and delivery of interventions for neglected tropical diseases: lessons from malaria. *Oxford Review of Economic Policy*, **32**(1): 64-87.

Bhat, S., Jacobs, J. M., Hatfield, K. and Graham, W. D. (2010) A comparison of storm-based and annual-based indices of hydrologic variability: A case study in Fort Benning, Georgia. *Environ Monit Assess*, **167**(1-4): 297-307.

Bhattarai, A., Ali, A. S., Kachur, S. P., Mårtensson, A., Abbas, A. K., Khatib, R., Al-mafazy, A.-w., Ramsan, M., Rotllant, G., Gerstenmaier, J. F., Molteni, F., Abdulla, S., Montgomery, S. M., Kaneko, A. and Björkman, A. (2007) Impact of Artemisinin-Based Combination Therapy and Insecticide-Treated Nets on Malaria Burden in Zanzibar. *PLOS Medicine*, **4**(11): e309.

Bi, P., Tong, S., Donald, K., Parton, K. and Ni, J. (2003) Climatic variables and transmission of malaria: A 12-year data analysis in Shuchen County, China. *Public Health Reports*, **118**.

Bliss, C. I. and Fisher, R. A. (1953) Fitting the negative binomial distribution to biological data. Biometrics, **9**(2): 176-200.

Bloszies, C. and Forman, S. L. (2015) Potential relation between equatorial sea surface temperatures and historic water level variability for Lake Turkana, Kenya. *Journal of Hydrology*, **520**: 489-501.

Boissière, M., Locatelli, B., Sheil, D., Padmanaba, M. and Sadjudin, E. (2013) Local perceptions of climate variability and change in tropical forests of Papua, Indonesia. *Ecology and Society*, **18**(4).

Bomblies, A., Duchemin, J. B. and Eltahir, E. A. B. (2009) A mechanistic approach for accurate simulation of village scale malaria transmission. *Malaria Journal*, **8**(1): 223.

Bousema, T., Stresman, G., Baidjoe, A. Y., Bradley, J., Knight, P., Stone, W., Osoti, V., Makori, E., Owaga, C., Odongo, W., China, P., Shagari, S., Doumbo, O. K., Sauerwein, R. W., Kariuki, S., Drakeley, C., Stevenson, J. and Cox, J. (2016) The Impact of Hotspot-Targeted Interventions on Malaria Transmission in Rachuonyo South District in the Western Kenyan Highlands: A Cluster-Randomized Controlled Trial. *PLOS Medicine*, **13**(4): e1001993.

Brandt, M., Tappan, G., Diouf, A., Beye, G., Mbow, C. and Fensholt, R. (2017) Woody Vegetation Die off and Regeneration in Response to Rainfall Variability in the West African Sahel. *Remote Sensing*, **9**(1): 39.

Brooks, R. T. (2009) Potential impacts of global climate change on the hydrology and ecology of ephemeral freshwater systems of the forests of the northeastern United States. *Climatic Change*, **95**(3-4): 469-83.

Caminade, C., Ndione, J. A., Kebe, C. M. F., Jones, A. E., Danuor, S., Tay, S., Tourre, Y. M., Lacaux, J. P., Vignolles, C., Duchemin, J. B., Jeanne, I. and Morse, A. P. (2011) Mapping Rift Valley fever and malaria risk over West Africa using climatic indicators. *Atmospheric Science Letters*, **12**(1): 96-103.

Carlson, J. C., Byrd, B. D. and Omlin, F. X. (2004) Field assessments in western Kenya link malaria vectors to environmentally disturbed habitats during the dry season. *BMC Public Health*, **4**(1): 33.

Ceccato, P., Connor, S. J., Jeanne, I. and Thomson, M. C. (2005) Application of Geographical Information Systems and Remote Sensing technologies for assessing and monitoring malaria risk. *Parassitologia*, **47**(1): 81-96.

Chaki, P. P., Kannady, K., Mtasiwa, D., Tanner, M., Mshinda, H., Kelly, A. H. and Killeen, G. F. (2014) Institutional evolution of a community-based programme for malaria control through larval source management in Dar es Salaam, United Republic of Tanzania. *Malaria Journal*, **13**(1): 245.

Chanda, E., Ameneshewa, B., Angula, H. A., Iitula, I., Uusiku, P., Trune, D., Islam, Q. M. and Govere, J. M. (2015) Strengthening tactical planning and operational frameworks for vector control: The roadmap for malaria elimination in Namibia. *Malaria Journal*, **14**: 302.

Chanda, E., Doggale, C., Pasquale, H., Azairwe, R., Baba, S. and Mnzava, A. (2013) Addressing malaria vector control challenges in South Sudan: Proposed recommendations. *Malaria Journal*, **12**(59).

Chanda, E., Mzilahowa, T., Chipwanya, J., Ali, D., Troell, P., Dodoli, W., Mnzava, A. P., Ameneshewag, B. and Gimnig, J. (2016) Scale-up of integrated malaria vector control: Lessons from Malawi. *A Bulletin of the World Health Organization*, **94**(6): 475-80.

Chaves, L. F. and Koenraadt, C. J. M. (2010) Climate Change and Highland Malaria: Fresh Air for a Hot Debate. *The Quarterly Review of Biology*, **85**(1): 27-55.

Chikoore, H. and Jury, M. R. (2010) Intraseasonal Variability of Satellite-Derived Rainfall and Vegetation over Southern Africa. *Earth Interactions*, **14**(3): 1-26.

Chirebvu, E.and Chimbari, M. J. (2015) Characteristics of *Anopheles arabiensis* larval habitats in Tubu village, Botswana. *Journal of Vector Ecology*, **40**(1): 129-38.

Christensen, J. H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R. K., Kwon, W. T., Laprise, R., Rueda, M. V., Mearns, L., Menéndez, C. G., Räisänen, J., Rinke, A., A., S. and Whetton, P. (2007) *Regional Climate Projections. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Collins, J. M. (2011) Temperature variability over Africa. *Journal of Climate*, **24**(14): 3649-66.

Cotter, C., Sturrock, H. J., Hsiang, M. S., Liu, J., Phillips, A. A., Hwang, J., Gueye, C. S., Fullman, N., Gosling, R. D. and Feachem, R. G. (2013) The changing epidemiology of malaria elimination: New strategies for new challenges. *Lancet*, **382**(9895): 900-11.

County Council of Baringo (2007) Lake Bogoria National Reserve: Integrated Management Plan (2007-2012). Nairobi.

Cubasch, U., Wuebbles, D., Chen, D., Facchini, M. C., Frame, D., Mahowald, N. and Winther, J.-G. (2013) *Introduction. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)].* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Cui, L., Shi, J., Yang, Y. and Fan, W. (2009) Ten-day response of vegetation NDVI to the variations of temperature and precipitation in eastern China. *Acta Geographica Sinica*, **7**(11).

Dale, P. E. R . and Knight, J. M. (2008) Wetlands and mosquitoes: A review. *Wetlands Ecology and Management*, **16**(4): 255-76.

Dambach, P., Machault, V., Lacaux, J.-P., Vignolles, C., Sié, A. and Sauerborn, R. (2012) Utilization of combined remote sensing techniques to detect environmental variables influencing malaria vector densities in rural West Africa. *International Journal of Health Geographics*, **11**(1): 8.

De Allegri, M., Louis, V. R., Tiendrébeogo, J., Souares, A., Yé, M., Tozan, Y., Jahn, A. and Mueller, O. (2013) Moving towards universal coverage with malaria control interventions: Achievements and challenges in rural Burkina Faso. The International *Journal of Health Planning and Management*, **28**(1): 102-21.

De Souza, D., Kelly-Hope, L., Lawson, B., Wilson, M. and Boakye, D. (2010) Environmental factors associated with the distribution of *Anopheles gambiae* ss in Ghana; An important vector of lymphatic filariasis and malaria. *Plos One*, **5**(3): e9927.

Debboun, M. and Strickman, D. (2013) Insect repellents and associated personal protection for a reduction in human disease. *Medical and Veterinary Entomology*, **27**(1): 1-9.

Deepthi, R., Naresh Kumar, S., Prasanna Kamath, B. and Rajeshwari, H. (2014) Participatory school health education on vector-borne diseases: Engaging children as change agents. *International Journal of Health Promotion and Education*, **52**(2): 68-77.

Deredec, A., O'Loughlin, S. M., Hui, T. Y. and Burt, A. (2016) Partitioning the contributions of alternative malaria vector species. *Malaria Journal*, **15**: 60.

Deressa, W., Yihdego, Y. Y., Kebede, Z., Batisso, E., Tekalegne, A. and Dagne, G. A. (2014) Effect of combining mosquito repellent and insecticide treated net on malaria prevalence in Southern Ethiopia: A cluster-randomised trial. *Parasites & Vectors*, **7**(1): 132.

Deser, C., Phillips, A., Bourdette, V. and Teng, H. (2012) Uncertainty in climate change projections: The role of internal variability. *Climate Dynamics*, **38**(3): 527-46.

Di Gregorio, A. (2005) *Land cover classification system: LCCS: Classification concepts and user manual.* Food & Agriculture Organization of the United Nations, Rome.

Division of Malaria Control (2009) Towards a Malaria Free Kenya. National Malaria Strategy 2009-2017. Nairobi.

Division of Malaria Control (2011) 2010 Kenya Malaria Indicator Survey. Nairobi.

Dlamini, S. V., Liao, C.-W., Dlamini, Z. H., Siphepho, J. S., Cheng, P.-C., Chuang, T.-W. and Fan, C.-K. (2017) Knowledge of human social and behavioral factors essential for the success of community malaria control intervention programs: The case of Lomahasha in Swaziland. *Journal of Microbiology, Immunology and Infection*, **50**(2): 245-53.

Elissa, N., Migot-Nabias, F., Luty, A., Renaut, A., Toure, F., Vaillant, M., Lawoko, M., Yangari, P., Mayombo, J. and Lekoulou, F. (2003) Relationship between entomological inoculation rate, *Plasmodium falciparum* prevalence rate, and incidence of malaria attack in rural Gabon. *Acta Tropica*, **85**(3): 355-61.

Elliott, J. M. (1977) *Some methods for the statistical analysis of samples of benthic invertebrates.* Cumbria, U.K.: Freshwater Biological Association Scientific Publication.

Engelbrecht, F., Adegoke, J., Bopape, M. J., Naidoo, M., Garland, R., Thatcher, M., McGregor, J., Katzfey, J., Werner, M. and Ichoku, C. (2015) Projections of rapidly rising surface temperatures over Africa under low mitigation. *Environmental Research Letters*, **10**(8): 085004.

Fillinger, U. and Lindsay, S. W. (2006) Suppression of exposure to malaria vectors by an order of magnitude using microbial larvicides in rural Kenya. *Tropical Medicine and International Health*, **11**(11): 1629-42.

Funk, C., Michaelsen, J. and Marshall, M. T. (2012) Mapping Recent Decadal Climate Variations in Precipitation and Temperature across Eastern Africa. *Remote Sensing of Drought: Innovative Monitoring Approaches*: 331.

Fyfe, J. C., Meehl, G. A., England, M. H., Mann, M. E., Santer, B. D., Flato, G. M., Hawkins, E., Gillett, N. P., Xie, S. P. and Kosaka, Y. (2016) Making sense of the early 2000s warming slowdown. *Nature Climate Change*, **6**(3): 224.

Gavrilov, M. B., Tošić, I., Marković, S. B., Unkašević, M. and Petrović, P. (2016) Analysis of annual and seasonal temperature trends using the Mann-Kendall test in Vojvodina, Serbia. *Időjárás*, **120**(2): 183-98.

Gerten, D., Schaphoff, S. and Lucht, W. (2007) Potential future changes in water limitations of the terrestrial biosphere. *Climatic Change*, **80**(3-4): 277-99.

Ghosh, S. K., Patil, R. R., Tiwari, S. and Dash, A. P. (2006) A community-based health education programme for bio-environmental control of malaria through folk theatre (Kalajatha) in rural India. *Malaria Journal*, **5**(1): 123.

Gilioli, G.and Mariani, L. (2011) Sensitivity of Anopheles gambiae population dynamics to meteo-hydrological variability: A mechanistic approach. *Malaria Journal*, **10**: 294.

Gillies, M. and Coetzee, M. (1987) *A supplement to the Anophelinae of Africa South of the Sahara (Afrotropical Region)*. Johannesburg: Publication of South Africa Institute of Medical Research

Githeko, A. K. and Ndegwa, W. (2001) Predicting malaria epidemics in the Kenyan highlands using climate data: A tool for decision makers. *Global Change and Human Health*, **2**(1): 54-63.

Githeko, A. K., Ogallo, L., Lemnge, M., Okia, M. and Ototo, E. N. (2014) Development and validation of climate and ecosystem-based early malaria epidemic prediction models in East Africa. *Malaria Journal*, **13**: 329.

Githinji, S., Kigen, S., Memusi, D., Nyandigisi, A., Wamari, A., Muturi, A., Jagoe, G., Ziegler, R., Snow, R. W. and Zurovac, D. (2014) Using mobile phone text messaging for malaria surveillance in rural Kenya. *Malaria Journal*, **13**(1): 107.

Godfray, H. C. (2013) Mosquito ecology and control of malaria. *Journal of Animal Ecology*, **82**(1): 15-25.

Govere, J., Durrheim, D.N., Coetzee M. , Hunf, R. H. and La Grange, J. J. (2000) Captures of mosquitoes of the *Anopheles gambiae* complex (Diptera: Culicidae) in the Lowveld Region of Mpumalanga Province, South Africa. *African Entomology*, **23**: 647-57.

Gownaris, N. J., Pikitch, E. K., Aller, J. Y., Kaufman, L. S., Kolding, J., Lwiza, K. M. M., Obiero, K. O., Ojwang, W. O., Malala, J. O. and Rountos, K. J. (2017) Fisheries and water level fluctuations in the world's largest desert lake. *Ecohydrology*, **10**(1): e1769.

Grashey-Jansen, S., Kuba, M., Cyffka, B., Halik, Ü. and Aishan, T. (2014) Spatio-temporal variability of soil water at three seasonal floodplain sites: A case study in Tarim Basin, Northwest China. *Chinese Geographical Science*, **24**(6): 647-57.

Gunathilaka, N., Abeyewickreme, W., Hapugoda, M. and Wickremasinghe, R. (2016) Determination of demographic, epidemiological, and socio-economic determinants and their potential impact on malaria transmission in Mannar and Trincomalee districts of Sri Lanka. *Malaria Journal*, **15**: 330.

Gyampoh, B., Amisah, S., Idinoba, M. and Nkem, J. (2009) Using traditional knowledge to cope with climate change in rural Ghana. *Unasylva*, **60**(281/232): 70-4.

Hanafi-Bojd, A. A., Vatandoost, H., Oshaghi, M. A., Charrahy, Z., Haghdoost, A. A., Zamani, G., Abedi, F., Sedaghat, M. M., Soltani, M., Shahi, M. and Raeisi, A. (2012) Spatial analysis and mapping of malaria risk in an endemic area, south of Iran: A GIS based decision making for planning of control. *Acta Tropica*, **122**(1): 132-7.

Hardy, A. J., Gamarra, J. G. P., Cross, D. E., Macklin, M. G., Smith, M. W., Kihonda, J., Killeen, G. F., Ling'ala, G. N. and Thomas, C. J. (2013) Habitat hydrology and geomorphology control the distribution of malaria vector larvae in rural Africa. *Plos One*, **8**(12): e81931.

Hay, S. I., Omumbo, J. A., Craig, M. H. and Snow, R. W. (2000) Earth Observation, Geographic Information Systems and *Plasmodium falciparum* Malaria in Sub-Saharan Africa. *Advanced Parasitology*, **47**: 173-215.

Herrmann, S. M., Anyamba, A. and Tucker, C. J. (2005) Recent trends in vegetation dynamics in the African Sahel and their relationship to climate. *Global Environmental Change*, **15**(4): 394-404.

Highton, R. (1983) Taxonomic Keys for the Identification of the Afrotropical Mosquitoes. Unpublished https://www researchgate net/profile/Mojca_Kristan/post [accessed on 23 January 2018].

Hopp, L. and McDonnell, J. (2009) Connectivity at the hillslope scale: Identifying interactions between storm size, bedrock permeability, slope angle and soil depth. *Journal of Hydrology*, **376**(3-4): 378-91.

Hoscilo, A., Balzter, H., Bartholomé, E., Boschetti, M., Brivio, P. A., Brink, A., Clerici, M. and Pekel, J. F. (2014) A conceptual model for assessing rainfall and vegetation trends in sub-Saharan Africa from satellite data. *International Journal of Climatology*, **35**(12): 3582-92.

Imbahale, S. S., Githeko, A., Mukabana, W. R.and Takken, W. (2012) Integrated mosquito larval source management reduces larval numbers in two highland villages in western Kenya. *BMC Public Health*, **12**(1): 362.

Imbahale, S. S., Paaijmans, K. P., Mukabana, W. R., van Lammeren, R., Githeko, A. K. and Takken, W. (2011) A longitudinal study on Anopheles mosquito larval abundance in distinct geographical and environmental settings in western Kenya. *Malaria Journal*, **10**(1): 81.

Ingabire, C. M., Rulisa, A., Van Kempen, L., Muvunyi, C., Koenraadt, C. J., Van Vugt, M., Mutesa, L., Van Den Borne, B. and Alaii, J. (2015) Factors impeding the acceptability and use of malaria preventive measures: Implications for malaria elimination in eastern Rwanda. *Malaria Journal*, **14**(1): 136.

IPCC (2001) *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]*. Cambridge, United Kingdom and New York, NY, USA.

IPCC (2007) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]*. Cambridge, United Kingdom and New York, NY, USA.

IPCC (2013a) *Annex I: Atlas of Global and Regional Climate Projections [van Oldenborgh, G.J., M. Collins, J. Arblaster, J.H. Christensen, J. Marotzke, S.B. Power, M. Rummukainen and T. Zhou (eds.)]. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]*. Cambridge, United Kingdom and New York, NY, USA.

IPCC (2013b) *Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]*. Cambridge, United Kingdom and New York, NY, USA.

IPCC (2014a) *Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]*. Geneva, Switzerland.

IPCC (2014b) *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]*. Geneva, Switzerland.

IPCC (2014c) *Climate Change 2014: Synthesis Report. Summary for Policymakers*. Gevena, Switzerland.

Jain, S. K. and Kumar, V. (2012) Trend analysis of rainfall and temperature data for India. *Current Science*, **102**(1): 37-49.

James, R. and Washington, R. (2013) Changes in African temperature and precipitation associated with degrees of global warming. *Climatic Change*, **117**(4): 859-72.

Juri, M. J. D., Estallo, E., Almiron, W., Santana, M., Sartor, P., Lamfri, M. and Zaidenberg, M. (2015) Satellite-derived NDVI, LST, and climatic factors driving the distribution and abundance of *Anopheles* mosquitoes in a former malarious area in northwest Argentina. *Journal of Vector Ecology*, **40**(1): 36-45.

Jury, M. R. and Funk, C. (2013) Climatic trends over Ethiopia: Regional signals and drivers. *International Journal of Climatology*, **33**(8): 1924-35.

Kabaria, C. W., Molteni, F., Mandike, R., Chacky, F., Noor, A. M., Snow, R. W. and Linard, C. (2016) Mapping intra-urban malaria risk using high resolution satellite imagery: a case study of Dar es Salaam. *International Journal of Health Geographics*, **15**(1): 26.

Kaimba, G. K., Njehia, B. K. and Guliye, A. Y. (2011) Effects of cattle rustling and household characteristics on migration decisions and herd size amongst pastoralists in Baringo District, Kenya. *Pastoralism: Research, Policy and Practice*, **1**(1): 18.

Karunamoorthi, K. (2011) Vector control: a cornerstone in the malaria elimination campaign. *Clinical Microbiology and Infections*, **17**(11): 1608-16.

Kass-Hout, T. A. and Alhinnawi, H. (2013) Social media in public health. B*ritish Medical Bulletin*, **108**(1): 5-24.

Kaufmann, R. K., Kauppi, H., Mann, M. L. and Stock, J. H. (2011) Reconciling anthropogenic climate change with observed temperature 1998–2008. *Proceedings of the National Academy of Sciences of the Unites States of America,108:11790-3*.

Kelly-Hope, L. A., Hemingway, J. and McKenzie, F. E. (2009) Environmental factors associated with the malaria vectors *Anopheles gambiae* and *Anopheles funestus* in Kenya. *Malaria Journal*, **8**: 268.

Kendall, M. (1975) *Rank Correlation Measures*. Charles Griffin. Charles Grifffin: London, UK.

Kibret, S. and Wilson, G. (2016) Increased outdoor biting tendency of *Anopheles arabiensis* and its challenge for malaria control in Central Ethiopia. *Public Health*, **141**: 143-5.

Kibret, S., Wilson, G. G., Tekie, H. and Petros, B. (2014) Increased malaria transmission around irrigation schemes in Ethiopia and the potential of canal water management for malaria vector control. *Malaria Journal*, **13**(1): 360.

Killeen, G. F. (2014) Characterizing, controlling and eliminating residual malaria transmission. *Malaria Journal*, **13**(1): 330.

Kimbi, H. K., Nkesa, S. B., Ndamukong-Nyanga, J. L., Sumbele, I. U., Atashili, J. and Atanga, M. B. (2014) Knowledge and perceptions towards malaria prevention among vulnerable groups in the Buea Health District, Cameroon. *BMC Public Health*, **14**(1): 883.

King'uyu, S. M., Ogallo, L. A. and Anyamba, E. K. (2000) Recent Trends of Minimum and Maximum Surface Temperatures over Eastern Africa. *Journal of Climate*, **13**(16): 2876-86.

Kipkorir, E., Raes, D. and Massawe, B. (2002) Seasonal water production functions and yield response factors for maize and onion in Perkerra, Kenya. *Agricultural Water Management*, **56**(3): 229-40.

KIRA (2014) Baringo County Baseline Analysis. Kenya Interagency Rapid Assessment, Nairobi.

Kirtman, B., Power, S. B., Adedoyin, J. A., Boer, G. J., Bojariu, R., Camilloni, I., Doblas-Reyes, F. J., Fiore, A. M., Kimoto, M., Meehl, G. A., Prather, M., Sarr, A., Schär, C., Sutton, R., van Oldenborgh, G. J., Vecchi, G. and Wang, H. J. (2013) *Near-term Climate Change: Projections and Predictability. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Kitau, J., Oxborough, R. M., Tungu, P. K., Matowo, J., Malima, R. C., Magesa, S. M., Bruce, J., Mosha, F. W. and Rowland, M. W. (2012) Species shifts in the *Anopheles gambiae* complex: Do LLINs successfully control *Anopheles arabiensis*? *Plos One*, **7**(3): e31481.

Klein, J. T. (2013) The Transdiciplinary Moment(um). *Integration Review*, **9**(2): 189-99.

KNBS (2010) The 2009 Kenya population and housing census. Vol. 1C.Government Printer, Nairobi.

KNBS (2015) Baringo statistical abstract. Kenya National Bureau of Statistics, Nairobi.

Knols, B. G., Njiru, B. N., Mathenge, E. M., Mukabana, W. R., Beier, J. C. and Killeen, G. F. (2002) MalariaSphere: A greenhouse-enclosed simulation of a natural *Anopheles gambiae* (Diptera: Culicidae) ecosystem in western Kenya. *Malaria Journal*, **1**(1): 19.

Knols, B. G. J., Farenhorst, M., Andriessen, R., Snetselaar, J., Suer, R. A., Osinga, A. J., Knols, J. M. H., Deschietere, J., Ng'habi, K. R., Lyimo, I. N., Kessy, S. T., Mayagaya, V. S., Sperling, S., Cordel, M., Sternberg, E. D., Hartmann, P., Mnyone, L. L., Rose, A. and Thomas, M. B. (2016) Eave tubes for malaria control in Africa: An introduction. *Malaria Journal*, **15**: 404.

Koenraadt, C. and Takken, W. (2003) Cannibalism and predation among larvae of the Anopheles gambiae complex. *Medical and Veterinary Entomology*, **17**(1): 61-6.

Kopprio, G. A., Freije, R. H., Arias-Schreiber, M. and Lara, R. J. (2013) An ecohydrological adaptive approach to a salt lake in the semiarid grasslands of Argentina: Future management perspectives. *Sustainability Science*, **9**(2): 229-38.

Krejcie, R. V. and Morgan, D. W. (1970) Determining sample size for research activities. *Educational and Psychological Measurement*, **30**(3): 607-10.

Kulkarni, M. A., Desrochers, R. E., Kajeguka, D. C., Kaaya, R. D., Tomayer, A., Kweka, E. J., Protopopoff, N. and Mosha, F. W. (2016) 10 years of environmental change on the slopes of Mount Kilimanjaro and its associated shift in malaria vector distributions. F*ront Public Health*, **4**.

Kweka, E. J., Munga, S., Himeidan, Y., Githeko, A. K. and Yan, G. (2015) Assessment of mosquito larval productivity among different land use types for targeted malaria vector control in the western Kenya highlands. *Parasites & Vectors*, **8**(1): 356.

Lacerda, F., Nobre, P., Sobral, M., Lopes, G., Chou, S., Assad, E. and Brito, E. (2015) Long-term temperature and rainfall trends over Northeast Brazil and Cape Verde. *Journal of Earth Science & Climatic Change*, **6**(8).

Lauenroth, W. K., Schlaepfer, D. R. and Bradford, J. B. (2014) Ecohydrology of Dry Regions: Storage versus Pulse Soil Water Dynamics. *Ecosystems*, **17**(8): 1469-79.

Liebmann, B., Hoerling, M. P., Funk, C., Bladé, I., Dole, R. M., Allured, D., Quan, X., Pegion, P. and Eischeid, J. K. (2014) Understanding recent eastern Horn of Africa rainfall variability and change. *Journal of Climate*, **27**(23): 8630-45.

Lin, Y., Xin, X., Zhang, H. and Wang, X. (2015) The implications of serial correlation and time-lag effects for the impact study of climate change on vegetation dynamics–a case study with Hulunber meadow steppe, Inner Mongolia. I*nternational Journal of Remote Sensing*, **36**(19-20): 5031-44.

Liu, H., Zhao, W., He, Z. and Liu, J. (2015) Soil moisture dynamics across landscape types in an arid inland river basin of Northwest China. *Hydrological Processes*, **29**(15): 3328-41.

Liu, Q., Liu, G., Huang, C., Liu, S. and Zhao, J. (2014) A tasseled cap transformation for Landsat 8 OLI TOA reflectance images. *In Geoscience and Remote Sensing Symposium (IGARSS)*, 541-4.

Logan, M. (2011) *Biostatistical design and analysis using R: A practical guide*. John Wiley & Sons, West Sussex, U.K.

Lourenço, P. M., Sousa, C. A., Seixa, J., Lopes, P., Novo, M. T. and Almeida, A. P. G. (2011) Anopheles atroparvus density modeling using MODIS NDVI in a former malarious area in Portugal. *Journal of Vector Ecology*, **36**(6): 279-91.

Lutomiah, J., Barrera, R., Makio, A., Mutisya, J., Koka, H., Owaka, S., Koskei, E., Nyunja, A., Eyase, F. and Coldren, R. (2016) Dengue outbreak in Mombasa City, Kenya, 2013–2014: Entomologic investigations. *PLoS Neglected Tropical Diseases*, **10**(10): e0004981.

Lyon, B. and DeWitt, D. G. (2012) A recent and abrupt decline in the East African long rains. *Geophysical Research Letters*, **39**(2).

Lyon, B. and Vigaud, N. (2017) *Unraveling East Africa's Climate Paradox*. In Patterns of climate extremes: Trends and mechanisms, 265-81.

Lyons, C. L., Coetzee, M. and Chown, S. L. (2013) Stable and fluctuating temperature effects on the development rate and survival of two malaria vectors, *Anopheles arabiensis* and *Anopheles funestus*. *Parasites & Vectors*, **6**(1): 104.

Machini, B., Waqo, E., Kizito, W., Edwards, J., Owiti, P. and Takarinda, K. (2016) Trends in outpatient malaria cases, following Mass Long Lasting Insecticidal Nets (LLIN) distribution in epidemic prone and endemic areas of Kenya. *East African Medical Journal*, **93**(10): 10-5.

MacKellar, N., New, M. and Jack, C. (2014) Observed and modelled trends in rainfall and temperature for South Africa: 1960-2010. *South African Journal of Science*, **110**(7-8): 1-13.

Maes, P., Harries, A. D., Van den Bergh, R., Noor, A., Snow, R. W., Tayler-Smith, K., Hinderaker, S. G., Zachariah, R. and Allan, R. (2014) Can timely vector control interventions triggered by atypical environmental conditions prevent malaria epidemics? A case-study from Wajir County, Kenya. *Plos One*, **9**(4): e92386.

Maheu-Giroux, M. and Castro, M. C. (2013) Impact of community-based larviciding on the prevalence of malaria infection in Dar es Salaam, Tanzania. *Plos One*, **8**(8): e71638.

Maidment, R. I., Allan, R. P. and Black, E. (2015) Recent observed and simulated changes in precipitation over Africa. *Geophysical Research Letters*, **42**(19): 8155-64.

Mala, A. O., Irungu, L. W., Shililu, J. I., Muturi, E. J., Mbogo, C. C., Njagi, J. K. and Githure, J. I. (2011a) Dry season ecology of *Anopheles gambiae* complex mosquitoes at larval habitats in two traditionally semi-arid villages in Baringo, Kenya. *Parasites & Vectors*, **4**: 25.

Mala, A. O., Irungu, L. W., Shililu, J. I., Muturi, E. J., Mbogo, C. M., Njagi, J. K., Mukabana, W. R. and Githure, J. I. (2011b) *Plasmodium falciparum* transmission and aridity: a Kenyan experience from the dry lands of Baringo and its implications for *Anopheles arabiensis* control. *Malaria Journal*, **10**(121).

Mamai, W., Simard, F., Couret, D., Ouédraogo, G. A., Renault, D., Dabiré, K. R. and Mouline, K. (2015) Monitoring dry season persistence of *Anopheles gambiae* s.l. populations in a contained semi-field system in southwestern Burkina Faso, West Africa. *Journal of Medical Entomology*, **53**(1): 130-8.

Mango, L. M., Melesse, A. M., McClain, M. E., Gann, D. and Setegn, S. (2011) Land use and climate change impacts on the hydrology of the upper Mara River Basin, Kenya: results of a modeling study to support better resource management. *Hydrology and Earth System Sciences*, **15**(7): 2245-58.

Mann, H. B. (1945) Nonparametric Tests Against Trend. *Econometrica*, **13**(3): 245-59.

Martínez, G., Pachepsky, Y. A. and Vereecken, H. (2014) Temporal stability of soil water content as affected by climate and soil hydraulic properties: A simulation study. *Hydrological Processes*, **28**(4): 1899-915.

Mboera, L. E. G., Mazigo, H. D., Rumisha, S. F. and Kramer, R. A. (2013) Towards malaria elimination and its implication for vector control, disease management and livelihoods in Tanzania. *Malaria World Journal*, **4**(19).

Meyers, J. I., Pathikonda, S., Popkin-Hall, Z. R., Medeiros, M. C., Fuseini, G., Matias, A., Garcia, G., Overgaard, H. J., Kulkarni, V. and Reddy, V. P. (2016) Increasing outdoor host-seeking in *Anopheles gambiae* over 6 years of vector control on Bioko Island. *Malaria Journal*, **15**(1): 239.

Michel, A. P., Ingrasci, M. J., Schemerhorn, B. J., Kern, M., Le Goff, G., Coetzee, M., Elissa, N., Fontenille, D., Vulule, J., Lehmann, T., Sagnon, N., Costantini, C. and Besansky, N. J. (2005) Rangewide population genetic structure of the African malaria vector *Anopheles funestus*. *Molecular Ecology*, **14**(14): 4235-48.

Midekisa, A., Senay, G., Henebry, G. M., Semuniguse, P. and Wimberly, M. C. (2012) Remote sensing-based time series models for malaria early warning in the highlands of Ethiopia. *Malaria Journal*, **11**: 165.

Midekisa, A., Senay, G. B. and Wimberly, M. C. (2014) Multisensor earth observations to characterize wetlands and malaria epidemiology in Ethiopia. *Water Resources Research*, **50**(11): 8791-806.

Mishra, N. B., Crews, K. A., Neeti, N., Meyer, T. and Young, K. R. (2015) MODIS derived vegetation greenness trends in African Savanna: Deconstructing and localizing the role of changing moisture availability, fire regime and anthropogenic impact. *Remote sensing of Environment*, **169**: 192-204.

Mlozi, M. R., Shayo, E. H., Senkoro, K. P., Mayala, B. K., Rumisha, S. F., Mutayoba, B., Senkondo, E., Maerere, A. and Mboera, L. E. (2006) Participatory involvement of farming communities and public sectors in determining malaria control strategies in Mvomero District, Tanzania. *Tanzan Health Res Bull*, **8**(3): 134-40.

Moiroux, N., Damien, G. B., Egrot, M., Djenontin, A., Chandre, F., Corbel, V., Killeen, G. F. and Pennetier, C. (2014) Human exposure to early morning *Anopheles funestus* biting behavior and personal protection provided by Long-Lasting Insecticidal Nets. *Plos One*, **9**(8): e104967.

Moiroux, N., Gomez, M. B., Pennetier, C., Elanga, E., Djenontin, A., Chandre, F., Djegbe, I., Guis, H. and Corbel, V. (2012) Changes in *Anopheles funestus* biting behavior following universal coverage of long-lasting insecticidal nets in Benin. *Journal of Infectious Disease*s, **206**(10): 1622-9.

Moshi, I. R., Ngowo, H., Dillip, A., Msellemu, D., Madumla, E. P., Okumu, F. O., Coetzee, M., Mnyone, L. L. and Manderson, L. (2017) Community perceptions on outdoor malaria transmission in Kilombero Valley, Southern Tanzania. *Malaria Journal*, **16**(1): 274.

Mshunqane, N. (2013) *A family based intervention to manage type 2 Diabetes in patients from lower socio-economic background*. Vol. Ph.D Thesis: University of the Witwatersrand, Johannesburg, SA.

Mukungu, N., Abuga, K., Okalebo, F., Ingwela, R. and Mwangi, J. (2016) Medicinal plants used for management of malaria among the Luhya community of Kakamega East sub-County, Kenya. *Journal of Ethnopharmacology*, **194**: 98-107.

Munga, S., Minakawa, N., Zhou, G., Mushinzimana, E., Barrack, O.-O. J., Githeko, A. K. and Yan, G. (2006) Association between land cover and habitat productivity of malaria vectors in western Kenyan highlands. *The American Journal of Tropical Medicine and Hygiene*, **74**(1): 69-75.

Musau, J., Mbaria, J., Nguta, J., Mbaabu, M. and Kiama, S. (2016) Evaluation of genotoxicity potential of plants traditionally used for mosquito control in Kenya’s south coast. *Merit Research Journal of Medicine and Medical Sciences*, **4**(4): 178-82.

Mushi, R. T. and Chilimo, W. (2013) Contribution of Information and Communication Technologies to Malaria Control in Tanzania. *In ICT Influences on Human Development, Interaction, and Collaboration*, 132-41: IGI Global.

Mushinzimana, E., Munga, S., Minakawa, N., Li, L., Feng, C.-c., Bian, L., Kitron, U., Schmidt, C., Beck, L. and Zhou, G. (2006) Landscape determinants and remote sensing of

Anopheline mosquito larval habitats in the western Kenya highlands. *Malaria Journal,* **5**(1): 13.

Mutero, C. M., Mbogo, C., Mwangangi, J., Imbahale, S., Kibe, L., Orindi, B., Girma, M., Njui, A., Lwande, W. and Affognon, H. (2015) An assessment of participatory integrated vector management for malaria control in Kenya. *Environmental Health Perspectives*, **123**(11): 1145.

Mutsotso, D. B. M. (2017) Overlap of Mukutani administrative boundary and its definition of the East Pokot Il-Chamus conflict in north western Kenya. *Journal of Sociology and Social Work*, **5**(2).

Mutua, E. N., Bukachi, S. A., Bett, B. K., Estambale, B. A. and Nyamongo, I. K. (2016) Lay knowledge and management of malaria in Baringo county, Kenya. *Malaria Journal*, **15**(1): 486.

Muturi, E. J., Mwangangi, J., Shililu, J., Jacob, B. G., Mbogo, C., Githure, J. and Novak, R. J. (2008) Environmental factors associated with the distribution of *Anopheles arabiensis* and *Culex quinquefasciatus* in a rice agro-ecosystem in Mwea, Kenya. *Journal of Vector Ecology*, **33**(1): 56-63.

Muturi, E. J., Mwangangi, J., Shililu, J., Muriu, S., Jacob, B., Kabiru, E., Gu, W., Mbogo, C., Githure, J.and Novak, R. (2007) Mosquito species succession and physicochemical factors affecting their abundance in rice fields in Mwea, Kenya. Journal of medical entomology, **44**(2): 336-44.

Mwakalila, S., Kangalawe, R. and Masolwa, P. (2011) Climate change impacts, local knowledge and coping strategies in the great Ruaha river catchment area, Tanzania. *Natural Resources,* **2**: 212-23.

Mwangangi, J. M., Mbogo, C. M., Orindi, B. O., Muturi, E. J., Midega, J. T., Nzovu, J., Gatakaa, H., Githure, J., Borgemeister, C., Keating, J. and Beier, J. C. (2013) Shifts in malaria vector species composition and transmission dynamics along the Kenyan coast over the past 20 years. *Malaria Journal*, **12**(1): 13.

Nagpal, B., Gupta, S. K., Shamim, A., Vikram, K., Srivastava, A., Tuli, N., Saxena, R., Singh, H., Singh, V. and Bhagat, V. (2016) Control of Aedes aegypti breeding: A novel intervention for prevention and control of dengue in an endemic zone of Delhi, India. *Plos One*, **11**(12): e0166768.

Namango, I. (2013) *Malaria risk and the role of routine outdoor nocturnal activities and livelihoods among adults in Dar es Salaam, Tanzania.* Thesis. University of Nairobi.

National Malaria Control Programme (2015) Towards a Malaria-Free Kenya: Kenya Malaria Strategy 2009-2018. Nairobi.

National Malaria Control Programme (2016a) Kenya Malaria Communication Strategy 2016-2021. Nairobi.

National Malaria Control Programme (2016b) Kenya Malaria Indicator Survey 2015. Nairobi.

Ng'ang'a, P. N., Jayasinghe, G., Kimani, V., Shililu, J., Kabutha, C., Kabuage, L., Githure, J. and Mutero, C. (2009) Bed net use and associated factors in a rice farming community in Central Kenya. *Malaria Journal,* **8**(1): 64.

Niang, I., Ruppel, O. C., Abdrabo, M. A., Essel, A., Lennard, C., Padgham, J. and Urquhart, P. (2014) *Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel,* *A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Nmor, J. C., Sunahara, T., Goto, K., Futami, K., Sonye, G., Akweywa, P., Dida, G. and Minakawa, N. (2013) Topographic models for predicting malaria vector breeding habitats: Potential tools for vector control managers. *Parasites & Vectors*, **6**(1): 14.

Odada, E. O., Onyando, J. O. and Obudho, P. A. (2006) Lake Baringo: Addressing threatened biodiversity and livelihoods. *Lakes and Reservoirs: Research and Management*, **11**: 1-13.

Okabayashi, H., Thongthien, P., Singhasvanon, P., Waikagul, J., Looareesuwan, S., Jimba, M., Kano, S., Kojima, S., Takeuchi, T., Kobayashi, J. and Tateno, S. (2006) Keys to success for a school-based malaria control program in primary schools in Thailand. P*arasitology International*, **55**(2): 121-6.

Okara, R. M., Sinka, M. E., Minakawa, N., Mbogo, C. M., Hay, S. I. and Snow, R. W. (2010) Distribution of the main malaria vectors in Kenya. *Malaria Journal*, **9**: 69.

Olago, D., Opere, A. and Barongo, J. (2009) Holocene palaeohydrology, groundwater and climate change in the lake basins of the Central Kenya Rift. *Hydrological Sciences Journal*, **54**(4): 765-80.

Olaka, L. A., Odada, E. O., Trauth, M. H. and Olago, D. O. (2010) The sensitivity of East African rift lakes to climate fluctuations. *Journal of Paleolimnology*, **44**(2): 629-44.

Omondi, C. J., Onguru, D., Kamau, L., Nanyingi, M., Ong'amo, G. and Estambale, B. (2017) Perennial transmission of malaria in the low altitude areas of Baringo County, Kenya. *Malaria Journal*, **16**(1): 257.

Omondi, P., Awange, J., Ogallo, L., Okoola, R. and Forootan, E. (2012) Decadal rainfall variability modes in observed rainfall records over East Africa and their relations to historical sea surface temperature changes. *Journal of Hydrology*, **464**: 140-56.

Omondi, P. A., Awange, J. L., Forootan, E., Ogallo, L. A., Barakiza, R., Girmaw, G. B., Fesseha, I., Kululetera, V., Kilembe, C., Mbati, M. M., Kilavi, M., King'uyu, S. M., Omeny, P. A., Njogu, A., Badr, E. M., Musa, T. A., Muchiri, P., Bamanya, D. and Komutunga, E. (2014) Changes in temperature and precipitation extremes over the Greater Horn of Africa region from 1961 to 2010. *International Journal of Climatology*, **34**(4): 1262-77.

Omukunda, E., Githeko, A., Ndong'a, M. F., Mushinzimana, E., Atieli, H. and Wamae, P. (2013) Malaria vector population dynamics in highland and lowland regions of western Kenya. *Journal of Vector Borne Diseases*, **50**: 85-92.

Opiyo, P., Mukabana, W. R., Kiche, I., Mathenge, E., Killeen, G. F. and Fillinger, U. (2007) An exploratory study of community factors relevant for participatory malaria control on Rusinga Island, western Kenya. *Malaria Journal*, **6**: 48.

Orsborne, J., DeRaedt Banks, S., Hendy, A., Gezan, S. A., Kaur, H., Wilder-Smith, A., Lindsay, S. W. and Logan, J. G. (2016) Personal protection of Permethrin-treated clothing against *Aedes aegypti*, the vector of Dengue and Zika Virus, in the Laboratory. *Plos One*, **11**(5): e0152805.

Ototo, E. N., Mbugi, J. P., Wanjala, C. L., Zhou, G., Githeko, A. K. and Yan, G. (2015) Surveillance of malaria vector population density and biting behaviour in western Kenya. *Malaria Journal*, **14**: 244.

Owek, C. J., Oluoch, E., Wachira, J., Estambale, B. and Afrane, Y. A. (2017) Community perceptions and attitudes on malaria case management and the role of community health workers. *Malaria Journal*, **16**(1): 272.

Paaijmans, K. P., Blanford, S., Bell, A. S., Blanford, J. I., Read, A. F. and Thomas, M. B. (2010a) Influence of climate on malaria transmission depends on daily temperature variation.

Proceedings of the National Academy of Sciences of the United States of America, **107**(34): 15135-9.

Paaijmans, K. P., Imbahale, S. S., Thomas, M. B. and Takken, W. (2010b) Relevant microclimate for determining the development rate of malaria mosquitoes and possible implications of climate change. *Malaria Journal*, **9**: 196.

Paaijmans, K. P., Jacobs, A. F. G., Takken, W., Heusinkveld, B. G., Githeko, A. K., Dicke, M. and Holtslag, A. A. M. (2008) Observations and model estimates of diurnal water temperature dynamics in mosquito breeding sites in western Kenya. *Hydrological Processes*, **22**(24): 4789-801.

Paaijmans, K. P. and Thomas, M. B. (2011) The influence of mosquito resting behaviour and associated microclimate for malaria risk. *Malaria Journal*, **10**(1): 183.

Patz, J. A., Strzepek, K., Hay, S. I., Kalkstein, L., Lele, S., Hedden, M., Greene, S., Noden, B. and Beier, J. C. (1998) Predicting key malaria transmission factors, biting and entomological inoculation rates, using modelled soil moisture in Kenya. *Tropical Medicine and International Health*, **3**(10): 818-27.

Perini, K. and Magliocco, A. (2014) Effects of vegetation, urban density, building height, and atmospheric conditions on local temperatures and thermal comfort. *Urban Forestry & Urban Greening*, **13**(3): 495-506.

Petrie, M. D. and Brunsell, N. A. (2012) The role of precipitation variability on the ecohydrology of grasslands. *Ecohydrology*, **5**(3): 337-45.

Pumo, D., Caracciolo, D., Viola, F. and Noto, L. V. (2016) Climate change effects on the hydrological regime of small non-perennial river basins. *Science of the Total Environment*, **542**: 76-92.

R Core Team (2015) *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Rangwala, I. and Miller, J. R. (2010) Twentieth century temperature trends in Colorado’s San Juan Mountains. *Arctic, Antarctic, and Alpine Research*, **42**(1): 89-97.

Rangwala, I. and Miller, J. R. (2012) Climate change in mountains: A review of elevation-dependent warming and its possible causes. *Climatic Change*, **114**(3-4): 527-47.

Ren, Z., Wang, D., Hwang, J., Bennett, A., Sturrock, H. J., Ma, A., Huang, J., Xia, Z., Feng, X. and Wang, J. (2015) Spatial-temporal variation and primary ecological drivers of *Anopheles sinensis* human biting rates in malaria epidemic-prone regions of China. *Plos One*, **10**(1): e0116932.

Rishmawi, K., Prince, S. and Xue, Y. (2016) Vegetation Responses to Climate Variability in the Northern Arid to Sub-Humid Zones of Sub-Saharan Africa. *Remote Sensing*, **8**(11): 910.

Rodgers, S. E. and Oliver, M. A. (2007) A geostatistical analysis of soil, vegetation, and image data characterizing land surface variation. *Geographical Analysis*, **39**(2): 195-216.

Rowell, D. P., Booth, B. B. B., Nicholson, S. E. and Good, P. (2015) Reconciling past and future rainfall trends over East Africa. *Journal of Climate*, **28**(24): 9768-88.

Royan, A., Hannah, D. M., Reynolds, S. J., Noble, D. G. and Sadler, J. P. (2013) Avian community responses to variability in river hydrology. *Plos One*, **8**(12): e83221.

Ruberto, I., Camara, S., Banek, K. and Loua, M. K. (2014) Knowledge, attitudes and practices of malaria control among communities from the health district of Forécariah in the Republic of Guinea, West Africa. *Journal of Vector Borne Diseases*, **51**(2): 119.

Ruddell, B. L. and Kumar, P. (2009) Ecohydrologic process networks: 1. Identification. *Water Resources Research*, **45**(3).

Russell, T. L., Beebe, N. W., Cooper, R. D., Lobo, N. F. and Burkot, T. R. (2013) Successful malaria elimination strategies require interventions that target changing vector behaviours. *Malaria Journal*, **12**: 56.

Saaty, T. L. (2008) Relative measurement and its generalization in decision making why pairwise comparisons are central in mathematics for the measurement of intangible factors the analytic hierarchy/network process. *RACSAM-Revista de la Real Academia de Ciencias Exactas, Fisicas y Naturales Serie A Matematicas*, **102**(2): 251-318.

Salami, K. K. and Onuegbu, C. M. (2016) Determinants of Preferences for Advertisement and Communication in the Promotion of Anti-Malaria Products in Ibadan, Southwestern Nigeria. *The Nigerian Journal of Sociology and Anthropology*, **14**(2): 17-33.

Sandholt, I., Rasmussen, K. and Andersen, J. (2002) A simple interpretation of the surface temperature/vegetation index space for assessment of surface moisture status. *Remote sensing of Environment*, **79**: 213-24.

Sanfo, S., Lamers, J., Mueller, M. and Fonta, W. (2014) Farmers' Perception of climate change and climate variability versus climatic evidence in Burkina Faso, West Africa. Cimate Change in Africa. https://doi.org/10.13140/2.1.4614.7528

Seneviratne, S. I., Corti, T., Davin, E. L., Hirschi, M., Jaeger, E. B., Lehner, I., Orlowsky, B. and Teuling, A. J. (2010) Investigating soil moisture–climate interactions in a changing climate: A review. *Earth Science Reviews*, **99**(3-4): 125-61.

Setiadi, W., Sudoyo, H., Trimarsanto, H., Sihite, B. A., Saragih, R. J., Juliawaty, R., Wangsamuda, S., Asih, P. B. S. and Syafruddin, D. (2016) A zoonotic human infection with simian malaria, *Plasmodium knowlesi*, in Central Kalimantan, Indonesia. *Malaria Journal*, **15**: 218.

Settele, J., Scholes, R., Betts, R., Bunn, S., Leadley, P., Nepstad, D., Overpeck, J. T. and Taboada, M. A. (2014) *Terrestrial and inland water systems. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, .

Sewe, M. O., Ahlm, C. and Rocklov, J. (2016) Remotely sensed environmental conditions and malaria mortality in three malaria endemic regions in western Kenya. *Plos One*, **11**(4): e0154204.

Shah, A. D., Bartlett, J. W., Carpenter, J., Nicholas, O. and Hemingway, H. (2014) Comparison of Random Forest and Parametric Imputation Models for Imputing Missing Data Using MICE: A CALIBER Study. *American Journal of Epidemiology*, **179**(6): 764-74.

Shepard, D. S., Halasa, Y. A., Fonseca, D. M., Farajollahi, A., Healy, S. P., Gaugler, R., Bartlett-Healy, K., Strickman, D. A. and Clark, G. G. (2014) Economic evaluation of an area-wide integrated pest management program to control the Asian Tiger mosquito in New Jersey. *Plos One*, **9**(10): e111014.

Shin, H.-J., Park, M.-J., Hwang, S.-J., Park, J.-Y. and Kim, S.-J. (2014) Hydrologic impact of climate change with adaptation of vegetation community in a forest-dominant watershed. *Paddy and Water Environment*, **12**(1): 51-63.

Shongwe, M. E., van Oldenborgh, G. J., van den Hurk, B. and van Aalst, M. (2011) Projected Changes in Mean and Extreme Precipitation in Africa under Global Warming. Part II: East Africa. *Journal of Climate*, **24**(14): 3718-33.

Shuford, K., Were, F., Awino, N., Samuels, A., Ouma, P., Kariuki, S., Desai, M. and Allen, D. R. (2016) Community perceptions of mass screening and treatment for malaria in Siaya County, western Kenya. *Malaria Journal*, **15**(1): 71.

Siebert, A. (2014) Hydroclimate extremes in Africa: variability, observations and modeled projections. *Geography Compass,* **8**(6): 351-67.

Sinka, M. E., Bangs, M. J., Manguin, S., Coetzee, M., Mbogo, C. M., Hemingway, J., Patil, A. P., Temperley, W. H., Gething, P. W., Kabaria, C. W., Okara, R. M., Van Boeckel, T., Godfray, H. C., Harbach, R. E. and Hay, S. I. (2010) The dominant Anopheles vectors of human malaria in Africa, Europe and the Middle East: Occurrence data, distribution maps and bionomic precis. *Parasites & Vectors,* **3**: 117.

Smith, K. R., Woodward, A., Campbell-Lendrum, D., Chadee, D. D., Honda, Y., Liu, Q., Olwoch, J. M., Revich, B. and Sauerborn, R. (2014) *Human health: impacts, adaptation, and co-benefits. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)].* Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, .

Snow, R. W. (2014) Sixty years trying to define the malaria burden in Africa: Have we made any progress? *BMC Medicine*, **12**(1): 227.

Snow, R. W., Kibuchi, E., Karuri, S. W., Sang, G., Gitonga, C. W., Mwandawiro, C., Bejon, P. and Noor, A. M. (2015) Changing Malaria Prevalence on the Kenyan Coast since 1974: Climate, Drugs and Vector Control. *Plos One,* **10**(6): e0128792.

Stresman, G. H. (2010) Beyond temperature and precipitation: Ecological risk factors that modify malaria transmission. *Acta Tropica,* **116**(3): 167-72.

Swana, E. K., Makan, G. Y., Mukeng, C. K., Mupumba, H. I., Kalaba, G. M., Luboya, O. N. and Bangs, M. J. (2016) Feasibility and implementation of community-based malaria case management with integrated vector control in the Democratic Republic of Congo. *Malaria Journal*, **15**(1): 413.

Tanser, F. C., Sharp, B. and Le Sueur, D. (2003) Potential effect of climate change on malaria transmission in Africa. *The Lancet*, **362**(9398): 1792-8.

Tarimo, D. S. (2015) Community knowledge and perceived effectiveness of interventions to reduce malaria: Implications for sustained use of malaria interventions in Rufiji district, Southeastern Tanzania. *International Quarterly of Community Health Education,* **35**(4): 335-47.

Thieme, M. L., Lehner, B., Abell, R. and Matthews, J. (2010) Exposure of Africa's freshwater biodiversity to a changing climate. *Conservation Letters*, **3**(5): 324-31.

Tietjen, B., Zehe, E. and Jeltsch, F. (2009) Simulating plant water availability in dry lands under climate change: A generic model of two soil layers. *Water Resources Research*, **45**(1).

Tobgay, T., Samdrup, P., Jamtsho, T., Mannion, K., Ortega, L., Khamsiriwatchara, A., Price, R. N., Thriemer, K. and Kaewkungwal, J. (2016) Performance and user acceptance of the Bhutan febrile and malaria information system: Report from a pilot study. *Malaria Journal*, **15**(1): 52.

Toé, L. P., Skovmand, O., Dabiré, K. R., Diabaté, A., Diallo, Y., Guiguemdé, T. R., Doannio, J. M. C., Akogbeto, M., Baldet, T. and Gruénais, M. E. (2009) Decreased motivation in the use of insecticide-treated nets in a malaria endemic area in Burkina Faso. *Malaria Journal*, **8**(1): 175.

Tonnang, H. E., Tchouassi, D. P., Juarez, H. S., Igweta, L. K. and Djouaka, R. F. (2014) Zoom in at African country level: Potential climate induced changes in areas of suitability for survival of malaria vectors. *International Journal of Health Geographics*, **13**: 12.

Tucker, C. J. (1979) Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment*, **8**(2): 127-50.

Turk, T., Newton, F. J., Netwon, J. D., Naureen, F. and Bokhari, J. (2013) Evaluating the efficacy of tuberculosis Advocacy, Communication and Social Mobilization (ACSM) activities in Pakistan: A cross-sectional study. *BMC Public Health*, **13**: 887-.

Tusting, L. S., Thwing, J., Sinclair, D., Fillinger, U., Gimnig, J., Bonner, K. E., Bottomley, C. and Lindsay, S. W. (2013) Mosquito larval source management for controlling malaria. *The Cochrane Database of Systematic Reviews*, **8**: CD008923.

USAID (2016) President's Malaria Initiative: Kenya Malaria Operational Plan FY 2016. Nairobi.

Van Eijk, A. M., Ramanathapuram, L., Sutton, P. L., Peddy, N., Choubey, S., Mohanty, S., Asokan, A., Ravishankaran, S., Priya, G. S. L. and Johnson, J. A. (2016) The use of mosquito repellents at three sites in India with declining malaria transmission: Surveys in the community and clinic. *Parasites & Vectors*, **9**(1): 418.

Vivoni, E. R., Rinehart, A. J., Méndez-Barroso, L. A., Aragón, C. A., Bisht, G., Cardenas, M. B., Engle, E., Forman, B. A., Frisbee, M. D., Gutiérrez-Jurado, H. A., Hong, S. H., Mahmood, T. H., Tai, K. and Wyckoff, R. L. (2008) Vegetation controls on soil moisture distribution in the Valles Caldera, New Mexico, during the North American monsoon. *Ecohydrology*, **1**(3): 225-38.

Walker, K. and Lynch, M. (2007) Contributions of Anopheles larval control to malaria suppression in tropical Africa: Review of achievements and potential. *Medical and Veterinary Entomology*, **21**(1): 2-21.

Walker, M., Winskill, P., Basáñez, M. G., Mwangangi, J. M., Mbogo, C., Beier, J. C. and Midega, J. T. (2013) Temporal and micro-spatial heterogeneity in the distribution of Anopheles vectors of malaria along the Kenyan coast. *Parasites & Vectors*, **6**(1): 311.

Wandiga, S. O., Opondo, M., Olago, D., Githeko, A., Githui, F., Marshall, M., Downs, T., Opere, A., Oludhe, C., Ouma, G. O., Yanda, P. Z., Kangalawe, R., Kabumbuli, R., Kathuri, J., Apindi, E., Olaka, L., Ogallo, L., Mugambi, P., Sigalla, R., Nanyunja, R., Baguma, T. and Achola, P. (2010) Vulnerability to epidemic malaria in the highlands of Lake Victoria basin: the role of climate change/variability, hydrology and socio-economic factors. *Climatic Change*, **99**: 473-97.

Wang, S., Fu, B., Gao, G., Liu, Y. and Zhou, J. (2013) Responses of soil moisture in different land cover types to rainfall events in a re-vegetation catchment area of the Loess Plateau, China. *Catena*, **101**: 122-8.

Wanjala, C. L., Zhou, G., Mbugi, J., Simbauni, J., Afrane, Y. A., Ototo, E., Gesuge, M., Atieli, H., Githeko, A. K. and Yan, G. (2015) Insecticidal decay effects of long-lasting insecticide nets and indoor residual spraying on Anopheles gambiae and Anopheles arabiensis in Western Kenya. *Parasites & Vectors*, **8**: 588.

Wassen, M. J., Okruszko, T., Kardel, I., Chormanski, J., Swiatek, D., Mioduszewski, W., Bleuten, W., Querner, E. P., El Kahloun, M., Batelaan, O. and Meire, P. (2006) *Eco-Hydrological Functioning of the Biebrza Wetlands: Lessons for the Conservation and*

Restoration of Deteriorated Wetlands. In Wetlands: Functioning, Biodiversity Conservation, and Restoration, 285-310 (Eds R. Bobbink, B. Beltman, J. T. A. Verhoeven and D. F. Whigham). Berlin, Heidelberg: Springer Berlin Heidelberg.

White, F. (1983) *The vegetation of Africa*. Switzerland: UNESCO.

WHO (1975) Manual on Practical Entomology in Malaria. Geneva, Switzerland.

WHO (2004) Global Strategic Framework for Integrated Vector Management. Geneva, Switzerland.

WHO (2013a) Larval Source Management: A Supplementary Measure for Malaria Vector Control. An Operational Manual. Geneva, Switzerland.

WHO (2013b) Seasonal Malaria Chemoprevention with Sulfadoxine–pyrimethamine plus Amodiaquine in Children: A field guide. Geneva, Switzerland.

WHO (2015a) Global technical strategy for malaria 2016-2030. Geneva, Switzerland.

WHO (2015b) World Malaria Report 2015. Geneva, Switzerland.

WHO (2016) A toolkit for Integrated Vector Management in sub-Saharan Africa. Geneva, Switzerland.

Wiebe, A., Longbottom, J., Gleave, K., Shearer, F. M., Sinka, M. E., Massey, N. C., Cameron, E., Bhatt, S., Gething, P. W. and Hemingway, J. (2017) Geographical distributions of African malaria vector sibling species and evidence for insecticide resistance. *Malaria Journal*, **16**(1): 85.

Williams, A. P., Funk, C., Michaelsen, J., Rauscher, S. A., Robertson, I., Wils, T. H., Koprowski, M., Eshetu, Z. and Loader, N. J. (2012) Recent summer precipitation trends in the Greater Horn of Africa and the emerging role of Indian Ocean sea surface temperature. *Climate Dynamics*, **39**: 2307-28.

Wolanski, E., Boorman, L. A., Chı´charo, L., Plater, A. J., Uncles, R. J. and Zalewski, M. (2004) Ecohydrology as a new tool for sustainable management of estuaries and coastal waters. *Wetlands Ecology and Management*, **12**: 235-76.

Yang, W., Seager, R., Cane, M. A. and Lyon, B. (2014) The East African long rains in observations and models. *Journal of Climate*, **27**(19): 7185-202.

Yaro, J. A. (2013) The perception of and adaptation to climate variability/change in Ghana by small-scale and commercial farmers. *Regional Environmental Change*, **13**(6): 1259-72.

Yawson, A. E., Mccall, P. J., Wilson, M. D. and Donnelly, M. J. (2004) Species abundance and insecticide resistance of *Anopheles gambiae* in selected areas of Ghana and Burkina Faso. *Medical and Veterinary Entomology*, **18**(4): 372-7.

Yé, Y., Louis, V. R., Simboro, S. and Sauerborn, R. (2007) Effect of meteorological factors on clinical malaria risk among children: An assessment using village-based meteorological stations and community-based parasitological survey. *BMC Public Health*, **7**(1): 101.

Yewhalaw, D., Getachew, Y., Tushune, K., W/Michael, K., Kassahun, W., Duchateau, L. and Speybroeck, N. (2013) The effect of dams and seasons on malaria incidence and *Anopheles* abundance in Ethiopia. *BMC Infectious Diseases*, **13**(1): 161.

Yohannes, M. and Boelee, E. (2012) Early biting rhythm in the afro-tropical vector of malaria, *Anopheles arabiensis*, and challenges for its control in Ethiopia. *Medical and Veterinary Entomology*, **26**(1): 103-5.

Zahir, A., Ullah, A., Shah, M. and Mussawar, A. (2016) Community Participation, Dengue Fever Prevention and Control Practices in Swat, Pakistan. *International Journal of MCH and AIDS*, **5**(1): 39-45.

Zewdie, W., Csaplovics, E. and Inostroza, L. (2017) Monitoring ecosystem dynamics in northwestern Ethiopia using NDVI and climate variables to assess long term trends in dryland vegetation variability. *Applied geography*, **79**: 167-78.

Zhang, Y., Su, F., Hao, Z., Xu, C., Yu, Z., Wang, L. and Tong, K. (2015) Impact of projected climate change on the hydrology in the headwaters of the Yellow River basin. *Hydrological Processes*, **29**(20): 4379-97.

Zhou, G., Afrane, Y. A., Dixit, A., Atieli, H. E., Lee, M. C., Wanjala, C. L., Beilhe, L. B., Githeko, A. K. and Yan, G. (2013) Modest additive effects of integrated vector control measures on malaria prevalence and transmission in western Kenya. *Malaria Journal*, **12**: 256.

Zhou, G., Minakawa, N., Githeko, A. K. and Yan, G. (2004) Association between climate variability and malaria epidemics in the East African highlands. *Proceedings of National Academy of Science, USA*, **101**(8): 2375-80.

Zhou, G., Munga, S., Minakawa, N., Githeko, A. K. and Yan, G. (2007) Spatial relationship between adult malaria vector abundance and environmental factors in western Kenya highlands. *America Journal of Tropical Medical Hygiene*, **77**(1): 29-35.

Zhou, Y., Zhang, L., Fensholt, R., Wang, K., Vitkovskaya, I. and Tian, F. (2015) Climate Contributions to Vegetation Variations in Central Asian Drylands: Pre- and Post-USSR Collapse. *Remote Sensing*, **7**(3): 2449-70.

Zhu, C., Lettenmaier, D. P. and Cavazos, T. (2005) Role of antecedent land surface conditions on North American monsoon rainfall variability. *Journal of Climate*, **18**(16): 3104-21.

Zollner, G. E. (2006) *Evaluation of residual insecticides and long-lasting, insecticide-impregnated materials to control adult sand flies in Iraq and Kenya. In The 2006 ESA Annual Meeting*, December 10-13, 2006.

APPENDICES

Appendix I: Focus Group Discussion guide

Part 1

a) What can be considered as the normal climate of this area/region?

b) For what period of time has this been constant?

c) Have you observed any recent changes in climatic conditions?

d) What are some of the observable changes?

e) Can you give historical account of some of the local climate hazards in the recent past?

  - Winds
  - Floods
  - Droughts
  - Cold
  - Heat wave

f) What are the effects of these climatic changes?

Part 2:

a) Do you think climatic changes can alter disease occurrence? If so, what are some of the diseases (and their causes) you can link to changing climatic conditions?

b) Can you give historical account of disease outbreaks that were related to climate?

c) What strategies have you or your family put in place to prevent / control malaria?

d) What are the sources of information and knowledge that guide your prevention/control malaria?

e) Are the existing malaria control strategies adequate? If no, would you suggest some local mechanisms for prevention and control?

f) Would you adopt new malaria prevention or control method? If not, what would be the reasons for your resistance?

Appendix II: Household Survey Questionnaire

A. Household identification

Sub-county	1. Baringo North 2. Baringo Central 3. Baringo South	Household code	
		GPS Coordinates Lat: Long:	
Ecological zone		Date:	
Location			
Village		Time:	
Type of respondent	1. HH 2. Spouse 3. FHH		

B. Respondent Information

1.	Sex	a) Male b) Female	6.	Highest level of education	a) None b) Primary c) Secondary d) Tertiary
	Marital status	a) Single b) Married c) Separated d) Widowed e) Divorced	7.	Number of children	≤ 5 yrs 6-18yrs Male: Female:
3.	Age		8.	Tribe	
4.	Source of cooking water	1. Public tap 2. Piped into compound 3. Borehole 4. Rain water collection 5. Dam/pond 6. River/stream 7. Lake 8. Other	9.	Main livelihood activity	1. Crop farming 2. Livestock keeping 3. Bee keeping 4. Self employed 5. Salaried employment 6. None 7. Other
5.	Source of drinking water	1. Public tap 2. Piped into compound 3. Borehole 4. Rain water collection 5. Dam/pond 6. River/stream 7. Lake 8. Other	10.	Supplementary livelihood activities	1. Crop farming 2. Livestock keeping 3. Bee keeping 4. Self employed 5. Salaried employment 6. None 7. Other

C. Climate variability

1.	Climate hazards and impact	In the last 10 years have you experienced the following climate events	Rate the frequency of occurrence 3=High 2=Moderate 1=Low	Rate severity of climate hazards 3=High 2=Moderate 1=Low	Rate the impacts of the of the hazards 3=High 2=Moderate 1=Low	Rate the difficulty of coping with hazards 3=very difficult 2=fairly difficult	Total vulnerability

						1=no difficulty	
a.	Changes in rainy season						
b.	Drought						
c.	Floods						
d.	Heavy rainfall						
e.	Hotter climate						
f.	Cooler climate						

D. Sources of climate information/knowledge

2.	What are your sources of climate information and knowledge (circle all that apply)	Sources: a) Meteorological service b. Radio (Vernacular) c. Radio (National) d. Television e. School/college f. Village elder g. Family/friends h. Government alerts i. Other	Rank: ___ ___ ___ ___ ___ ___ ___ ___ ___

E. Ecohydrological conditions

1.	In the last 5 - 10 years have you observed the following (circle all that apply)	What is the frequency of occurrence 3=Frequent 2=Moderate 1=Rare
a)	**Vegetation condition:** 1. Greener 2. Low vegetation 3. More trees growing 4. More grass 5. More ground covered during most months of the year 6. Soil exposed during most months of the year	__ __ __ __ __ __
b)	**Hydrological conditions**: 1. River flow increased almost year round 2. River flow reduced almost year round 3. New springs 4. Flash floods 5. Other	__ __ __ __ __

E. Perceptions on causes and control of malaria

	Statement	Yes	No		Yes	No
1.	Mosquito bites cause malaria			Do you have any bed nets currently		
	Eating sugary foods cause malaria			How many bed nets do you have		
	Drinking muddy water cause malaria			Are the bed nets comfortable		
	Excess stomach acid cause malaria			Where did you get the bed nets you are currently using: a) Gift		

				b) Purchase c) Government hospital d) Government mass distribution e) NGOs f) Other		
	Conventional cooking oil cause malaria			Are bed nets affordable		
	Staying outdoor after dark exposed someone to mosquito bite			Bed nets reduce chances of getting malaria		
	List factors that you think increase malaria in this area			Are existing malaria control strategies adequate		
	There are more mosquitoes at night than day			Would you use other malaria control strategies		
	Climate can alter malaria occurrence			During the last 1-year was your compound sprayed with insecticide to reduce mosquitoes		
	In the last 1 year, have you ever received any teaching about malaria from community health worker			During the last 1-year was your house sprayed with chemicals that kill mosquitoes		
	What are the sources from which you get information on malaria? (circle all that apply) a. Family b. Friends c. Radio (Vernacular) d. Radio (National) e. Television f. Health facility g. Community health worker h. Local herbalist i. Personal experience j. Other			During the last 1 –year did you use mosquito repellents in your house/compound. (Circle all that apply). a. Mosquito coil b. Creams/lotions c. Indoor aerosols d. Cow dung e. Burning plant leaves		

Appendix III: Various habitat types sampled for the presence of mosquito larvae.


Canal overflow


Concrete tank


Rain pool


Water pit


Pan dam


River fringe


Swamp edge


Canal


Lake margin


Hoof prints

Appendix IV: Key Informant Interview (KII) Guide

Introduction:

I am a student from UON doing a research on climate change and malaria risks. I would like to ask you some questions with regard to malaria: access to medical services, and community risk factors with a view to increase eco-health interventions.

Part A: Health practitioners

1. How many health facilities are there in the county? How would you rate the level of staffing in the health facilities: well-staffed, understaffed, or overstaffed
1. What is the average catchment (in terms of km)?
2. What are the common diseases in the county?
3. How would you rank malaria amongst other diseases?
4. What is the trend of malaria cases over the past 5-10 years (increasing or decreasing)?
5. How is the supply of antimalarial drugs in the county? (Sufficient; inadequate)
6. How is the consumption of antimalarial drugs? (Fast; moderate; slow)
7. Are there instances where patients miss antimalarial from the hospitals? How frequent are the cases?
8. What are the malaria control interventions in the county?
9. Are there mass net distributions? If yes, name the lead institutions (GOK vs NGOs)?
10. When was the last mass net distribution? What is the frequency of net distribution?
11. How many nets are usually given per household? Or what is the criteria used in net distribution?
12. If answer to Q 10 is a NO: How do community members get bed nets that government provide?
13. Are there trainings for health workers? What is the frequency?
14. Has there been curriculum modifications lately?
15. Do you conduct community health education? What is the frequency?
16. Are there platforms /programs for communication and information exchange:
    a. Different health departments?
    b. With communities?
17. From your own experience what are some of the community practices or activities that increase their risk to malaria infection?

18. Are there gender roles that predispose communities to malaria?
    a. Men?
    b. Women?
    c. Girls?
    d. Boys**?**
19. From your experience, what are the areas that need improvement in the provision of medical services, specifically malaria service provision?

Part B: Community gatekeepers

1. How many health facilities are there in your location?
2. What are the common diseases in the county?
3. How would you rank malaria among diseases affecting community members?
4. How severe are the malaria cases?
5. What the average distance travelled to hospital?
6. What the common modes of transport? What is the average cost and time of travel?
7. How would you rate the level of staffing in the health facilities: well-staffed, understaffed, or overstaffed
8. Have you heard of sick people missing anti-malarial from the hospitals? How frequent are these cases?
9. What do sick people do when they miss medicines?
10. What are the other malaria control interventions that community members use?
11. Have there been mass net distributions? If no, how do the people acquire the nets?
12. If yes, How frequent are the net distribution?
13. Are there community health education and campaigns? Name the lead institutions (GOK vs NGOs)? How frequent are the meetings?
14. What are some of the community practices and activities increasing risk of malaria attack?
15. Are there gender roles increasing malaria risk?
    a. Men
    b. Women?
    c. Boys
    d. Girls?
16. Has the settlement pattern changed in the recent past? How was it then (year)?
17. How does the community use resources like grazing fields, wetlands, forests and plants? Has there been any change from the past (document)?

18. Are there platforms for communication and information exchange among community members and with health officers? Name them?
19. If above question is a no. what do community members rely on for information and communication?
20. How would you rate healthcare provision in the location? Good; Average; poor

Appendix V: List of key informants, their respective codes and interview dates

Key informants	Codes	Interview dates
Baringo Central malaria coordinator	KI1	21/11/2016
Baringo North malaria coordinator	KI2	23/11/2016
Baringo South malaria coordinator	KI3	25/11/2016
County disease surveillance officer	KI4	22/11/2016
County Pharmacist	KI5	22/11/2016
Baringo Central public health officer	KI6	21/11/2016
County Health records and information officer	KI7	21/11/2016
Assistant chief, Keturwo	KI8	23/11/2016
Assistant chief, Salawa	KI9	24/11/2016
Chief, Salabani	KI 10	25/11/2016
Community resource person, Kapkuikui	KI 11	18/11/2016
Community resource person, riverine	KI 12	23/11/2016

Appendix VI: Summary of malaria cases per hospital during the 2005 - 2014 period

Year	Month	Barwessa	Keturwo	Marigat	Kampi ya Samaki
2005	Jan	89	21	33	89
2005	Feb	83	14	403	149
2005	Mar	27	12	331	164
2005	Apr	62	4	315	94
2005	May	91	8	409	143
2005	Jun	138	17	489	236
2005	Jul	82	24	568	218
2005	Aug	66	24	382	196
2005	Sep	72	47	505	428
2005	Oct	33	34	785	242

Year	Month	Barwessa	Keturwo	Marigat	Kampi ya Samaki
2005	Nov	43	129	487	275
2005	Dec	59	53	345	217
2006	Jan	18	57	314	132
2006	Feb	8	96	459	201
2006	Mar	10	108	380	264
2006	Apr	22	70	340	223
2006	May	40	95	345	152
2006	Jun	51	19	100	138
2006	Jul	103	301		153
2006	Aug	169	223		148
2006	Sep	98	168	100	208
2006	Oct	12	169	141	174
2006	Nov	7	123	146	145
2006	Dec	23	105	211	157
2007	Jan		285	438	418
2007	Feb	25	353	558	614
2007	Mar	78	85		274
2007	Apr	73	46		138
2007	May	49	107	167	94
2007	Jun		140	278	61
2007	Jul		167	382	379
2007	Aug	15	132	633	263
2007	Sep	19	108	534	171
2007	Oct	15	197	447	139
2007	Nov	25	127	213	133
2007	Dec	21	73	183	81
2008	Jan	23	127	183	31
2008	Feb	65	145	159	59
2008	Mar	125	72	198	
2008	Apr	109	69	87	12
2008	May	165	143	170	
2008	Jun	27	191	177	62
2008	Jul	40	148	273	13
2008	Aug	37	53	320	14
2008	Sep	101	272	392	
2008	Oct	84	147	55	10
2008	Nov	109	160	586	6
2008	Dec	52	143	411	5
2009	Jan	107	113	579	38
2009	Feb	109	139	882	37
2009	Mar	64	97	827	71
2009	Apr	71	68	565	74

Year	Month	Barwessa	Keturwo	Marigat	Kampi ya Samaki
2009	May	94	117	705	87
2009	Jun	67	107	820	81
2009	Jul	97	104	854	168
2009	Aug	83	121	866	88
2009	Sep	70	147	517	77
2009	Oct	60	232	1126	75
2009	Nov	95	255	706	117
2009	Dec	46	118	386	144
2010	Jan	69	213	452	198
2010	Feb	106	214	269	300
2010	Mar	83	114	409	248
2010	Apr	123	116	495	203
2010	May	122	262	286	323
2010	Jun	132	173	509	359
2010	Jul	195	372	909	441
2010	Aug	133	176	366	317
2010	Sep	165	323	316	345
2010	Oct	99	282	517	432
2010	Nov	100	248	360	191
2010	Dec	80	114	402	148
2011	Jan	95	282	161	153
2011	Feb	106	350	666	169
2011	Mar	102	274	863	264
2011	Apr	124	274	558	333
2011	May	69	162	381	258
2011	Jun	120	358	375	231
2011	Jul	92	249	261	219
2011	Aug	61	212	158	222
2011	Sep	41	382	292	212
2011	Oct	63	269	196	190
2011	Nov	77	229	344	267
2011	Dec	91	231	55	254
2012	Jan	114	145	93	332
2012	Feb	57	111	20	292
2012	Mar	68	119	25	200
2012	Apr	47	108	230	117
2012	May	92	163	161	177
2012	Jun	71	152	302	207
2012	Jul	76	107	30	330
2012	Aug	68	135	154	248
2012	Sep	96	148	186	224
2012	Oct	124	153	275	325

Year	Month	Barwessa	Keturwo	Marigat	Kampi ya Samaki
2012	Nov	84	112	208	179
2012	Dec	68	127	152	68
2013	Jan	68	73	266	73
2013	Feb	54	80	306	132
2013	Mar	78	129	453	101
2013	Apr	89	135	254	53
2013	May	147	207	333	49
2013	Jun	86	168	565	99
2013	Jul	107	192	569	92
2013	Aug	75	191	449	52
2013	Sep	33	339	601	36
2013	Oct	51	654	394	44
2013	Nov	60	349	234	
2013	Dec	32	193	597	53
2014	Jan	67	359	59	61
2014	Feb	40	312	636	14
2014	Mar	44	247	534	13
2014	Apr	51	273	474	11
2014	May	66	363	746	43
2014	Jun	53	386	754	176
2014	Jul	47	101	508	289
2014	Aug	44	116	151	
2014	Sep	52	126	321	
2014	Oct	50	170		145
2014	Nov	39	141		113
2014	Dec	58	129		

Appendix VII: The distribution of stakeholders by ecological zones

Stakeholder category	**Lowland zone**	**Riverine zone**
Village heads	5	5
Chiefs/Assistant Chiefs	4	2
Community volunteers	3	2
Religious leaders	3	3
Nurses	2	1
Public health officers	1	1
Teachers	2	2
Disease surveillance officers	1	1
Sub-county malaria coordinator	1	2
CBO officials	2	0
Assistant county commissioners (ACC)	1	2
Total	**25**	**21**