UNIVERSITY OF NAIROBI

INVESTIGATING SOCIO-ECONOMIC IMPACTS ON SUSTAINABLE MOUNTAIN FRESHWATER ECOSYSTEM SERVICES IN MT. ELGON WATERSHEDS UNDER A CHANGING CLIMATE

BY

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DEDICATION

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ABSTRACT

The Mt.Elgon watersheds are important freshwater catchment for rivers that provide water for all aspects of human livelihoods in the region. The increasing pressures of anthropogenic drivers of climate change are impacting mountain freshwater ecosystem service provision in the watersheds. These have not been fully addressed, whereas degradation continues unchecked.

This study focused on investigating the socio-economic impacts of sustainable mountain freshwater ecosystem services in Mt.Elgon watersheds under a changing climate. The study used both quantitative and qualitative data collecting tools. Livelihood was the independent variable, freshwater ecosystem services as the extraneous variable and climate change as the dependent variable, classified based on the view point of causation, stressing man's role and responsibility.

Data is key in any research. Both primary and secondary data was collected. An intensive systematic evaluation of literature review on anthropogenic impacts on mountain freshwater ecosystem services was carried out to focus study, when carrying out unstructured interviews during field visits. Historical climate data for precipitation and discharge for the period 1960-2016 and 1948-2016, obtained from meteorological and water resources management government agencies of Kenya and Uganda was analysed for trend. Data for simulation modelling for opportunity cost and climate change impacts was provided with ecoengine model.

Results from the study showed climate variability depicting both upward and downward trends for climate and discharge data. Results depicted increasing population rates and demand for land for livelihood activities which has led to increased demand for freshwater ecosystem services. Potential impacts projected, showed that with continued poor ecosystem management, freshwater ecosystem services are likely to be depleted affecting the sustainability of freshwater ecosystem services. Results of the study confirmed that socio-economic activities are impacting sustainable mountain freshwater ecosystem services in the Mt. Elgon watersheds. These will inform decision making for policy development, economic planning, enhance environmental quality, hazard mitigation and conservation for sustainable freshwater resources and services.

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LIST OF ACRYONYMS

ACES	Agricultural, Consumer and Environmental Sciences
ArcGIS	Arc Geographical Information Systems
AR5	Fifth Assessment Report
CRA	Centre for Resorce Analysis Limited
DDC	Data Distribution Center
DFID	Department of International Development
DPSIR	Drivers-Pressures-State-Impacts-Responses
ES	Ecosystem
ESML	EcoService Models Library
FAO	Food and Agricultural Organization
GDP	Gross Domestic Product
GFC	Global Forest Cover
GIS	Geographical Information Systems
GHGs	Green House Gases
IIED	International Institute for Environment and Development
IFPRI	International Food Policy Research Institute
IFRC	International Federation of the Red Cross/Red Crescent
IPCC	Intergovernmental Panel on Climate Change
ITFC	Institute of Tropical Forest Conservation
IUCN	International Union for Conservation of Nature
LVNCA	Lake Victoria North Catchment Area
MA	Millennium Ecosystem Assessment
MEA	Millennium Ecosystem Assessment
MK	Mann-Kendall Method
MWE	Ministry of Water and Environment
NDVI	Normalized Differentiation Vegetation Index
NEMA	National Environmental Management Authority
P4GES	Paying for Global Ecosystem Services

UNEP	United Nations Environmental Programme
PAs	Protected Areas
QGIS	Quantum Geographical Information Systems
RCPs	Representative Concentration Pathways
RVCA	Rift Valley Catchment Area
SCOPE	Scientific Committee on Problems of the Environment
SDGs	Sustainable Development Goals
SRES	Special Report on Emissions Scenarios
UBOS	Uganda Bureau of Statistics
UNESCO	United Nations Educational Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
WRMA	Water Management Agency
WWC	World Water Commission
WWF	World Wide Fund
WRTDS	Weighted Regressions on Time, Discharge and Seasons

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter examines the background of the study, the problem statement, justification of study, research questions, objectives of the study, hypothesis, and significance of the study and area of study.

1.2 Background of the Study

Protected ecosystems including freshwater ecosystems as well as restored ecosystems and a conserved biodiversity, enhances provision ecosystem services and thus support other ecosystems. This will aid mitigation of climate change, increasing resilience amidst rising human needs and disasters (UN, 2017). While ecosystems easily adapt to change, some changes are not reversible. Proof of observed impacts of climate change is more comprehensive for natural systems affecting other global systems. In many regions in the world, fluctuating rainfall levels, melting glaciers and snowfall are modifying hydrological systems. This is distressing water resources affecting their quantity and quality (IPCC, 2014). The world's climatic conditions are increasingly altering, and this is most pronounced in recent years. Over-all human engineered Green House Gas (GHG) emissions have continued to intensify over 1970 to 2010 with greater total decadal increases more towards the end of this period (IPCC, 2014). Impacts of Climate change mostly affect communities who depend on sectors which are sensitive to changes in climate for example; agriculture, forestry and freshwater ecosystems (Xu *et al.,* 2013). Changes in the accessibility to freshwater is projected to be of major concern of anticipated changes in climate (Kingston and Taylor, 2010).

Mountain regions in East Africa are the main water catchments for most of the major rivers in the region. While many people rely on the benefits provided by mountain ecosystems in Uganda, these regions are amongst those expected to be most impacted by climate change (MWE, 2013). Mt. Elgon, is a trans-boundary natural resource between Kenya and Uganda. It is an extinct volcano with fertile volcanic soils. It has drawn special attention due to its richness in animal and plant life. It is a significant source of water for several rivers and streams that flow into Lake Victoria, Lake Turkana and Lake Kyoga contributing to the River Nile system (MWE, 2013).

The changing climate is of utmost concern in the watersheds, for the reason of its potential to impact the ecology and environment of both the uplands and lower lands. It causes fluctuating precipitation levels affecting river discharge levels. This will adversely affect ecosystem services and most especially the mountain freshwater environmental services that other ecosystems depend on for survival. Climate change has the potential on how economic activities will be affected by social dimensions, as well as the political aspects of the economy resulting in low income per capita. The impacts of climate change will negatively affect the livelihoods of poor people in developing countries, and most especially those living in mountain regions due to their dependence on the mountain resources, where poverty exposes them to harmful effects due to their vulnerability (Abeygunawardena *et al.*, 2009). Temporary settlements built on unstable landscapes will be at risk of flooding and landslides, further stressing mountain freshwater ecosystem services as a result of altered landscapes, poor land management and deforestation.

In this study, these aspects are illustrated using the Drivers-Pressures-State-Impacts-Responses (DPSIR) framework. The Driving Forces are the socio-economic and socio-cultural forces, driving human activities like, poor agricultural practices, deforestation, population growth and density increasing stress on the environment. Direct stresses are both human imposed and natural, due to insatiable human needs with economic development. This causes freshwater ecosystem degradation resulting in depleted freshwater ecosystem services in the watersheds.

The Mt Elgon watersheds are highly populated areas. The eight districts surrounding the mountain have the highest population density in Uganda, with 226 persons living per square kilometers, in comparison to the national average of 123 people per square kilometer (UBOS, 2006) based on the latest 2002 population census. As the people in the area are farmers and the population continues to grow, shortage of land results in cultivation in steep slopes, deforestation and loss of soil cover. The rate of growing population of up to 4% per year, in the watersheds has raised the demand for natural resources leading to over-exploitation. This is affecting the functions of Mt. Elgon ecosystem that is at threat from human activities. For example encroachment on national reserves, cultivation into the steep landscape, wetlands and riverbanks (MWE, 2013). This triggers landslides that alter freshwater ecosystems of rivers on the slopes affecting the sustainability of freshwater ecosystem services, thus affecting water quality and causing sedimentation in river channels and thereby causing flooding. The over exploitation of mountain ecosystems for human livelihoods resulting in deforestation and land degradation, may lead to extinction and change of the ecological system. This will affect the capability of ecological services, and sustainability of freshwater ecological services as mentioned in the Sustainable Development Goals report (UN, 2017).

Deforestations and degradation in water catchment areas also causes increased surface water runoff causing increased soil erosion which further pollute and silt the river systems in the region (Sakinatu and Muhammad, 2017). This has equally affected the ability of recharge of groundwater aquifers due to reduced water percolation affecting river flow levels and hence putting increased stress on the service provision. The increased use of fertilizers for agricultural production has furthered polluted the rivers, impacting the value and magnitude of freshwater ecological benefits, enhancing the emission of greenhouse gasses furthering global warming as a result of increased human activities (FAO, 2015).

This study carried out an assessment of freshwater ecosystem resources and associated ecosystems and their services. This was achieved by modelling with the ecoengine model through WaterWorld and Co$ting Nature policy-support tools. This was to cost the natural capital and carry out analysis for ecosystem services provided by natural environments, in the watersheds. The focus was costing nature by understanding the watershed's capabilities and the opportunity cost of protecting its natural resources. This is to enhance realised benefits from freshwater ecosystem services provided by the watersheds, as opposed to valuing nature. That is to mean, how much one is willing to pay for it so as to exploit it. This was achieved by assessing impacts and recognizing the recipients of these services, while evaluating the effects of what has been done in terms of interventions towards conservation prioritisation and planning. The tool calculated the spatial dispersal of ecosystem services for carbon, tourism and water. It identified distribution of threatened ecosystems with human pressures and future threats to determine conservation priorities. It also enabled the use of intermediations policy options or scenarios of change and how they impact on ecosystem service provision.

1.3 Problem Statement

Climate change effects are presently more evident now than before. Diverse natural resources have been impacted by these effects. These are caused by both natural and anthropogenic drivers. Freshwater ecosystems and services, are increasingly endangered by a changing climate eventually affecting associated ecosystems that sustain the entire global ecosystem. According to (Dodds *et al.*, 2013), anthropogenic impacts of climate change on freshwaters is an international phenomena that result in flow alteration, thermal alteration, increases in ultraviolet radiation, pollution, specimens invasions and extinctions.

According to MWE, (2013), in the Mt. Elgon watersheds, human activities done along riparian zones are reducing their ability to provide environmental purposes of water purification and floods regulation. They are a source of water for industrial and domestic use in both Kenya and Uganda. Masese at al., (2012) points out that in developing countries, water supply infrastructure has not been fully developed and therefore rivers are the main sources for water for domestic purposes, and it is usually not treated before use. According to Taylor *et al.,* (2012) the economic and social price resulting from climate are most usually borne by the poor groups whose socio-economic livelihoods depend on natural resources for survival.

The Mt. Elgon watersheds have originally be charaterised with several rivers and streams as well as well-springs. The watersheds were a habitant to thriving biodiversity of flora and fauna. Overtime some of these rivers have dried up and some places now face water scarcity. As more forests and vegetation is cleared to open up land for agricultural production and other livelihood activites, water levels are dwindling severely. In the watersheds, re-occurring landslides and increased loss of top soil to erosion, resulting in declined soil fertility, is evidence of a deteriorating state. With Climate change, this will likely worsen (MWE, 2013). The importance of preserving freshwater ecosystem services and associated ecosystem services is not just for preservation of mankind and all creation, but for stewardship, fruitfulness and increased realisation of benefits for sustainability. This raises a question. “How can the Mt.Elgon watersheds freshwater ecosystems be conserved to ensure sustainable freshwater ecosystem services?”

1.4 Research Questions

The research questions below were considered:

i) What are the socio-economic dimensions impacting mountain freshwater ecosystems services sustainability in the Mt.Elgon watersheds enhancing climate change?

ii) How are the mountain freshwater ecosystem services impacted by socio-economic dimensions in Mt.Elgon watersheds.

iii) What is the opportunity cost for conserving freshwater ecosystems, for freshwater ecosystem services sustainability in Mt.Elgon watersheds with the presence of climate change

1.5 Objectives of Study

The main objective of this study was to investigate the socio-economic dimensions impacting sustainable mountain freshwater ecosystem services in Mt.Elgon watersheds under a changing climate.

Specific objectives used to achieve this objective were:

i) To evaluate the socio-economic dimensions impacting mountain freshwater ecosystem services enhancing climate change.

ii) To determine mountain freshwater ecosystem services driven by socio-economic dimensions.

iii) To examine the opportunity cost for conserving freshwater ecosystems, for freshwater ecosystem services sustainability with the presence of climate change.

1.6 Hypothesis:

i) If livelihoods in mountain watersheds improve then mountain freshwater ecosystem services will improve

ii) If mountain freshwater ecosystems improve then mountain freshwater ecosystem services will improve.

iii) If mountain freshwater ecosystem services are evaluated then there will be informed decision making for policy formulation and implementation for sustainability.

1.7 Assumptions:

i) Improved land use practices and cover change for livelihood activities in mountain watersheds, improve vegetation/forest cover influencing climate and hydrological trends in mountain freshwater ecosystems watersheds.

ii) Improved mountain freshwater ecosystems in a mountain watershed, enhances improved freshwater ecosystem services and dependent ecosystems in the entire ecosystem.

iii) Evaluating realised freshwater ecosystem services, unrealised freshwater ecosystem services and potential freshwater ecosystem services in a watershed, enables informed decision making for utilisation and sustainability.

1.8 Justification of Study

Freshwater ecosystems deliver varied services and benefits that support other earth systems of life, including human life. Some of the services ecosystems provide include food, water provision, flood protection to spiritual renewal (Petersen *et. al.,* 2017). Freshwater ecosystems provide ideal conditions for reproduction of living organisms and as a habitant for some flora and fauna. Human activities are increasingly degrading rivers, lakes, wetlands and aquifers for livelihood. There is need for consciousness towards the significance of healthy freshwater ecosystems and their contribution to carbon sequestration to avert adverse impacts of a changing climate (Everard, 2017).

As human populations grow in many countries whose geographical features enable ideal conditions for biodiversity to thrive, there is increased pressure on the health of most ecosystems (Harper *et. al.,* 2017) more so in the Mt. Elgon watersheds and the rest of the African continent. These pressures are driven by high fertility rates in some communities, high poverty levels due limited livelihood alternatives identified. Increasing populations means increased consumption not commensurate with replenishment of the environmental base fueled by misappropriation by an uninformed populace. Climate change is posing significant threats to the health of ecosystems and affecting their ability to deliver services (Dasgupta *et al.*, 2009). Currently, universal economic models and structures of national accounts do not give adequate attention and consideration to the benefits derived from ecosystems with time. In some instances they are not taken into account. Because of this, this results in over exploitation, misappropriation and even underuse of natural resources, instead of efficient and sustainable use. Unless the full benefits of ecosystems are valued in regards to the opportunity foregone to exploit them, degradation will continue and sustainability will be a myth, leading to the eventual collapse of ecosystem functions and services most especially under a changing climate.

The need to understand the possible consequences of human impacts on freshwater ecosystem services for conservation management and alternatives to livelihoods for human survival, and sustainability of diminishing freshwater ecosystem benefits need to be researched in order to cope, adjust and change our lifestyles to overcome climate change and its impacts. Therefore, there is a need to amalgamate the science of ecosystems with the principles of socioeconomic dimensions that prompt institutional change and coordination, enhancing collaborative decision making for conservation.

1.9 Significance of the Study

The Mt. Elgon watersheds is a major ecosystem resource for freshwater. It supports other ecosystems and is a source of livelihoods in the East African region as well as the river Nile system, providing diverse ecological services which contribute significantly to the economies of countries benefiting from these services. This study seeks, help in finding lasting solutions to mountain freshwater ecosystem services sustainability in the Mt. Elgon watersheds. Results of the study will contribute towards informed decision making for alternative and improved livelihoods to enhance conservation of freshwater ecosystems for improved freshwater ecosystem services in the watersheds. By understanding the value of the entire natural resource, the benefits of freshwater ecosystems and the opportunity cost of protecting it, based on informed policy options, will enhance sustainable ecosystem services in the entire watersheds.

1.10 Area of Study

The Mt Elgon watersheds span an area of a once-a-time volcano that rises to a height of 4,321m above sea level at its highest point. The watersheds are occupied by the districts of Mbale, Manafwa, Kapchorwa Bududa, Sironko, Bulambuli, Kween, and Bukwo in eastern Uganda (RoU, 2012). In Kenya it is shared by Bungoma and Trans Nzoia counties. The mountain runs approximately in a North East-South Western direction in Kenya (Mwaura, 2011) and is located about 100km^2 northeast of Lake Victoria (Laman *et al.*, 2001) as seen in Figure 1.1

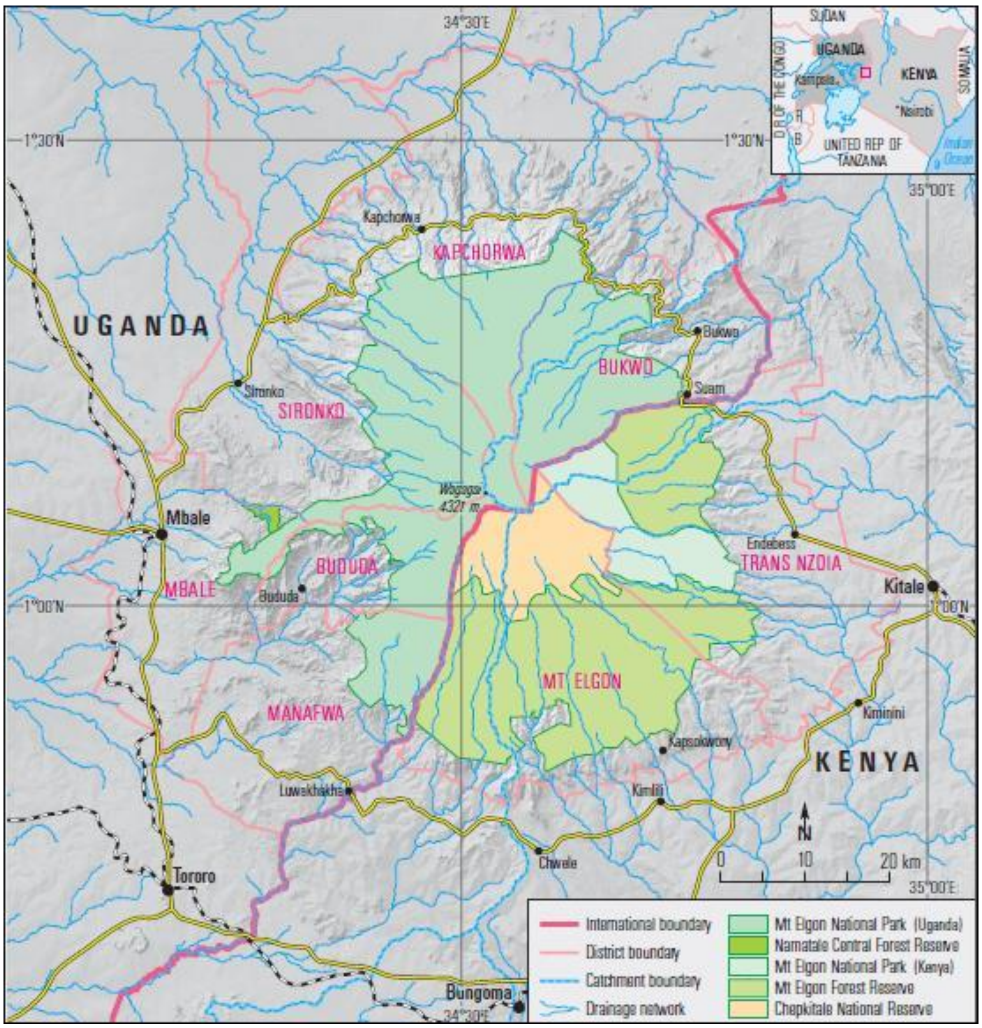

Figure 1.1: Location Map of Mt.Elgon Watersheds (Muhweezi et.al., 2007)

The Area of Study is a catchment area covering about 45,000 km^2, situated amid longitudes 33.5º and 35.5ºE, and latitudes 0.0ºand 2.0ºN. The watersheds topography is characterized by steep uplands that gradually slope towards Lake Victoria in the south, Lake Turkana in the North and Lake Kyoga in the North West. The altitude spans from 878m above sea level in the Nzoia River basin in the south, to 4321m above sea level at the Mt. Elgon peak.

The study area focused on the lower inclines of Mount Elgon Region below the National Park Reserves of the 2045 km^2 to the agricultural lower land and regions of in both Uganda and Kenya. All sampled areas were areas below the protected areas of Mt.Elgon towards Lake Victoria, Lake Kyoga and Lake Turkana where these rivers feed into. The main river catchments are; Sipi, Manafwa, Sironko, Namatala, Simu, Sio and Mpologoma for Uganda, and Nzoia, Rongai, Kuywa and Suam for Kenya.

1.10.1 Delimitations of Study Area

The study mainly focused on freshwater ecosystem services impacted by livelihood activities in the Mt. Elgon watersheds and the ability of the freshwater ecosystems to provide sustainable freshwater ecosystem services under changing climate.

1.10.2 Climatology of the Area of Study

The climatology of the area of study is tropical humid, with an average yearly precipitation level ranging from 1400 to 1800mm and mean annual temperatures ranging from 14 to 24^{o}C. However, both precipitation and temperature levels keep changing with elevation (Musau *et al.,* 2015). The north-easterly and south-westerly airstreams define the climate of the region. Though the months of July, August and December to February are moderately dry, it is still rains in all these months (Sassen *et al.,* 2013). The region experiences two main rainy seasons. Long rain season from March to June and short rain season from September to November. Temperatures are lowest between June and September. Emergent evapotranspiration declines as altitude increases (Githui *et al.,* 2009). Precipitation on other hand varies with altitude. As the altitude increases, the precipitation increases. This is also influenced by proximity to the forests which are located at the top of the mountain.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapters details the freshwater ecosystem services derived from freshwater ecosystems and associated ecosystems, the socio-economic benefits and impacts affecting their ability to provide sustainable freshwater ecosystem services, citing approaches to sustainable solutions.

2.2 Freshwater Ecosystems and their Associated Ecosystems and Services

Mountains are among the terrestrial ecosystems which have unique natural and socioeconomic characteristics (Foggin, 2016). Mountain ecosystems are sensitive to change and the community of mountain ecosystems is poor and diverse in culture world over. The area of mountains and ecosystem services that mountains provide are vast. Among the ecosystem services of mountains, is provision of freshwater, biodiversity and climate regulation services which are all significant for both human and animal survival and resilience (Odi, 2015).

Mountain ecologies play a major role in enabling watersheds as sources for provisioning of freshwater for both consumptive and non-consumptive use. They regulate streamflow, recharge groundwater aquifers and regulate floods (Bergkamp and Cross, 2006). The effectiveness of ecosystems to deliver services is dependent on the a country's climate and the quality of its watersheds. Both the natural drivers and anthropogenic drivers of climate change impact mountain ecosystems. They alter the natural water resources and their natural hydrological cycle affecting their ability to provide services.

Rising 4421m above sea-level, Mt. Elgon is a trans-boundary isolated extinct standout volcano situated along the Uganda-Kenya boundary located northwards from the equator (Petursson *et al.,* 2013). The mountain is forested with widespread undulating hills with gentle slopes (Sassen *et al.,* 2013) as well as steep slopes in several places created by breakaway loose soils due to landslides. Beyond the cultivated gardens between 2000m to 3500m asl, it is has a wide range of important indigenous species (Van Heist, 1994). It is also endowed with vast range of biodiversity with vegetation zoned by altitude (Petursson *et al.,* 2013). Beyond the 3500m asl, the vegetation is Afro-Alpine heath and moorland with rare bird species making it a major tourists attraction and a major source of income for both the locals and governments of Uganda and Kenya (*Nature*Uganda, 2011, IUCN 2000).

Mt Elgon watersheds are important water-catchments for major rivers flowing into the Lake Kyoga and Lake Victoria, that form part of the river Nile system. It is also a catchment for Lake Turkana situated in the semi-arid areas of Northern Kenya. The presence of plentiful rainfall and fertile soils, make it ideal for productive agriculture and a suitable habitat for biodiversity to thrive. The freshwater ecosystems sustains the highlands and lowlands of the Elgon region and beyond. These provide a varied range of freshwater ecosystem services upon which both human and the biodiversity depend. Freshwater ecosystems and their associated ecosystems are also a major storage for carbon sequestration. Van Heist, (1994) underscores this stating "Elgon's afro-mountainous flora has high biodiversity value, both locally and on a global scale."

The ability of a watershed to perform to its fullest capacity is largely determined by the climate. Shadananan, (2016), discusses that varying magnitude and seasonality of precipitation influences quantity and quality of water realized in an area. He points out that lack of adequate water cause severe health and various socio-economic challenges. Precipitation and temperature form rainfall and snow determining the hydrological cycle, as well as runoff. Any changes that influence these aspects negatively, will affect the availability and accessibility of freshwater in both the mountainous and lowland areas (Viviroli *et al.,* 2007). IPCC, (2007) mentions that mountain areas predominantly will be affected by climate change and evident changes are already being witnessed in the hydrological cycle in these regions. With climate change impacts, Mt. Elgon watersheds' ability to provide sufficient quality freshwater ecosystem services will be compromised. It is the consistent occurrence of the rainfall events as opposed to the overall amount determines the availability of water of a region (Shadananan, 2016). He further points out that, when rainfall is proportionally distributed throughout the rainy months, it increases soil moisture retention and increases water disposal in drought period. With the uncertainty of a changing climate, accelerated with anthropogenic drivers, the state of the ecosystem is bound to change affecting the ability of the watersheds to provide the much needed freshwater ecosystem services.

2.3 Socio-Economic Pressures in Mt.Elgon Watersheds

The location of the Mt. Elgon watersheds along the international boundary of Kenya and Uganda, makes it an important source for freshwater for Lake Victoria, Kyoga, Turkana and the Nile River system (Rannveig and Bernardas, 2012). The ecosystem comprises montane forest landscapes conserved as protected areas (UNEP,2009, Muhweezi *et al.*, 2007). The adjacent slope which is the area of focus is mainly agricultural landscape that supports about 2 million people who mainly rely on the ecosystems' goods and services for their livelihood (Muhweezi *et al.*, 2007).

The national forest reserves forest cover is a major component for the formation of rainfall in the Mt.Elgon watershed. Efforts to stop encroachment on the protected areas continue to be a challenge (Mugagga and Buyinza, 2013). This is as a result of the need for more agricultural land by the community. This is due to a growing population and the loss of soil fertility raising the need to open new land. This is exacerbated by collusion by National Park staff and meddling by political leaders (Mugagga and Buyinza, 2014) in the forestry affairs. This interference is causing local conflict within communities as well as trans-boundary conflict due to the increased need for water, food and livelihood as they make effort to survive on the limited remaining resources. All these activities in one way or the other depend on freshwater ecosystem services.

The socio-economic activities carried out by a communities forms their livelihood. Livelihoods are people's abilities, possessions, income and actions vital to secure the requirements of life (DFID, 2000a). It is a sustainable livelihood if it supports a community survive amidst life's shocks like earthquakes and famine while enhancing their well-being without compromising the resource base of future generations (IFRC, 2006). Sustainable livelihoods depend on sustainable resources. Sustainable freshwater ecosystem services are vital for sustainable livelihoods.

According to Muhweezi *et al.*, (2007), the growing population in Mt. Elgon Region ranges between 2.3 and 4.3% rate per year. Most households are poor with landholdings of approximately 0.8 ha on average per capital landholdings. The communities are primarily peasant farmers, mainly carryout commercial farming at a small scale and subsistence agriculture and livestock farming. Other economic activities the community does is poultry keeping, lumbering and beekeeping (UNDP, 2012). Mugagga *et al.,* (2010), discusses, that in Uganda, land is the main source of livelihoods for rural communities covering up to approximately 80% that depend on it for agriculture as their main source of livelihoods. Along the riverbanks and in wetlands, human activities carried out include; sand mining, harvesting of craft materials from swamps. There is diversion of streamflow for irrigation for agriculture and pond fishing farming. Livestock rearing and harvesting of herbal medicines (MWE, 2013) as well brick making and pottery is carried out. These all rely on the availability of freshwater ecosystem services for their sustainability.

2.3.1 The Need and Demand for Increased Food Production

The sustainability of any community depends on its ability to have sustainable resources to ensure its access to food at all times. The Food and Agricultural Organisation (FAO, 2014) describes food security as a "situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life." The access to food is a human right and necessary for human life, survival and livelihood. Rockstrom *et al.,* (2004), point out that as more food is grown upstream of the watershed, more stress is put on the freshwater services downstream. Published results show that between 5 million to 170 million more people are prone to face hunger by 2080 (Schmidhuber and Tubeiello, 2007).

Food production comes with consequences of availability of suitable fertile agricultural land. Clearing vegetative cover affects precipitation levels impacting the hydrological cycle. Temperature and precipitation variations related to continuous emissions of greenhouse gases, are likely to affect the aptness of land and crop yields. Extreme rainfall events will lead to flooding and is bound to increase incidence of water–borne diseases mainly in low capacity regions. With poor water management systems in environmentally degraded environments, poor-hygiene and sanitation accessibility will expose people to water borne diseases like typhoid (IPCC, 2007), and as such reduce the capability of communities to efficiently utilise food.

2.3.2 Impacts of Increased Food Production

Mt. Elgon region is endowed with rich volcanic soils, however the need to meet sufficient food demands for a growing population through agricultural farming has led to increased use of fertilizers. Modern agricultural practices promote the use of fertilizers to enhance increased crop production which pollute freshwater ecosystems. The incidence of chemicals diminishes the ability of freshwater resources to deliver quality water for both consumptive and non-consumptive uses. Polluted water sometimes is filled with heavy metals which are harmful to human health. It is also filled with sulphur and nitrogen based compounds.

The quality of water resources is affected by the release of nutrients that drive eutrophication, the presence of base compounds such as nitrogen and sulphur and heavy metals. The water quality is affected by acidification as result of the presence of organic compounds, floating particles, contaminants such as amoeba and salinity. The Millennium Ecosystem Assessment (MA, 2005), points out that variations in the state of freshwater and related water ecosystems on land had occurred due to direct drivers caused by the introduction of species in new habitats, land use change through human activities, and climate change. Re-affirming the impacts of the socio-economic activites. The Indiscriminate clearing of forests for timber and agricultural production has led to deforestation causing land cover change and land degradation.

Deforestation is adversely impacting the ecological services delivered by forests, depleting biodiversity and contributing to impacts resulting from climate change causing negative effects on ecological systems and benefits they provide (Petursson *et al.*, 2013). This is as result of logging or agricultural practices that can be driven by political, economic or even institutional or cultural factors (Geist and Lambin, 2009). Despite efforts to institute Protected Areas (PA) in the Elgon Water Towers Catchment, deforestation is still a challenge. Like in many countries, Protected areas (PAs) are measures taken by country as a measure to conserve, manage and protect natural resources from over exploitation and allow regeneration for sustainability.

Increasing need for agricultural production to meet the increasing population has led to deforestation for opening more agricultural land. Growing populations and the inability to sustainably exploit alternative resources for livelihoods is the main reasons of depletion of land resources in Sub-Saharan Africa (Sassen *et al.,* 2013). Though Logging is a main economic activity, for a while permissible logging in the native forest has not been carried out widely on the Ugandan side (Cavanagh and Benjaminsen, 2014). Though a Presidential decree in 1986 banned the logging of all trees in Kenya's native forests, the Mt.Elgon protected forest reserve was exempted (Hitimana *et al.,* 2004).

According to Soini, (2007), the fertile land in the Elgon watershed are amongst the most inhabited regions in East Africa. It is estimated the population density exceeds 1,000 people km^{-2} in some areas with more than 2 million people due to urbanization (Petursson *et al.,* 2013). This is exacerbated by land-use change in pursuit for survival, climatic variability with natural factors of weathering and clay filled soils enhancing landslides destroying life and property. With a growing population rate and the effects of climate change, this is bound to stress this water shed even more.

Of recent landslides are a common occurrence in the Mt.Elgon watersheds. Landscape alteration of slopes, indiscreet irrigation practices, deforestation and extreme rainfall trigger landslides making the East African highlands a vulnerable region (Glade and Crozier, 2005). Slope disturbance and river channel alteration pollute the freshwater ecosystems with sedimentation, impacting the freshwater ecosystem services in both quality and quantity. Increased pressure on land resulting in increased soil erosion and reduced agricultural productivity (Mugagga *et al.,* 2010). Increased land cover/ land-use change directly impacts the capacity of freshwater ecosystems to deliver services in both quality and quantity. Over exploitation of the land, exposes the ground affecting the ability of the soils to trap rainfall runoff for percolation to recharge underground aquifers and maintain discharge levels in rivers resulting in hydrological drought.

2.4 Mountain Fresh Water Ecosystem Services

Mountain freshwater ecosystem services are the ecological benefits derived from freshwater ecosystems by nature such as watersheds, rivers, groundwater systems, wetlands, floodplains and mountain "water towers" which are central to human survival and dependent ecosystems.

Aylward *et al.,* (2005), defines ecological services as the values derived directly and indirectly for human use from ecosystems and biodiversity. The Millennium Ecosystem Assessment (MA, 2005), refers to freshwater as a "provisioning" service because it provides fresh water for household and industrial use. Others services include the provision of water for irrigation, hydropower generation, and as a means of transportation. They sustain inland water resources as well as provide cultural benefits, regulate the hydrological cycle recreation and scenic values and support the maintenance and sustainability of fisheries (Aylward *et al.,* 2005). Literature shows new species of fish and birds are continually discovered in freshwater ecosystems. For example the *Glypotothorax gopoii* and *Garra simbalbaraensis*, new fish species recently discovered in the Kaladan river drainage found in Mizoram in Northeast India and Simbalbara River found in Himachal Pradesh, India (Kosygin, 2019: Rath, 2019). This makes freshwater ecosystems an ideal habitat for breeding of living organisms and reproduction for new species.

Fresh water sustain freshwater-dependent ecosystems like the mangrove forests, the inter-tidal zones, and estuaries, that are a source of livelihood for local communities and recreation for tourists. In its normal form, fresh water differs substantially in terms of its accessibility in time and space (MA, 2005). Freshwater ecosystem services provide plants for food and medicines. They provide regulatory service for the maintenance of water quality as a medium for natural system for filtration in wetlands. Other regulatory services include water treatment, shielding flood flows, controlling erosion rates in river channels and flood control. Cultural and supporting benefits derived from freshwater ecosystems are for recreation, tourism as well as for existence value for personal satisfaction. As a supporting service, they play a part in nutrient cycling, principal production and for ecosystem resilience.

Despite their importance, available freshwater ecosystems are unequally distributed world-over limiting provision of freshwater ecosystem services. (Mayers *et al.,* 2009) re-emphasizes that Fresh water from freshwater ecosystems is essential to life contributing to all the main benefits provided to humans. While the Mt.Elgon watersheds are a major source for freshwater ecosystem services for surrounding regions, its sustainability is greatly threatened. Stress to the hydrological cycle will affect streamflow volume and timing, ecosystem dynamic forces as well as social and economic structures (Musau *et al.,* 2015). The magnitude of the impacts to local communities exposure and ecosystems to these stresses to a greater extend depend on the specific features of the area, as well as the extent and spatial distribution of the changes that will be experienced (Hagg *et al.*, 2007; Matondo *et al.*, 2004). With global temperature changes, likely to exceed 1.5°C of warming by the year 2100 (UNFCCC, 2015), acclimatizing to climate change is possibly the most profound challenge that humanity is currently faced with and the Mt.Elgon Water Tower watershed is no exception to this.

The increased concentrations of GHGs in the atmosphere and variations in the albedo of the earth's surface due to land-use change have resulted in enhanced global average surface temperatures leading to global warming. This will lead to increased rates of evapotranspiration and uncertain and varying precipitation levels. According to van Vliet *et al.,* (2011), river discharge also impacts the reaction of river temperatures. They discuss that air temperature increases of 2^0C, 4^0C and 6^0C are projected to lead to upsurges of annual mean river temperatures of 1.3^0C, 2.6^0C and 3.8^0C correspondingly. Global average temperatures will largely determine the water resources base including freshwater ecosystem quantities, quality and affect the hydrological cycle, including runoff. This will negatively affect the sustainability of freshwater ecosystem services in the region and beyond Viviroli *et al.*, 2007). Scarcity of surface water will intensify dependency on groundwater aquifers.

Increased withdrawals of water for agriculture production may lead desertification, land deprivation and reduced soil fertility (Nair, 2016). This will result in opening up of new land in catchment areas leading to more deforestation, putting more pressure on resources. Nair, (2016) discusses the need for sustainable use of water to realize its maximum socio-economic benefits. The increasing human population and socioeconomic progression has led to a rapid rate of water resources infrastructural developments replacing and altering natural systems with modified human-engineered systems. To determine the purpose of ecosystem benefits requires the participation of the communities that benefit from these resources dependent on available data determined by the water quality and quantity to meet their need. This can only be achieved by pooling knowledge and expertise in the various necessary field and involving all stakeholders. This raises the need to cost the opportunity cost of sustaining freshwater ecosystem and their associated ecosystems by conservation, to derive maximum realised services in the Mt. Elgon watershed.

This will inform decision making to enhance sustainability most especially to adapt to climate change. According to Mancosu, (2015), agriculture as an economic sector leads in the use of fresh water resources taking up-to 70% of total water use. In order to formulate meaningful water assessment policies, it is important to understand water scarcity world over (Liu *et al*., 2017). According to Kummu *et al.*, (2016), areas faced with both water shortage and stress cannot easily cope compared to areas under only stress or only shortage challenges. Human activites impacting mountain freshwater ecosystem services in Mt. Elgon watershed are summarized in Table 2.1.

Table 2.1: Impacts of human activity on freshwater ecosystems services in the Mt. Elgon watersheds.

Human Activity	Impact on Freshwater ecosystem services
Dam construction	Alters the timing and quality of river flows. It affects water temperatures, nutrient flow and interfering in sediment transport causing flooding. Delta replenishment blocks fish migrations affecting reproduction. Construction of water reservoirs for rice irrigation causes flooding and streamflow hydrology
Stream diversion	Reduces water levels in stream affecting quantity during drought depriving downstream populations of quantity and quality services
Human footprint	Contamination by defecation of human and non-human individuals polluting streams. The release of polluted water from fishponds affecting water quality
Rice cultivation	Increases the release of GHGs-Methane in the atmosphere from peat, and depletions the ability of filtration and nutrient cycling of freshwater ecosystem services. Upland rice cultivation requires irrigation for quality production
Draining and reclamation of wetlands	Destroys the ability of flood control, regulation and supporting services for organisms reproduction
Deforestation, land use and cover change	Ability to enhance precipitation and climatic factors that enhance its formation. Poor agricultural practices lead to land degradation resulting in soil erosion, polluting water bodies with silt. Alters channel morphology and runoff patterns, inhibiting groundwater recharge. Increased carbon emissions and carbon dioxide in the atmosphere, and reduced sequestration.
Sand mining/ Exposed river banks due to livelihood activities	Depletes river of the ability to retain water and moisture for drought periods and organisms reproduction. Increased evapotranspiration depletes water levels and the ability of the streamflow to support agricultural livelihoods

According to MWE, (2013), most river catchments are used for agricultural production particularly during the dry season. Increased demand for food production for a growing population has resulted in even more pressure on the services provided by Mt. Elgon watersheds. Rivers like River Sironko and River Namatale which form part of the spatial pattern of the watersheds have been particularly affected leading to soil erosion, siltation and flooding. Confirming the fact that human well-being has come at the expense of ecosystem degradation (MA, 2005). While Ecosystem services involving freshwater studies have received some attention not much has been done regarding measuring the opportunity cost for conservation of these services in Mt. Elgon watersheds. However, awareness in quantifying ecosystem services as well as the benefits derived from nature has increased.

2.5 Impacts of Climate Change: The Opportunity Cost for Conservation of Sustainable Freshwater Ecosystem Services

Climate change is expected to bring about diverse impacts on the hydrological cycle as a result of anticipated spatial and temporal variations in changing temperature and rainfall patterns (Musau *et al.*, 2015). Climatic extremes are shifting and dependable information is required by decision makers for strategic planning to cope with these changes. According to Fischer, (2013, 2014), most Climate Models project increased temperatures and short erratic precipitation episodes. Common occurrences of conflict due to the land use patterns in Mt. Elgon region is evident between ecosystem protection measures enforced by the government and the subsistence farmers. The hydrological cycle significantly impacted by climate change and destructive human actions (Xu *et al.*, 2013) rise reason enough for study. It is of great significance to investigate the impact of climate change on freshwater ecosystem services so as to appreciate potential future changes of water resources and extremes, providing relevant water management solutions.

Sustainable economic development is key to every economy. The effects of climate change are undeniably threatening development and economic stability (Hussein M.A., 2011). Hydropower contributes about 16% of total power supply world-wide. It also provides 86% source of renewable power energy (Hamududu and Killingtveit, 2012). It is projected that future impacts of climate change are likely to rise temperatures with more unpredictable precipitation occurrences causing significant variations in runoff. Runoff is key for hydropower generation

Hamududu and Killingtveit, (2012) affecting economic development (Hussein M.A., 2011). It should be noted that to meet the targets of a stable global climate by promoting renewable energy development, stretches freshwater ecosystems and species undermining achievements.

East Africa mainly relies on rain-fed agriculture. This makes livelihoods in rural areas as well as food security extremely susceptible to climate variability. For example shifts in the growing seasons circumstances (IPCC, 2001). In the WWF, (2006) report, it is argued that in East Africa, extreme rainfall resulting in damages caused by severe flooding will greatly impact agriculture. Erratic rainfall will cause loss of topsoil to erosion, causing flooding of places that were previously arid soils, as well as causing leaching of nutrients in soil resulting to land degradation and hence poor production. This clearly indicates that this impact on livelihoods of poor communities in Mt.Elgon watersheds and the far reaches of the lowlands that benefit from this ecosystem will further stress mountain freshwater ecosystem services provision. Poff *et al*., (2003), discussed that raising conflict is leading to armed conflict traversing political boundaries due to impacted livelihoods. With increasing climate change impacts, this is bound to increase.

According to Zhou *et al.,* (2004), scientific findings show that, there is a relationship between precipitation and remarkable extreme high temperatures and malaria incidence. Their argument is that, between 1920 and 1950 there was high incidence of malaria outbreak in the highlands of Eastern Africa, fatal outbreaks becoming more frequent with an increasing geographical coverage. It is also noted that seasons are longer, with increasing temperatures in formerly cooler high altitudes in East Africa, a condition ideal for the malaria-mosquito breeding. WWF, (2006), cites that climate change impacts have the ability to retard and slow down development in agriculture and tourism affecting human livelihoods. In the Mt.Elgon case, this has prompted migration further into the highlands for cooler temperature which is encroaching further on the watershed.

The impacts of Climate change are threatening some of the largest conservation reservoirs protecting some of Africa’s splendid migrant biodiversity species. It is predicted, that plant life will migrate so as to exploit suitable freshwater ecosystem services like water and nutrients necessary for their survival and sustainability. This means that in many geographical locations the ideal habitat for biodiversity survival there will be a shift well beyond protected zones (WWF, 2006), threatening biodiversity sustainability. This is likely to fuel conflict between communities and forest rangers which are already strained due to encroachment in the Mt.Elgon Region water tower watershed. Pressure on the ecosystem will impact its ability to provide sufficient services, equally affecting the rivers depending on these watersheds. Competition for freshwater ecosystem services for livestock, irrigation, domestic use and other livelihood activities within wetlands is a major cause of conflict among livestock farmers and agricultural farmers during dry spells (MWE, 2013). This is bound to worsen as the resource diminish.

2.6 Adaptation Strategies for Sustainable Freshwater Ecosystem Services

This study sort to evaluate the opportunity cost of conserving freshwater ecosystems, with their associated ecosystems for freshwater ecosystem services sustainability in Mt. Elgon Water Tower watershed under changing climate. Traditionally several adaptation strategies has been used overtime, however with the growing needs for the available limited resources these have been ignored overtime. With the evident signs of climate change, efforts by several stakeholders are being made with competing human needs. Hjerpe and Nasiritousi, (2015), points out that some conservation strategies may be preferred to others due to the opportunity cost related to the conservation strategy taken for sustainability.

Recent research study show Africa is predominantly susceptible to multiple stresses and has a very low capacity to adapt to these stresses (IIED, 2009). However, it is pointed out that there are possible alternatives to adjust to modifications in water ecosystem services shaped by climate change as technological measures. For example structural defenses against flooding, behavioral revision such as improved food choices, management adaptation such as reformed farming practices and through policy such as planning regulations. According to IPCC, (2008), current water-use controls may possibly not be vigorous enough to deal with climate change impacts on water resource service provision reliability. These are risks associted with flood occurence, wellbeing, agriculture, energy and water resource ecosystems. It is noted that in serveral places water-use controls practices cannot adequately handle the contemporary climate variability. As a result great damage is experienced during the occurrence of floods or drought spells. Increasing population rates and damage prospects, would intensify impacts in the future.

Revenga *et al.,* (2005), argue that as countries endeavor to meet global targets so as to achieve a stable climate through renewable energy development makes hydropower a leading potential energy source. This, places additional pressure on freshwater ecosystems and species. They point out that given the pressures, assessing the condition and rates of change of freshwater species and habitants is of critical importance for preserving the integrity of these ecosystems and the goods and services we derive from them.

Climate change is very evident, and decision makers express a strong need for reliable information on further changes over the coming decades as a basis for adaptation strategies (Fischer *et al.,* 2013). According to literature, there is yet to be internationally set instruments for attainment, storage and salvaging, as well as sharing of cohesive climate change risk data, information, knowledge and experiences. Where it has been achieved, it is not comprehensive and the quality of the data is inadequate. Accessing data under government institutions many times is inhibited by bureaucratic tendencies. Combining shared information is sometimes hindered by the data sets being in multiple formats and incompatible form.

Research also shows that various factors influence the way in which knowledge is perceived. This includes political association, educational achievement as well as the level of confidence associated to the source of information (McCright and Dunlap, 2011). Viable water resources management hinges on dependable hydrological forecasts which are compared with actual occurrences to identify patterns. The Primary steps of acquiring hydrological data is by collecting and accessing it to ensure its quality and consistence so that any future plans decisions are based on researched facts (Rwigi *et al.,* 2012) while considering projected information.

Many hydrological problems can be better understood and managed using hydrological modeling. Many hydrological problems are particularly stark in countries with low income where factors like recent population rates, agriculture and infrastructural growth have incapacitated their ability to manage their effect on water resources. Some of these are proactive land-use, water infrastructural planning, reconsidering management of hydrological impacts of inadvertent land-use change and climate change (Mulligan and Soesbergen, 2016).

2.7 Conceptual framework of the Study

The conceptual framework illustrates the inputs, processes and outputs of this study, highlighting the variables and the methodology. Mt.Elgon region Water Tower watershed freshwater ecosystem services, and how they are impacted by livelihoods activities and climate was the main focus of study, sampling major rivers as demonstrated in Figure 2.1

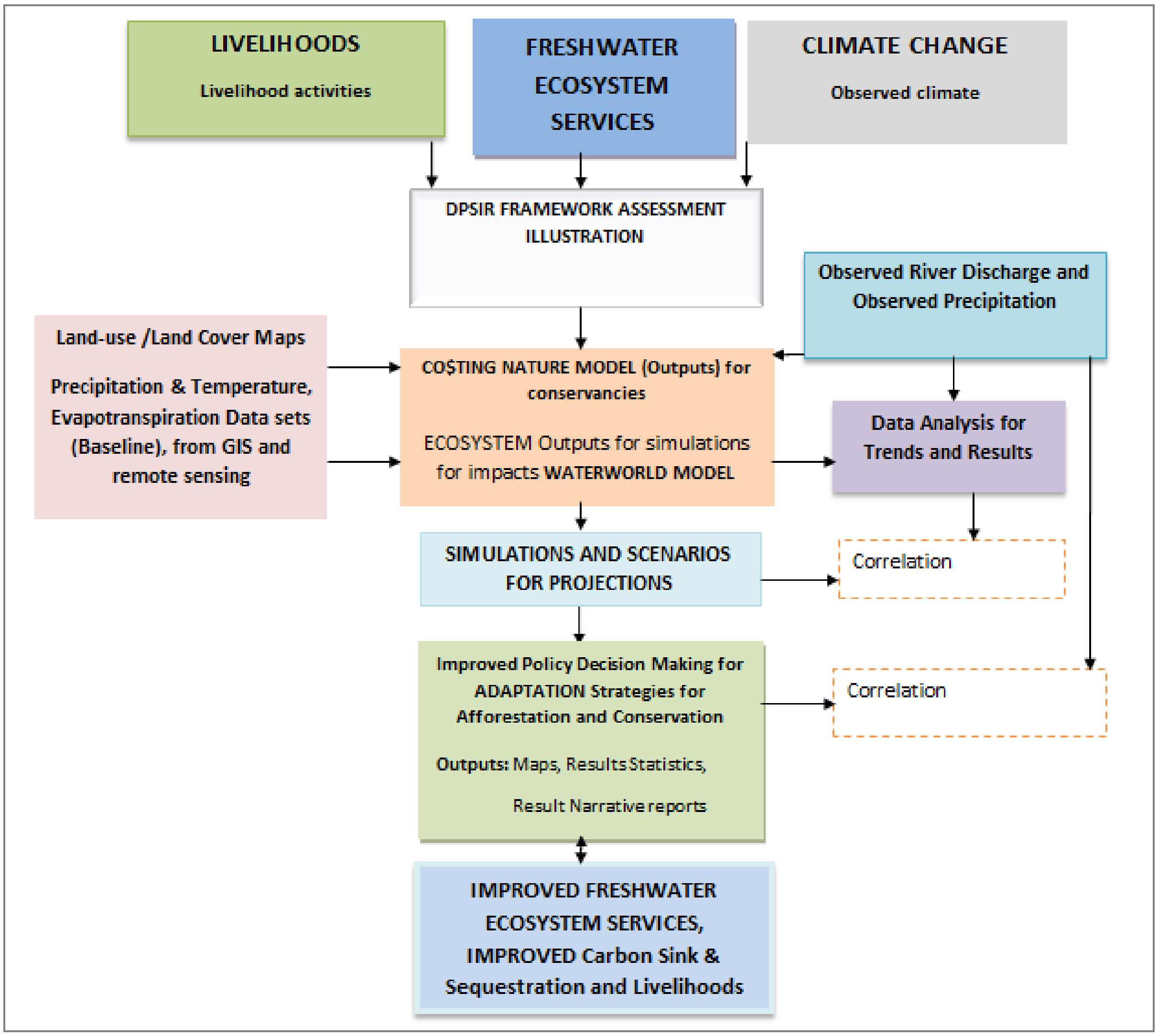

Figure 2.1: Conceptual Framework of the Study

CHAPTER 3

DATA AND METHODOLOGY

3.1 Introduction

This chapter presents the research design, a systematic layout of data, data processing and quality control, mixed research methodology and data analysis that were applied in this study in order to achieve the specific objectives.

3.2 Research Design

This research used both quantitative and qualitative data collecting tools. A plan in form of a theoretical framework was formulated to guide the study and a conceptual framework structure designed to illustrate the major stages and processes of the study. A strategy was set by identifying and obtaining suitable data for precipitation and discharge data ensuring quality processing, control and analysis. By carrying out an intensive systematic literature review, a mixed research methodology was identified as the most suitable for carrying out the investigation of the study. The study design was based on the nature of the investigation assuming a 'cause-and effect' relationship. This was by defining, plotting a map and selecting major rivers in the Mt.Elgon watersheds. These were mapped using QGIS and ArcGIS mapping software. Precipitation and discharge data was obtained. The study identified livelihoods as the independent variable, freshwater ecosystem services as the extraneous variable and climate change as the dependent variable. These were classified based on the view point of causation.

3.3 Types and Sources of Data

This research relied on data collected from primary and secondary sources. Data is either quantitative or qualitative. Quantitative data is numerical while qualitative data is descriptive. Qualitative data may be more than just words or text but may be composed of photographs, videos and sound recordings. It should be noted the basis of all quantitative data is qualitative findings. While all qualitative data is descriptive and can be presented in numerical form (Trochim. W, 2006)

3.3.1 Primary Data and sources

Primary data is first-hand experience evidence collected by an investigator based on a specific research purpose from an original source. This is categorized as either primary quantitative data collected using structured interviews and questionnaires or as primary qualitative data collected by a participants observation and unstructured interviews. Interviewing and observation are qualitative methods of collecting data to enable the researcher have a deeper and wider understanding of the findings based on documented interpretation (Creswell J.W., 2007). For this study, data was obtained through observation, photography and unstructured interviews.

3.3.1.1 Unstructured Interviews

Patton, (2002) defined unstructured interviews as a form of observation that lengthens as a result of prompting questions that arise as one interacts with the participant. This is with the intention of obtaining information without the knowledge of the interviewee. Punch, (1998), argued that they are a way of understanding the behavior of people by not judging who they are as this hinders the amount of information one obtains in a formal interview. An Unstructured interview is an casual, conversational interaction using a set of questions that arise as one interacts further with the interviewee that are not preplanned (Gray D.E., 2009). Minichiello and Minichiello *et al.* (1990, 2008, 2014), defined unstructured interviews as questions and nor answers that are not prearranged in an interview. Instead, they depend on the social interaction of the investigator and the investigated (Zhang and Wildemuth, 2016).

To achieve the most out of this research method, a bit of techniques of each type of unstructured interviews was used based on the level of interaction of interviewee and their willingness to respond. Note should be made that the interviews were focused on the themes identified in the literature review. It is conventional that interviews be guided by some form of laid down questions (Zhang and Wildemuth, 2016). Unstructured interviews were carried out with interview key informant persons and people involved in livelihood activites that impact freshwater ecosystems. Sketch notes were taken with a purpose to develop a DPSIR framework with a narrative with the identified themes in the theoretical framework as a guide. Wayne Fife, (2005) points out that the researcher keeps in mind the themes and deliberately charters the discussion with the purpose and scope of study in mind.

3.3.1.2 Still Photography by Observation

By observation, suitable sites were identified and data collected by taking still photographs, depicting interactions between ecosystems and human activities. These comprised of locations severely affected by degradation, specifically locations of interaction with the freshwater ecosystems while taking note of existing freshwater ecosystem services and adaptation strategies. These are supported by empirical data and processes summarised in Table 2.1 in subsection 2.4. Observational methods are additional means for validating research findings (Jamshed, 2014). Gray D.E., (2009) submits that, observational data is confirmatory research.

3.3.2 Secondary Data and Sources

Secondary data are documented facts that were collected and recorded by others other than the person that uses this information. It is already collected data readily available from other sources. Secondary data too is categorized as secondary quantitative data collected from official statistics and secondary qualitative data collected from published letters, journals, and articles. Data was obtained from both quantitative and qualitative secondary data sources for this study.

The researcher obtained Official statistical data for Climate observational data for precipitation from the Meteorological Departments of both Uganda and Kenya, for the synoptic stations in the Mt. Elgon watersheds. Stream flow values for the sampled rivers of the area of study were collected from Water Resources Management of the Government of Kenya and the Ministry of Water and Environment of Uganda for the period 1948 to 2016.

Literature review is a major source for empirical data. Kumar, (2005), states that, literature review is an integrals part of the entire research process and makes a valuable contribution to almost every operational step. He points out that, it serves to enhance and consolidate the researcher's knowledge base and integrate findings with existing knowledge. Secondary data was mainly acquired from literature review and baseline maps from Landsat and MODIS. Land-use/Land cover, precipitation, temperature, evapotranspiration baseline datasets and Geospatial output from remote sensing, were provided by ecoengine model for Co$ting Nature and WaterWorld, policy support tools. The models provide high spatial resolution of 1km or 1-hectare resolution depending on the modelling need, global in extent, suited to varied environments with limited data (Mulligan, 2018), Due to factors like poverty, climatic water scarcity, increased population demands, inadequate land and water resources. Modelling enable the knowledge on how the benefits from these resources are shared revealing poor water management practices as these tend to be environments with very little relevant data (Mulligan et al., 2011c). These were used for modelling and simulation. Selection for scenario was done referring to IPCC, (2014) Data Distribution Center (DDC) website as instructed in model. For this study the Climate Change: assess impacts of climate change scenario was selected. According to IPCC, the aim of using scenarios is to enhance the understanding of uncertainties' and alternative futures. The cmip5rcp45worldclimhe20412060 option was selected for simulation with baseline database and default parameters settings.

3.4 Data Processing and Quality Control

Procedures and tasks were developed on how to collect data, sort, aggregate and summarise data obtained from data collection agencies. Quality was emphasized, ensuring validity, objectivity and accuracy. Data was subjected to statistical analysis to ensure it was clean and useful. Data analysis was carried out for collected data for all sampled data sets for both runoff and precipitation as well as graphical data analysis. According to Helsel and Hirsch (2002), graphs offer visual synopses of data that easily and satisfactorily provide essential information more than tables of numbers. Graphs give perception of the data investigated illustrating important concepts during presentation of results. The hydro meteorological data was processed to determine trends.

Data was obtained from primary and secondary sources using research tools. Among these where observation forms, unstructured interview schedules, and a camera for still photography. The information obtained was analysed for relevancy to the study. DPSIR framework was developed and an analysis of the relationships and impacts was carried out.

3.4.1 Hydro-Meteorological Data Processing and Quality Control

Secondary data was collected from published journals and publications. Hydro-meteorological data for precipitation and river discharge collected daily by the data collection agencies computed on a daily time scale, was processed to obtain monthly, annual and long-term mean values. Observational time series data for precipitation and river discharge values was obtained from meteorological and government water resources agencies in electronic form. The observational time series data was then sorted for meaningful description and ascertained for quality before analysis scrutinizing data sets to establish completeness and consistency.

3.4.2 Filling in of Missing Data, Ensuring Integrity of and Homogeneity Test

Availability and adequacy of data was a major limitation in the study. For data quality control checks, estimation of missing data and homogeneity tests was carried out. This was done for both data for runoff and precipitation. In cases where missing data gaps were at a high level, the data for that period were deliberately omitted.

3.4.2.1 Filling of Gaps using the K-Nearest Neighbor Method (K-NNI)

The filling of gaps for missing data was carried out using the K-Nearest Neighbour Imputation identified as the most suitable method to ensure continuity. The K-nearest neighbor method, is where the mean of the previous observation and later after the missing gap for single observation gaps in the daily data was used. The nearest neighbor method is reliable and practical to treat missing hydrological data through the application of KNN imputation by Lee and Kang (2015) in (equation 1). The average of k is calculated using the weighted mean estimation in (equation 2).

$$d(x_a, x_b) = \sqrt{\sum_{j=i}^{m} \left(x_{aj} - x_{bj}\right)^2} \quad \text{.........} \quad 1$$

In the equation $d(x_a, x_b)$ denotes the distance between the target observation, x_a and observation x_b , x_{aj} is thevalue of the variable -j on the target observation x_a .*J= 1,2,3,…m* and x_{bj} *is* value of the variable -j on the other observation x_b. *J= 1,2,3,….m*

$$\hat{}x_j = \frac{1}{W} \sum_{k=1}^{K} w_k v_{kj} \quad \text{.........} 2$$

where jv_{kj} are the values of the variable-*j* at observation *k*, *k=1, 2, ..., K; W=* $\sum_{k=i}^{n} w_{k,}$, w_k are the nearest observation weights of k, which is formulated as follows: 2 $w_k = \frac{1}{d(x, v_k)^2}$

3.4.2.2 Testing for Homogeneity in Data Sets using the Pettit's Test

The Pettit's test in (equation 3), was used to test for homogeneity. Data homogeneity is a statistical requirement for research results to be regarded as acceptable (Rwigi *et al.*, 2012). According to Pohlert, (2018), the methodology after Pettitt, (1979) is usually applied to detect a single change-point in observed time series with continuous data for hydrology and climate. The Pettitt test is a non-parametric test illustrated in (equation 4) and (equation 5), that easily detects inhomogeneous structures within time series (Costa and Soares, 2009). The change point if significant located as in (equation 6). It tests the Ho: The T variables follow one or more distributions that have the same location parameter (no change), against the alternative: a change point exists.;

$$K_T = \max\left|U_{t,T}\right| \quad \ldots\ldots 3$$

Where

$$U_{t,T} = \sum_{i=1}^{t}\sum_{j=t+1}^{T} \operatorname{sgn}\left(x_i - x_j\right), 1 \le t \lhd T \quad \ldots\ldots 4$$

Where

$$sign\left(x_t - x_j\right) = \begin{cases} +1 & if \quad \left(x_t - x_j\right) > 0 \\ 0 & if \quad \left(x_t - x_j\right) = 0 \\ -1 & if \quad \left(x_t - x_j\right) < 0 \end{cases} \quad \ldots\ldots 5$$

The change-point of the series is located at K_T, provided that the statistic is significant. The significance probability of K_T is approximated for $p \le 0.05$ with (equation 6)

$$p \cong 2\exp\left(\frac{-6K_T^2}{T^3 + T^2}\right) \quad \ldots\ldots 6$$

For every data set for both runoff and precipitation a test statistic and confidence level (*p)* for the sample length (*n*) was computed.

3.4.3 Modelling of Spatial Data

The Co$ting Nature and Waterworld web-based policy support tools were run on the eco-engine model, that provide all the data essential for application. Within each tool the area modelled was defined based on coordinates as in area of study. The study used a spatial resolution of 1-hectare at a local scale so as to better understand the localized impacts of socio-economic dimensions on the entire ecosystem and specifically on the freshwater ecosystems in the watersheds. The area was modelled as Lower and Upper Elgon in order to confine the study within the area of study.

Modelling was carried out using spatial data in form of baseline maps. These were obtained by providing coordinates of the area of study and carrying out simulations for baseline run. Key maps generated included forest cover, vegetation, land use, water resources, human foot print on water quality, hillslope erosion, biodiversity and conservation priority. These were remote sensing GIS maps obtained from Landsat and MODIS satellite websites through the models. The baseline maps were analysed for interpretation of historical information. A re-run of the tools was done for the actual scenarios. Meteorological and climatological data in form of geo-spatial data maps was provided. The procedure to prepare data and run simulations for baseline and projections was the same in both tools. However in WaterWorld it differed when selecting policy choices.

Using the WaterWorld tool hydrological baseline representative of mean water balance for the period 1950-2000 was modelled. The model enabled the application of ensemble scenarios for a selected period for climate change of 2041 to 2060 examining the impact of land use and climate change on the watershed as the selected policy choices. These can be land cover change for the area of study or interventions to improve land management practices (Mulligan, 2018), making these the most suitable tools for this study. However, options are provided for the user to use their own data. The study opted for the provided data for ease and validity as availability and adequacy of data was a main limitation. These included climate data, realised, potential and at risk ecosystem services for land-use or land-cover maps, provided as baseline data. This was prepared and validated before running the models giving result maps and narrative reports of conclusion for climate impact projections.

3.4.4 Data Sampling

This study used both satellite data and observational data for Precipitation, Temperature and Stream flow for some of the major rivers in the watersheds of the area of study. 13 rivers were selected out of the rivers mapped in the study area representative of the entire watersheds. River discharge gauging stations where selected as well as 4 rain guaging monitoring station. Streamflow was a major component in the sampling exercise, however due to limited availability of discharge data, rivers with only data sets with record of over 15 years were selected. Based on the importance, relevancy and availability of data for discharge and precipitation for rivers and rain monitoring station within the study area, 13 rivers and 4 rainfall monitoring stations were selected out of 20 major rivers and 8 rain monitoring stations within the watersheds. The focus of sample selection was regional representation for Upper and Lower Elgon as well as Kenya and Uganda. Availability of data within study period and location of gauging station was a main determinate for selection.

Cluster (area) random sampling and multi-stage sampling was used for selecting sample for the study. This was done by identifying and using Normalized Differentiation Vegetation Index (NDVI) for mapping vegetation out of the sampled clusters, representative of the both Uganda and Kenya. Geographical Information Systems (GIS) and remote sensing software was used to map rivers flowing from the Mt.Elgon watersheds. This was carried out using the WaterWorld and Co$ting Nature ecoengine model to map vegetation. ArcGIS and QGIS software was used to map districts covered under the watersheds and the spatial patterns of rivers in the study area.

The area of study was defined using grid references. This area has not been studied using the ecoengine model before. Therefore data was generated using remote sensing at a 1hactare resolution within the tools and prepared for simulation. Using remote sensing in the system and outputs based on instructions in the model, data was prepared by selecting options of missing data to enable simulation to generate baseline maps for baseline runs. The results outputs were maps, statistical graphs and equations as well as narrative of result which were accessed based on access rights as a scientist. A test bed was first run to test the model before actual runs These were used to run simulations for future projections for the same area modelled.

3.5 Mixed Method Research Methodology

Research methodology is a comprehensive strategy "that silhouettes our choice and use of specific methods, relating them to the anticipated out comes (Crotty M., 1998)." According to (Johnson *et al.,* 2007), mixed methods research is where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, theories and or language into a single study. This study used a mixed method research approach, in order provide diverse findings to ascertain the investigated theory and support the limited research done in this particular study and region based on the data analysis carried out. The following methods were used to achieve desired results of the study;

3.5.1 Systematic Evaluation of the Literature Review Method for DPSIR Framework

An intensive systematic evaluation of literature review was carried out in methods, models, tools and databases for freshwater ecosystem research. This method was applied to research the socio-economic dimensions that impact on mountain freshwater ecosystem services sustainability under a changing climate. This was to identify drivers, pressures, state, impact and responses in the Mt. Elgon watersheds and as a comparison to actual field findings. In this study this was achieved by under-taking the following processes detailed below;

This was achieved by searching for and acquainting with existing literature on anthropogenic activities impacting mountain freshwater ecosystem services as discussed in chapter one, two and three of this report based on topics identified in the theoretical framework. This too was done for existing literature on the opportunity cost for conserving freshwater ecosystems, associated ecosystems and their sustainability. This was in similar mountainous watersheds like the Himalayas and Mozambique where similar studies have been done and how this can be replicated in the Mt. Elgon watersheds.

The search was based on the problem that was being investigated, "How can the Mt. Elgon watersheds freshwater ecosystems be conserved to ensure sustainable freshwater ecosystem services?" This was achieved by compiling a bibliography of the broader area, using books, journals and articles, as source documents. This search was achieved by using library catalogues based on *Library of Congress Subject Heading* and the use of publications such as Book Review Index. While for journals the search was based on indices of journals, abstracts of articles and citation indices. For example basing on the topic Environmental and Natural Resources under science and technology using database title ACES (Agricultural, Consumer and Environmental Sciences) an e-resource free online catalogue. The ACES research encompasses initiatives in environmental sustainability, food and agricultural systems, global climate change and more. SCOPE (Scientific Committee on Problems of the Environment) an international scientific non-governmental organisation that provides publications to identify and undertake analyses of emerging environmental issues that are caused by or impact humans and the environment.

Using the ESML (EcoService Models Library), an online database for searching for, investigating and making comparison between environmental models used for measuring ecosystem benefits. Co$ting Nature and WaterWorld tools based on the ecoengine model, were identified as the most suitable for this study as they specifically model ecosystem services, proving data for the model. The search criteria was used to find publications by a particular author or on a particular theme.

Second was the review of literature selected. This was achieved by reading the literature critically so as to pull together themes and issues that are associated slotting the findings in a rough theoretical framework in logical themes ensuring relevance to the framework developed under the themes of socioeconomic pressures, mountain freshwater ecosystem services impacted by anthropogenic activities and the adaptation strategies with a brief global perspective of each main theme narrowing to Mt. Elgon watersheds as discussed in the literature review.

Note was taken of theories put forward by different researchers, the criticisms and their basis and methodologies adopted. Significant differences among researchers was noted, giving opinion about the validity of these differences and their criticisms while identifying gaps in body of knowledge. This was done in reviewing the literature putting theories forward in order to examine the extend of generalisation to other situation. Several researchers have carried out studies on costing ecosystems based on their economic value, while this study focused on the opportunity cost for conservation to realize full benefits.

The theoretical framework formulated, enabled a focus in literature review search. It was a guide to effectively review the literature, looking at the universal perspective and then the more specific or local perspective of the Mt. Elgon watersheds. The theoretical framework consisted of the theories or issues in which this study is embedded. In this study, these theories are summarised to develop a Drivers-Pressures-State-Impact-Response (DPSIR) framework. These describe the human impact on the environment and vice versa due to the inter-dependency of the components in the ecosystems. Out of the theoretical framework, a conceptual framework was formulated that formed the basis of this study which is the basis of the research problem. The aspects of conceptual framework selected, became the basis of the inquiry.

The systematic literature review revealed that the Lake Kyoga basin located in Uganda in which the Mt. Elgon watersheds is a sub-catchment, experiences extensive land use and cover changes as a result of natural and anthropogenic processes. This emphasizes how drivers and stressors impact freshwaters ecosystems. These modifications have led to severe soil erosion, disruption of water sources drying up of rivers altering river channel morphology. This is further intensified by silting caused by extensive sand mining livelihood activities. Frequent recurrence of extreme weather events such as floods and droughts and increasing erratic rainfall causing a challenge to water resources management.

These occurrences were observed and depicted in the photographs taken during the study. The study illustrated the Natural and Socio-economic impacts on freshwater ecosystem services using the Drivers-Pressures-State-Impact-Response (DPSIR) framework in Figure 3.1 showing drivers and stressors their relationships, identifying sustainable solutions to mountain freshwater ecosystem services established by empirical evidence.

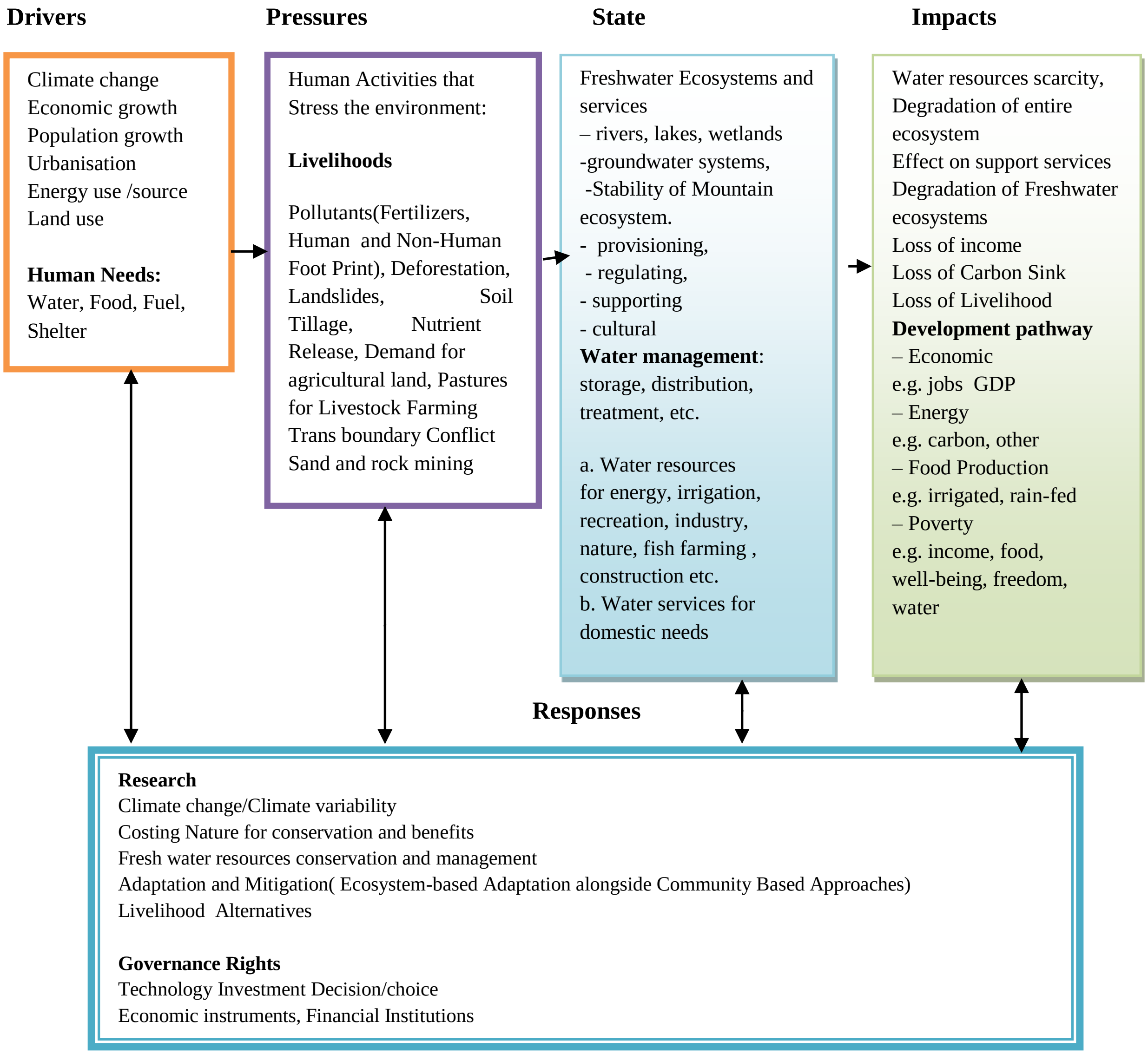

Figure 3.1: The DPSIR Framework of Drivers and Stressors on Mountain Freshwater Ecosystem Services and Resulting Impacts and Responses in the Mt.Elgon Watersheds

3.5.2 Unstructured Interviews and Observation Method

To enable an effective rapport with community on the livelihood activities carried out along the rivers and how this interaction impacted the freshwater ecosystem services,. a unstructured interview guide was developed. An illustration can be seen in appendix 1. Interviews were done through informal conversations and findings were incorporated in the DPSIR framework. The unstructured interviews were carried out with key informant persons in the communities of the locations visited. These included the different persons found carrying out livelihood activities, local council chairpersons and in some instances local elders and officials of the locations like Sironko, Buwagogo, Buginyanya, Bunagawoya, Bukwo, Manafwa, Nzoia, Kakamega forest reserve and several locations along the some of the river channels. Most of the questions asked focused on the benefits derived by the communities. These were benefits from freshwater ecosystem services, the livelihood activities carried out alongside rivers in the riparian zone and land use activities adjacent to these zones. Interviewees were asked challenges experienced by the communities and adaptation strategies in place to ensure sustainability of the freshwater ecosystem services.

The use of evaluation of literature review method, enabled the identification of suitable sites for observations. Observation forms were designed as a tool to focus the study during visits of study area, see appendix 2. They were used as a guide to observe and identify occurrence of events based on topics in the theoretical framework. Still Photographs of sampled sites were taken using a camera and interpreted based on empirical evidence. Through observation, various processes were taken into account. These were mainly, freshwater ecosystem services, socio economic pressures in terms of livelihood activities, mountain freshwater ecosystem services impacted by anthropogenic activities and the adaptation strategies in place in the study area. Sampled sites were the different livelihood activities and how they impact freshwater ecosystem services.

Findings from using unstructured interview schedules, the observation forms, still photographs, DPSIR framework and information from intensive systematic evaluation of literature review, as well as analysis of key output maps from modeling and simulation from both Co$ting Nature and Water World models enriched the DPSIR framework.

3.5.3 Mapping Runoff Temporal Patterns and Monitoring Stations with QGIS and ArcGIS

Using mapping as a method, GIS software tools for QGIS 2.6 and ArcGIS were used. To illustrate the geographical extent and influence of the Mt.Elgon watersheds, mapping with QGIS the location of study area and spatial patterns of river runoff was carried out. This was done by uploading vector shape files for administrative outside boundaries for Kenya and Uganda, aggregating districts and counties in the area of study, overlaid with majors river and water bodies for both Kenya and Uganda in area of study and beyond, and labeled.

Sampling of rivers was carried out of 25 major rivers in the watershed. Out of these 13 were selected based on availability and relevance of data. On this basis water monitoring stations sampled and selected. The Sampling was based on regional representation and availability of data based on the period of study and sample period. Sampled water monitoring stations were identified and mapped using ArcGIS software following the same procedure, as above. The location of sampled water resource monitoring stations in the Elgon Sub Catchment that are within the Elgon watersheds was indicated based on data collected.

Mapping was based on shape files for QGIS and ArcGIS ArcMap layer maps for Kenya and Uganda. The shape files used included: Kenya major rivers, Uganda rivers, Uganda water bodies, Uganda-Lakes-rivers (2005), Kenya water bodies, Kenya Water Resource Management Agency (WRMA) catchments, Uganda Regions-2014 and Kenya-Outside boundary shape-files. The data for shape-files for the location of monitoring stations was sourced from WRMA.

3.5.4 Trend Analysis with the rank-based Mann-Kendall Method (MK)

Most rivers fluctuate in terms of state and quantity most especially if there are significant changes in the watershed. Trends in hydrologic data could be due to long term climatic changes or in the case of stream-flow due to changes in a catchment's response to effective rainfall owing to land-use changes that lead to the deforestation of watershed (Rwigi et. al.,2014). The Mann-Kendall method (Mann,1945: Kendall 1975) trend test is commonly used to assess the significance of trends. It is used to analyze data collected overtime for consistently increasing or decreasing in Y values. This is mainly a nonparametric form of monotonic trend regression analysis in hydro meteorological time series such as water quality, streamflow, temperature and precipitation (Yue *et al.,* 2002). It has for example been used in the works of (Helsel and Hirsch, 1992: Burn and Elnur 2002; Tue *et al,*2003). The Mann-Kendall test examines the indication of the variance between data measured after and data measured before the variance. Each value measured before the variance is equated to all tenets measured before subsequently a total of n(n-1)/2 possible sets of two of data, where n is the overall sum of observations (Meals *et al.,* 2011). The Mann-Kendal test supposes that a value can each time be confirmed less than, greater than, or equal to another value; that data are autonomous; and that the dissemination of data stay constant in both the original units and converted units (Helsel and Hirsch,1992). In this case this was an investigation for monotonic trend in a time series founded on Kendall rank correlation of z and t. The equation (7) below depict the formula for Mann-Kendal trend test.

$$S = \sum_{i=1}^{n-1} \sum_{j=t+1}^{n} sign\left(y_i - y_j\right) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

Where *n* denotes the number of data points while y_j and y_i are the data values in the time series *i* and *j* where (*j*>*i)* respectively and $sign(y_j - y_i)$ with the sign function as in equation (8) as To execute the Mann-Kendall test, the variance between the value measured after and the all values measured before were calculated. Represented by $(y_j - y_i)$ and where $j>i$ assigning the integer value of 1, 0 or -1 to positive variances and negative variances computing the investigated statistic *S* as the total of the integers as follows:

$$sign\left(y_j - y_i\right) = \begin{cases} +1 & if \quad \left(y_j - y_i\right) > 0 \\ 0 & if \quad \left(y_j - y\ \right) = 0 \\ -1 & if \quad \left(y_j - y_i\right) < 0 \end{cases} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 8$$

Once variance (*S)* is a greater positive number, values measured after have a tendency to be greater than values before and an ascending trend is shown. While once (S) is a greater negative number, values after have a tendency to be lesser than values before and a descending trend is shown. Once the total value of (*S)* is trivial, no trend is shown. The variance in trend was computed using the following equation (9) below;

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{p} t_i\left(t_i - 1\right)\left(2t_i + 5\right)}{18} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 9$$

In the equation (*S)* denotes the variance, *n* denotes the number of data points, p is the number of tied groups,(∑)denotes the summation of all tied groups which are the sample of data with equal value and t_i denotes the number of data values in the p^{th} group.

Using the Mann-Kendal trend test, a statistical trend analysis was done to test the hypothesis. The null hypothesis Ho is that there is no trend: each test has its own parameters for accepting or rejecting Ho. This was carried out for all sampled datasets for both stream flow and precipitation. Where there was failure to reject Ho did not imply that there is not a trend, but indicated that the evidence is not sufficient to conclude with a specified level of confidence that a trend exists. Deducing the reason of a trend was based on the hydrological progressions of stream flow, land use management and anthropological activities in the watershed.

In the study of investigating the impacts of anthropogenic drivers in the watershed on the freshwater ecosystem services, streamflow trends was tested. Climatic change intervals of 30 to 60 years of collected data of between 32 to 62 years were analyzed so as to determine the impact of climate change on precipitation and discharge levels in both one climate change period to two periods. However were limited data was collected of period within range it was utilized. Runoff was grouped into 62, 44 and 32 years categorized periods; A (1955-2016), B (1963-2006) and C (1963-1993) respectively. Taking into account the socio-economic activities present in the watersheds overtime. The main focus was livelihood activities along the riparian zones as well as basin of the sampled rivers. However this depended on availability of data sets for individual samples selected and the significance of change in trend and stream flow patterns in relation to precipitation recorded. To enable quick observation of trend, the time series in this study were divided into shorter periods, observing graphical representation and observing data patterns for entire sample size.

To test for the presence of trend, a test statistic was applied. This was computed as in Equation 10 below:

$$\tau = \frac{S}{n(n-1)/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 10$$

The range for the test is -1 to +1. The null hypothesis of no trend was rejected when S was τ which was significantly different from zero. The Sen slope estimator was used to define the level of trend. Helsel and Hirsch, (1992) mention that when a substantial trend is established, the level of change can be computed by means of the Sen slope estimator as in (equation 11).

$$\beta_1 = \text{median}\left(\frac{y_j - y_i}{x_j - x_i}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.11$$

For all i < j and i = 1, 2…..n-1 and j = 2,3……n: in order words, computing the slope for all pairs of data that were used to compute S. The median of those slopes is the Sen slope estimator. Due to magnitude of statistical computation required, sampled river discharge was analysed to determine trends of stream flows in relation to precipitation for the period 1948 to 2016, using statistical software Excel XLSTAT and the Waterworld policy support tool for entire watershed.

According to Amelie *et al.,* (2010), this method provides a quick visual observation of the presence of trend in a given time series. Streamflow runoff for 8 major rivers at 9 monitoring stations in the Mt.Elgon Watersheds were investigated for trend. These are river, Manafwa, Namatala, Mpologoma, Sironko, and Simu for the Elgon region in Uganda, while river Nzoia, Rongai, and Suam for Kenya. Nzoia River is a major river in the Mt. Elgon watersheds that contributes significantly to the Nile river system through Lake Victoria. It is comprised of several tributaries and river gauging stations. Nzoia gauging station 1BB01 is located 0.92^0N, 35.13^0E on a tributary at the headwaters of Nzioa river. While Nzoia gauging station 1EE01 is located 0.18^0 N, 34.22^0 E on the main Nzoia river, lower Nzoia sub-basin towards Lake Victoria.

3.5.5 Co$tingnature v.3 [.2] and Waterworld v.2[.92] Model Simulations

Modelling is hypothesizing a theory at an abstraction level. This involves application of the mathematical computations in the physical model based on equations. Modelling enables quantitative expression of current state of a system based facts or data by exhibiting what is known and at times what is unknown. Simulation is the execution or operation of a model over a period of time with a focus for implementation for testing a theory. Modelling and simulation was carried out using ecoengine for waterworld v.2 [.92] and ecoengine for: costingnature v.3 [.2] models. Co$ting Nature is a web based tool for natural capital accounting and analysing the ecosystem services provided by natural environments (i.e nature’s benefits), identifying the beneficiaries of these services and assessing the impacts of human interventions (Mulligan and Soesbergen, 2016).

Mulligan points out that this policy support system is a test-bed for the development and implementation of conservation strategies focused on sustaining and improving ecosystem services. The system incorporates detailed spatial datasets at a 1-square km and 1hectare resolution for the entire world, spatial models for biophysical and socio-economic processes along with scenario for climate and land use. It also points out that the tool calculates a baseline for current ecosystem service provision and allows a series of interventions in form of policy options in this case Paying for Global Ecosystem Services (P4GES) or scenarios of change so as to understand their impact on ecosystem delivery.

WaterWorld is a physical based universal model for water balance. It is a 'self-parameterised web based policy support tool focused mainly in conservation hydrology as well as development applications. It simulates hydrological baselines of average monthly plus yearly values from 1950-2000. Based on targeted area of study, simulations are carried out at a resolution of 1 hectare for tiles of a dimension of 1^0 of latitude and longitude or $1km^2$ resolution for 10^0 tiles. It is also used to compute hydrological scenarios for climate change, land use change and can be used to analyse the impacts of the different options of land management practices that have been applied (Mulligan, 2013).

3.5.5.1 Modelling and Simulation for Policy Exercise Scenario with Land use and cover change

Modelling and simulations for Policy exercise for recent changes in how land is used and changes in land cover was carried so as to assess how this affects Ecosystems (ES). This was based on recent changes of forest cover to herbaceous cover and herbaceous cover to forest cover. That is to mean when changing forest cover replaces forest (tree cover) with pasture or cropland (herb cover). Changes of between -99% and 99% represent selective deforestation and afforestation respectively. This simulation is done by Deforesting a given percentage per pixel of trees by -15 or reforesting by a given percentage per pixel of trees by 15 specifying the study area and by what percentage (per pixel) deforestation or reforestation should occur. In this study deforestation was by -100 percentage per pixel specifying both Upper and Lower Elgon as the targeted area.

3.5.5.2 Modelling and Simulation for Policy Exercise Scenario with Waterworld

To assess possible future impacts of climate change RCPs are used. Representative Concentration Pathways (RCPs) scenarios, are the four new GHG concentration established scenario set comprising concentration, emission, and land-use trajectories approved by the fifth Assessment Report AR5 IPCC (Van Vuuren *et al.*, 2011; IPCC, 2014). These are Representative Concentration Pathways 2.6, Representative Concentration Pathways 4.5, Representative Concentration Pathways 6.0 and Representative Concentration Pathways 8.5. These describe the four possible projected climate futures which explain the possible projected range of radiative forcing numerical toward the year 2100, in relation to radiative forcing before industrial development era. The simulation is a cmip5rcp45worldclimhe20412060 with baseline database and default parameter set illustrated in Table 3.1. Results will help guide and inform policy decision making for freshwater ecosystem service sustainability in the Mt. Elgon watersheds.

An alternative simulation was run in the Waterworld v.2[.92] model for Climate Change scenario to assess projected possible effects of climate change for the projected period 2041 to 2060. The simulation carried out was for the tile degree of 2.0^0N, 1.0^0S, 34.0^0E and 35.0^0W, which was named ElgonUpper and run at a tile of 1 hectare resolution and for the tile degree of 1.0^0N, 0.0^0S, 34.0^0E and 35.0^0W, named ElgonLower and run at a tile of1 hectare resolution. Modelling Climate: to access the impacts of climate using the policy **cmip5rcp45worldclimhg20412060** was selected.

The watershed was modelled based on the reference presented in Table 3.2 below at local scale, as presented below in figures 3.2 and 3.3 for the period 1950-2019. Results were generated from simulations and application of policy and scenarios giving output maps illustrated as figures. Reports were generated in form of Results maps examining the impacts of land-use and cover change, water balance and quality and runoff, as well as result statistics of time series and result narratives with scenario and policy interventions. Outputs remote sensing maps defined figures and discussed in relation to study area.

Table 3.1: An Illustration of Simulation Policy Exercise Option Selection

Stack 0 / Variable	**Value**
IPCC Assessment Report	cmip5
Emissions scenario	rcp45
Downscaled by	WorldClim
GCM name	HadGEM2-CC Met Office Hadley Centre
Projection year	2041-2060

Table. 3.2: Model and Study Area Modelling Reference

Run name	**Eco-engine Model & Model version**	**Run type resolution**	**Coordinates**	**Center coordinates**
Upper Elgon	Costing nature v.3 [.2]	Tiled/1hectare	N 2.0^o, S 1.0^o, W 34.0^o, E 35.0^o	1.5^o, 34.5^o
Upper Elgon	Waterworld v.2 [.92]	Tiled/1hectare	N 2.0^o, S 1.0^o, W 34.0^o, E 35.0^o	1.5^o, 34.5^o
Lower Elgon	Costing nature v.3 [.2]	Tiled/1hectare	N 1.0^o, S 0.0^o, W 34.0^o, E 35.0^o	0.5^o, 34.5^o
Lower Elgon	Waterworld v.2 [.92]	Tiled/1hectare	N 1.0^o, S 0.0^o, W 34.0^o, E 35.0^o	0.5^o, 34.5^o

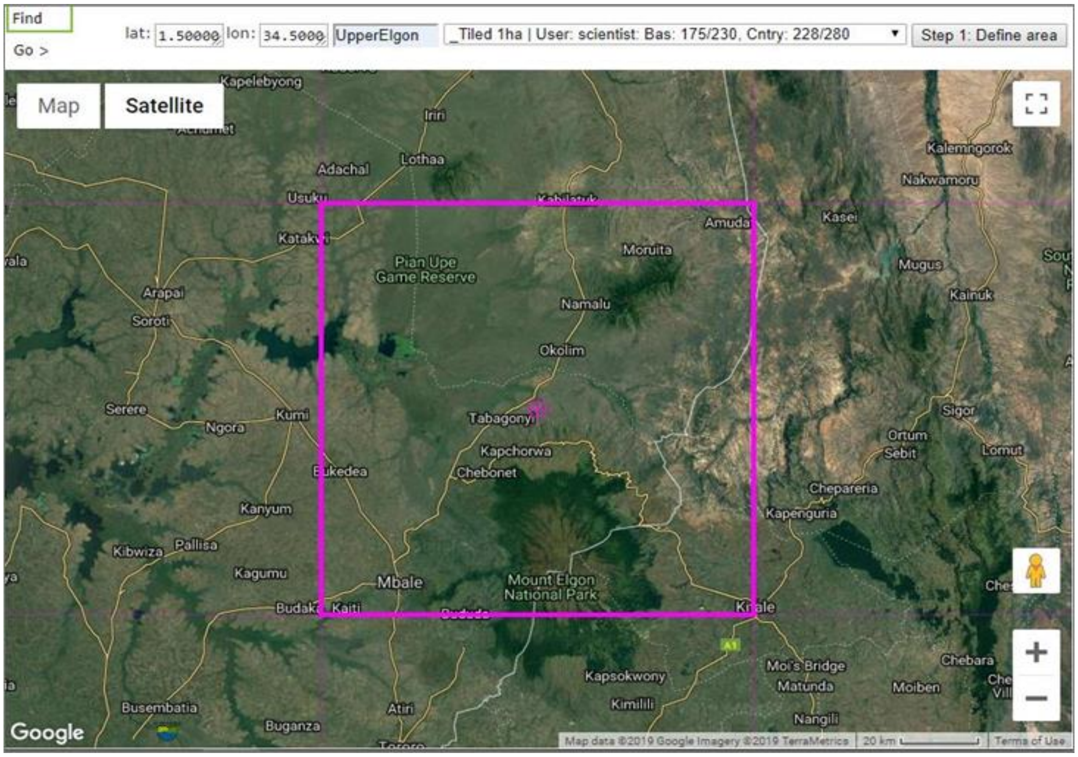

Figure 3.2: Map of the Area Modelled for Upper Elgon

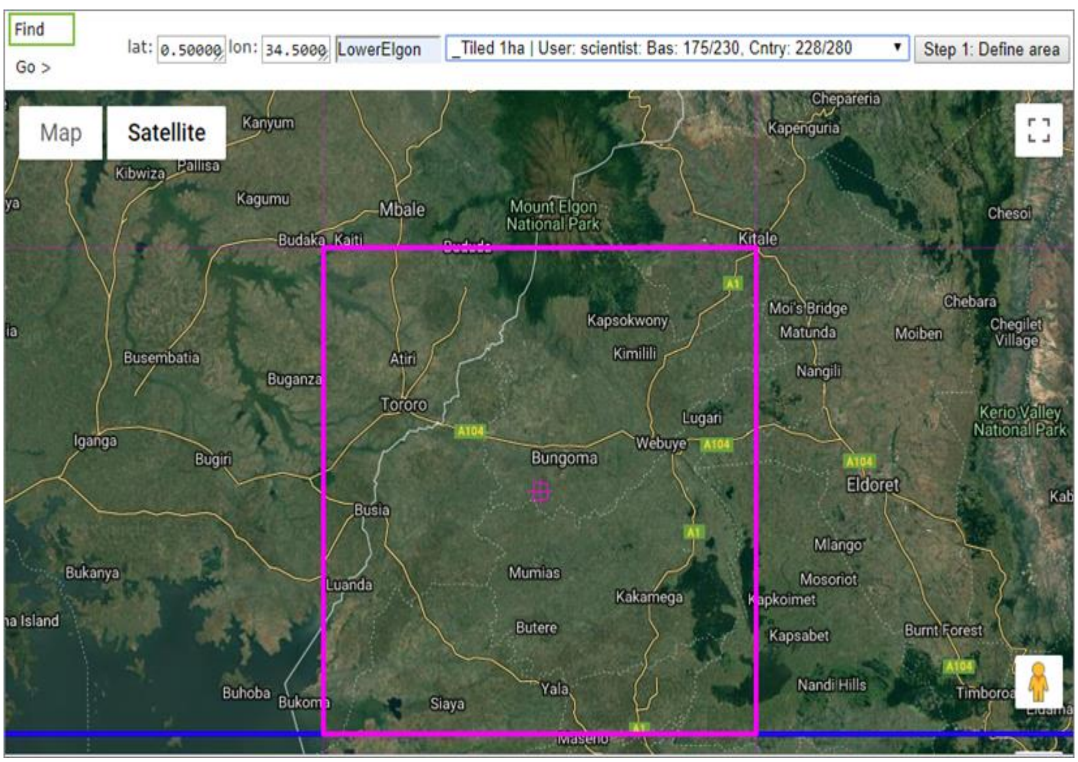

Figure 3.3: Map of the Area Modelled for Lower Elgon

3.6 Data Analysis

Every aspect of mountain freshwater ecosystem service depends on the ability of the watershed to consistently and continually generate and provide the freshwater natural resources. The benefits derived from freshwater ecosystems are many however, vary with quantity, quality and availability of freshwater resources. Under a changing climate these are dependent on the drivers of climate change. To investigate the impact of anthropogenic causes of climate change on the freshwater ecosystem services, a Mann-Kendal trend test was carried out on the runoff and precipitation datasets of the sampled gauging stations to observe the increasing, or decreasing or no trend in data collected. This means that the variable consistently increases or decreases through time, however the trend may or may not necessarily be linear. The MK test tests whether to reject the null hypothesis (H0) and accept the alternative hypothesis (Ha), where H0 is no monotonic trend and Ha is monotonic trend is present.

3.6.1 Runoff Trends

Datasets of 9 stations was selected out of the 13 gauging stations of data collected for runoff and categorized into 3 periods (1955-2016, 1963-2006 and 1962-1993) illustrated in Table 3.3 below. This was based on representation, relevance, availability and importance to the study. The datasets were categorized and analysed in three group of periods ; A- 1955-2016, B-1963-2006 and C-1962-1993.

Table 3.3: Categorized Dataset Periods for Runoff Gauging Stations per Location

Gauging Station	**Station ID**	**Sample Period**	**Years**	**Location**	**Longitude**	**Latitude**	**Category**
Manafwa	82212	1955-2016	62	Lower Elgon	34.15778	0.936944	A
Namatala	82213	1955-2016	62	Upper Elgon	34.17278	1.108611	A
Mpologoma	82217	1955-2016	62	Lower Elgon	33.79028	0.826944	A
Sironko	82240	1955-2016	62	Upper Elgon	34.25694	1.236111	A
Simu	82241	1955-2016	62	Upper Elgon	34.28722	1.298333	A
Rongai	1GB07	1955-2016	62	Lower Elgon	34.925	0.773611	A
Nzoia	1BB01	1963-2006	44	Lower Elgon	35.133333	0.920833	B
Nzoia	1EE01	1963-2006	44	Lower Elgon	34.225	0.177778	B
Suam	2B07	1962-1993	32	Upper Elgon	35.008333	1.481944	C

The period 1955-2016 of 62 years, comprised of datasets from gauging stations ; Manafwa (82212), Namatala (82213), Mpologoma (82217), Sironko (82240), Simu (82241) and Rongai gauging station1GB07. For the period 1963-2006 of 44 years, comprised of Nzoia gauing station 1BB01 and Nzoia gauging station 1EE01. For period 1962-1993 of 32 years comprised Suam gauging station 2B07. Due to the limitation of availability of data efforts were made to selects datasets representing both Upper and Lower Elgon from Latitude 0^0 in order to give a general picture of the complete Elgon watershed. Summary statistics for annual mean runoff values for all selected datasets was computed and results presented.

3.6.2 Precipitation Trends

Mann-Kendall trend test analysis was carried out for the Annual mean precipitation for the following rain gauging stations selected based on representation of regions in area of study and availability of data collected. These were; Buginyanya-Upper Elgon, Tororo-Lower Elgon, in Uganda and Kitale-Upper Elgon and Kakamega-Lower Elgon in Kenya. Sample period for each dataset was dependent on the availability of data for sampled gauging station within period 1955-2016. The sample period for the rain gauging stations was; Buginyanya (1995-2016), Tororo (1960-2011), Kitale (1986-2016) and Kakamega (1961-2008) respectively.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results obtained as per the objectives of the study based on the methods presented in chapter three.

4.2 Data Quality Control

Time series datasets for collected data for river runoff for the period 1948-2016 and precipitation for 1960-2016 for Mt. Elgon region, were quality-controlled by testing for homogeneity using the Pettitt test. A sample period for sampled data sets of cumulative annual totals per station, were tested and plotted as graphs. Results for all stations datasets were homogenous. Figure 4.1 and 4.2 are graphical representation of Namatala gauging station is R^2 = 0.9983 and Kakamega is R^2 = 0.9998 for runoff and precipitation respectively, depicting that the data are homogenous.

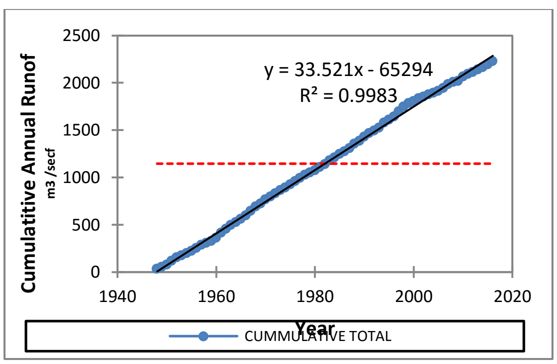

Figure 4.1: Annual Runoff data homogeneity for Namatala Station for the Period (1948-2016)

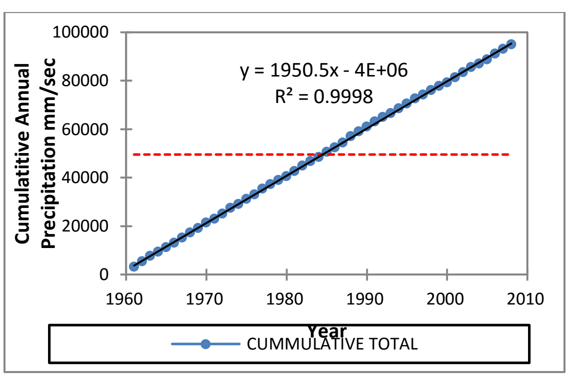

Figure 4.2: Annual Precipitation data homogeneity for Kakamega Station for the Period (1961-2008)

Summary statistics was computed for the minimum, maximum, mean and standard deviation for annual totals for Runoff data and the results for homogeneity test presented in Table 4.1and 4.2.

Table 4.1: Results for Summary Statistics for Cumulative Totals for Runoff Data collected in the Mt.Elgon Watersheds for the Period (1948-2016)

Cumulative Total per Station	Sample period	Sample size	Minimum	Maximum	Mean	Standard deviation
2B07 Suam	1962-1993	32	113.5776	4883.0363	2661.9105	1487.1012
IBB01 Nzoia	1948-2006	59	23.0939	2374.9645	1229.4058	728.4337
IEE01 Nzoia	1963-2006	44	1510.9886	50420.2115	24990.7273	14563.2598
IBG07 Rongai	1960-2015	56	64.9583	4600.3389	2414.9890	1495.2731
Manafwa	1945-2016	69	100.7305	7226.0366	3531.0415	2254.8055
Mpologoma	1949-2016	68	28.4677	21869.0013	10275.6055	6471.3997
Namatala	1948-2016	69	29.9787	2226.5885	1145.2476	673.0819
Simu	1953-2016	64	31.6341	2820.8314	1425.7558	859.4692
Sironko	1953-2016	64	40.3753	3526.2699	1723.0066	1062.6726

Table. 4.2: Results for Homogeneity using the Pettitt's Test for Runoff Data collected in the Mt.Elgon Watersheds for the Period (1948-2016)

Station	K-	t	p-value (One-tailed)	alpha	99% Confidence interval on p-value:	Conclusion
2B07 Suam	0.0000	1962	0.9683	0.05	(0.9638, 0.9728)	Data are homogeneous
IBB01 Nzoia	0.0000	1948	0.9821	0.05	(0.9787, 0.9855)	Data are homogeneous
IEE01 Nzoia	0.0000	1963	0.9754	0.05	(0.9714, 0.9794)	Data are homogeneous
IBG07 Rongai	0.0000	1955	0.9853	0.05	(0.9822, 0.9884)	Data are homogeneous
Manafwa	0.0000	1948	0.9865	0.05	(0.9835, 0.9895)	Data are homogeneous
Mpologoma	0.0000	1949	0.9845	0.05	(0.9813, 0.9877)	Data are homogeneous
Namatala	0.0000	1948	0.9854	0.05	(0.9823, 0.9885)	Data are homogeneous
Simu	0.0000	1953	0.9842	0.05	(0.9810, 0.9874)	Data are homogeneous
Sironko	0.0000	1953	0.9840	0.05	(0.9808, 0.9872)	Data are homogeneous

Summary statistics and result for homogeneity test for precipitation are presented in Table 4.3 and Table 4.4 respectively. The p-value was computed using a significance level of 5% and 1000 Monte Carlo simulations with a 99% confidence interval on the p-value as presented in Table 4.2 and 4.4. The results for all data sets the p-value is greater than the significance level alpha of 0.05 and therefore one cannot reject the null hypothesis Ho that data are homogenous.

Table.4.3: Results for Summary Statistics for Cumulative Totals for Precipitation Data collected in Mt.Elgon Watersheds for the Period (1960-2016)

Cumulative Total per Station	**Sample period**	**Sample size**	**Minimum**	**Maximum**	**Mean**	**Standard deviation**
Buginyanya	1995-2016	22	2231.6668	50280.7450	25921.3323	15089.0722
Tororo	1960-2011	52	1656.1091	79832.3870	40761.0397	22655.5379
Kitale	1986-2015	30	883.2000	38580.4000	19186.6800	11371.3658
Kakamega	1961-2008	48	3074.4000	94908.4000	49490.4104	27309.6408

Table.4.4: Results for Homogeneity Test using the Pettitt's Test for Precipitation Data collected in the Mt.Elgon Watersheds for the Period (1960-2016)

Station	**K-**	**t**	**p-value (One-tailed)**	**alpha**	**99% Confidence interval on p-value:**		**Conclusion**
Buginyanaya	0.0000	1995	0.9548	0.05	(0.9494,	0.9602)	Data are homogeneous
Tororo	0.0000	1960	0.9822	0.05	(0.9788,	0.9856)	Data are homogeneous
Kitale	0.0000	1986	0.9638	0.05	(0.9590,	0.9686)	Data are homogeneous
Kakamega	0.0000	1961	0.9796	0.05	(0.9760,	0.9832)	Data are homogeneous

4.3 Results from Systematic Evaluation of Literature Review

A systematic evaluation of literature review of anthropogenic activities impacting mountain freshwater ecosystem services was carried out and a theoretical framework was developed as illustrated in Table 4.5 using a step by step methodology detailed in section 3.5.1 page 32. The theoretical framework informed areas to focus on during observation in the study as well as identifying possible questions for unstructured interviews what to look for during the area of study visits. Findings were used to inform the DPSIR framework.

Table. 4.5: Result Summary for Systematic Evaluation of Literature Review Theoretical Framework of Study to Guide the Research and DPSIR Framework Formulation

S/N	Subject of literature
1	Freshwater ecosystem services and associated ecosystem services -International perspective -local perspective in Mt. Elgon watersheds
2	Socio-economic pressures - Conflict - Population - Human activity a) Irrigation b) Dam construction c) Levees d) Diversions e) Drainage of wetlands f) Deforestation g) Pollution h) Sand mining - The need and demand for increased food production - The impacts of increased food production
3	Mountain freshwater ecosystem services impacted by human activity
4	Impacts of climate change and opportunity cost for freshwater ecosystem service sustainability
5	Adaptation strategies

4.4 Results from Unstructured Interviews and Observation

Findings showed that major resources of freshwater ecosystems, present in the area of study, were mainly rivers, streams and well springs of varying sizes and magnitude. Most streams and rivers are seasonal. However, many are drying up for example river Namatso in Mbale. The freshwater ecosystem services identified were consumptive and non-consumptive services. These are provisioning services for domestic use and irrigation for agriculture and food production, fish farming, water point for livestock, as well as hydro power energy production. Many other ecosystems in the Mt.Elgon watersheds are dependent on the freshwater ecosystem services, supporting the richness of the biodiversity of flora and fauna. Other services identified include flood control, cultural and recreation benefits. Interactions with the members of the community through unstructured interviews and observations were very fruitful. The community willingly showed some places where they carry out livelihood activities where it could have not been able to freely access. Land in the Mt. Elgon watersheds is mostly owned through sole ownership and through inheritance from family except government protected areas. As such, access to areas along rivers must be granted to access local paths and gardens or this can be seen as trespass.

Still photographs were taken based on empirical data from systematic literature review on freshwater ecosystems and associated ecosystem and services, socio-economic drivers and impacts as well as model result outputs. This was in relation to selected topics in the theoretical framework. A compilation was done and some of the suitable views are presented in the following discussion. Some depicted some of the mountain freshwater ecosystem services in the watershed in areas visited. Most rivers at accessible points, are source for water for domestic use for communities in the surrounding area. In places where no destructive human activites are carried out, various types of herbal medicinal plants that the communities depend on for their survival are collected, as medical centers are not easily accessible. The river discharge is used for agricultural irrigation for all year round horticulture and pond fish farming as well as livestock farming which are major livelihood activities in the area. The river streamflow contributes to the land formations like caves and waterfalls in Sipi and Simu which form part of tourist attractions in the area. Swimming as a recreation activity, is a common sight.

In a few sections on the river banks Sironko river which have not been severely tampered with by human activities, the river provides habitat for natural vegetation for medicinal plants. These form part of the riparian zone as a natural flood control mechanisms and protect the water from exposure to high evaporation rates. It also provides habitat for small edible fish and other ecosystems of biological organisms for reproduction and nitrification were sand mining has not been carried out. Findings were based on observations made in comparison to others locations.

Freshwater ecosystem services provide supporting services to forests reserves and woodlots in the region, that enhance the formation of precipitation, which is the source of all water. In Figure 4.3 (i &ii) below, is a water body and collection of streams found in Kakamega forest reserve. These water resource reservoirs sustain the forest and other important ecosystems. Kakamega forest reserve is a major component of the formation of rainfall in Western Kenya, contributing to the cool climatic conditions and main source of endangered plant species as well as herbal medicinal plants and habitat for wild life. Figure 4.3(ii) depicts Nzoia river a main source for agricultural irrigation, domestic use, flood control and habitat for other ecosystems and a habitat for mating crocodiles.

Figure.4.3(i & ii):A Water Body in Kakamega Forest Reserve and Nzoia River; Provisioning, Regulatory and Supporting Freshwater Ecosystem Services in the Mt. Elgon Watersheds-Kenya

Figure 4.4 *(i) and(i)i* below are some of the rare species found in Kakamega forest reserve. They are not only medicinal in kind, but also are both used for research and study purposes as well as

Figure 4.4(i & ii): Kakamega Forest Reserve a Result of Mountain Freshwater Ecosystem Services in the Mt.Elgon Watersheds Providing Regulatory, Cultural and Recreation Benefits-Kenya

tourist attractions due to their importance and the need to conserve these species. The forest reserve provides tourist attractions like Isiukhu waters falls. found in the forest reserve. It is to be noted that Kakamega forest reserve is a major income contributor to Kenya's economy as well as source for livelihood to the surrounding communities as source for traditional medicinal plants.

Figure 4.5 (*i & ii)* depicts River Bukwo (Uganda) which flows to Kenya as Suam River. Along this river in Uganda is a Hydro Power energy generation plant. The figure depicts the water

i *ii*

Figure.4.5: (i & ii) Shows Bukwo Hydro Power Plant on River Suam Headwaters a Provisioning and Regulatory Freshwater Ecosystem Services in the Mt Elgon Watersheds.

Intake which includes trash rack a gate and an entrance to a canal the fore-bay to the penstock that conveys the water under pressure to the powerhouse. This houses the turbine and generator shown in figure on the right. It converts the power of harnessed form the water into electricity and the water is finally released back to the river through the tailrace. Hydro power energy is a renewable energy, a vital source of energy under a changing climate. The river provides other economic uses for industrial development in the urban centers and irrigation for agriculture.

Livelihood activities in Mt.Elgon watersheds are impacting mountain freshwater ecosystem services. The pressure is increased by population increase in these areas. In several locations in the mountain headwaters of the watersheds in Uganda are unchecked river diversions to make man-made fish ponds and irrigation as well as in the lowland wetlands are being destroyed. These are made by who-ever is able to and owns land along the river banks see photographs Figure 4.6 (i-iv). Chemicals and food supplements to enhance the growth of fish are used. The water in the fish ponds after a period is released into the mainstream polluting it. Other livelihood activities carried out alongside the rivers is goat rearing, cattle farming as well as piggery releasing waste in the rivers increasing non-human foot print. These were observed in Buwagogo along Simu river. Sand mining leading to silting and loss of retention of discharge by river, channel alteration, and agricultural cultivation are a common sight along the river banks

Figure 4.6(i-vi): Shows Livelihood Activities; Piggery, Cattle Rearing, Fish Pond Farming and Sand-mining are Impacting Mountain Freshwater Ecosystem Services in the Mt.Elgon Watersheds

impacting the river's ability of flood control and regulation. Impacts of livelihood activities on mountain freshwater ecosystem services in Mt.Elgon watersheds are evident. Sand and rock mining and agricultural activities are evident livelihood activities along Nzoia river. The riparian zone has been greatly encroached on exposing the river to frequent flooding and destruction of habitat for other ecosystems like fish and breeding grounds for crocodiles and snails. The rock that forms sections of the river bed as seen in Figure 4.3 (ii) is indiscriminately mined for gravel and aggregate. This enhances silting which is a common sight and the water is discolored affecting its quality. Silting of river beds due to sand mining and reclamation of swamps along river Mpologoma resulting in aftermaths of flooding of unprotected riverbanks and destroyed food crops in flood plains is a common sight.

Diversion of streamflow for rice irrigation and fish pond farming in Figure 4.7 (i) below. This has caused pollution and affected discharge levels downstream. This has caused the formation of algae and insufficient water levels affecting the rivers to provide sustainable services. The distribution of clean and safe water for domestic and industrial use by Mbale Town Water Supply has been impacted leading to" water rationing", see Figure 4.7 (*ii)*. Impacts of livelihood activities due to river diversions for fish farming and brick making for construction and as a source of income have caused deformation of river channels and river morphology. Poor crop harvests are realized due to hydrological drought affecting moisture retention in soils and poor water retention in streamflow as a result of sand mining are now a common phenomenon causing increased stress on freshwater ecosystem services inhibiting the role of freshwater ecosystems to regulate climate due to increased evapotranspiration and reduced rainfall.


i

ii

Figure 4.7(i & ii): Shows Pollution and Diversion of Streamflow Result in Impacts of Livelihood Activities on the Freshwater Ecosystem Services in Mt.Elgon Watersheds

Poor agricultural practices, over-cultivation of agricultural land and sand mining along the river banks of River Nzoia, has led to loss of regulatory services for flood control. This has led to soil erosion causing silting and discoloration of stream flow and encroachment on habitat for crocodiles of other freshwater ecosystems and breeding grounds for organisms like fish which are supported by freshwater ecosystem services.

Impacts on freshwater ecosystems services due to human activities has received concern by the government to a certain extend. Figure 4.8 below depicts some of the efforts made by the government together with the communities towards climate change adaptation strategies for sustainable freshwater ecosystem services. The Figure depicts a tree nursery bed initiative in Buwagogo. Seedlings are distributed to schools and the community to promote tree planting and

Figure 4.8(i, ii, iii &iv): Some of the Efforts towards Climate Change Adaptation Strategies Practiced in in Bwagogo, along River Sironko and River Manafwa inthe Mt.Elgon Watersheds in Uganda

along river banks for flood control and regulate evapotranspiration to maintain river levels, soil erosion in gardens avoiding loss of top fertile soils to the rivers and sequestrate carbon dioxide. Individual farmers construct gullies in their gardens to control soil erosion and rainfall runoff. Planting reeds along river banks by willing farmers is an effort for retention of the natural riparian zone in to control evapotranspiration and to improve habitat for other freshwater ecosystems. Though not sustainable, bags of sand are put in the river to raise water levels to attain required water levels for domestic and industrial distribution.

4.5 Results from Evaluation of Anthropogenic Activities Impacting Mountain Freshwater Ecosystem Services

To evaluate anthropogenic activities impacting mountain freshwater ecosystem services in Mt.Elgon watersheds, findings from unstructured interviews with communities and photography from observations made were discussed. These were enriched using information from systematic evaluation of literature review to confirm documented research as well as analysis of key output maps from modeling and simulation from both Co$ting Nature and Water World policy support tools. The DPSIR framework is discussed as the Drivers, Pressures, State, Impacts as well as the Responses, these were identified in the findings and systematic evaluation literature review.

4.5.1 Drivers

The Drivers of climate change on Mt.Elgon freshwater ecosystem impacting freshwater ecosystem services are both natural and anthropogenic. Mt.Elgon being originally a volcanic mountain covered with loose loam soils, under natural processes which include weathering and landscape transformation caused by earth movements. Over time deep cracks have developed due to expansion and contraction of rocks impacted changing temperatures. These run along the mountain peaks raising fear and concern in the communities. According to the community during rainy season these provide points of weakness as the loose volcanic loam soils absorb a lot of runoff leading to landslides causing landscape change. This alters channel morphology of many rivers, causing flooding and silting polluting the rivers, destroying farms, property and cause loss of human and animal life. These have become more frequent and uncertain. The anthropogenic drivers are mainly due to human activities. Economic growth in the region has partially lead to population growth due to improved health care services and as well as improved standards of living. This has led to urbanization and increased demand for raw materials and natural resources resulting in the clearing of forests for energy use affecting forest and vegetation cover and demand for more freshwater ecosystem services. All the above social economic activities take some form of land use, so as to meet the many human needs of water, food fuel and shelter. However these cannot be discussed in isolation due to the interactions of human activities with earth systems.

4.5.2 Pressures

The limitless varying human needs increasing human activities is stressing the environment in the Mt.Elgon watersheds putting pressure on the freshwater ecosystems affecting the ability of the watershed to provide sufficient sustainable freshwater ecosystem services. Increased economic growth has led to the demand for modern and permanent shelter for both domestic and commercial purposes, and as result increased demand for land. Unfortunately, land is a fixed natural resource. The Mt.Elgon region is one of the most populated regions in East Africa. Being a trans boundary natural resource has led to conflict as a result of limited land to accommodate the increasing population, for its fertile volcanic soils hence increased demand on water resources.

Vegetation and land cover play a vital role in climate for rainfall formation and soil water percolation and retention. Livelihood activities that stress the environment in the watersheds include cutting of trees for charcoal burning, timber for construction and the increased demand for agricultural land has led to deforestation in the watershed. Even with the few individual woodlots the demand out-races the rate of growth. Poor soil tillage practices and over-use of land due to population pressure leaves it exposed resulting in frequent landslides.

The increased demand for grazing land pastures for livestock farming especially during the dry season, has caused conflict within communities, between cross bounder communities as well as with the forest reserve rangers and surrounding communities. The communities demand their rights to access pastures in the forest reserves running battles with the forest rangers, destroying land cover due to overgrazing and polluting the freshwater ecosystems at headwaters. Domesticated livestock farming of cattle, goats and piggery is a common sight along the river banks as this provides easy access to water for the animals and green lash pastures for food. The waste thereof is released into the river systems which is used by both humans and livestock. This fact is established by outputs from the models depicting pollution by defecating populations

The need for increased food production to meet the human food needs has caused increased encroachment on wetlands for rice production. It has also exposed the watershed to the impacts of increased use of Fertilisers both organic and inorganic affecting the natural filtration systems and flood control mechanisms. This is a common phenomenon that has led to water pollution through nutrient release and pollutants from fertilizer usage. Increased human and non-human footprint by defecation in the freshwater ecosystems plus pollutants from residues chemicals from food supplement used in fish farming all as means of livelihoods as seen in figures. This is becoming more evident as the soils in the watershed get more degraded as observed in model outputs for Paying for Global Ecosystem Services (P4GES) depicting extent of degradation raising the need for prioritizing conservation to enhance the health of freshwater ecosystems

The demand for sand and gravel for construction has put pressure on freshwater ecosystems. This is affecting their ability to provide freshwater ecosystem services of regulating and retention of water in the river channel, as well as destroyed the habitat for several organisms. Over mining of sand and rock in river beds has destroyed the ability of many rivers to provide other support services. This has increased the rates of evapotranspiration as the vegetation cover on the river banks are destroyed in the process, resulting in drying up of rivers causing drought and poor crop production stressing associated ecosystems in the watersheds as in Figure 4.6 (vi) page 50.

4.5.3 State

The Mt.Elgon watershed freshwater ecosystem and services are a main source for water for rivers, lakes, wetlands, groundwater systems and the stability of the mountain ecosystem in the region. It also contributes to the River Nile system and Lake Turkana. Some of the major functions of the freshwater ecosystem services in the watershed include provisioning, regulating, and supporting cultural and recreation services. These are being impacted by poor water management practices affecting their storage, distribution and treatment and as a result affecting their ability to provide sustainable freshwater ecosystem services. This affects the ability to provide sufficient sustainable water resources for energy production, irrigation, recreation, industry and natural resources conservation and sustainability. Sustainable provision for water services to meet domestic needs is equally endangered. This can be sighted in Figure 47 (i&ii) where water is diverted for irrigation and fish pond farming and thus affecting the water levels for domestic and industrial supply. Impacting the economic development negatively. In Figure 48(iv) the crude methods applied to raise water levels affects it quality for domestic consumption as well as creates a lot trash blocking the water purification water supply system. This can be overcome by good water governance to regulate water diversion and construction of values, water gates and water reservoirs and dams to serve during water droughts.

4.5.4 Impacts

As a result of the limitless socio-economic human needs, there is increased pressure on the ecosystem that are altering its state and likely to cause irreversible impacts. For example altered landscape, caused by river diversion for irrigation and fish pond farming affecting the river channel morphology causing intentional drought and water scarcity in the low laying areas. The ability of the freshwater ecosystems to provide support services in the whole mountain ecosystem has been compromised. Water levels have dropped significantly and rivers are drying up during dry season which was not the case before for some rivers. Streams and even some springs too have dried up. There is evidence of formation of algae due to dwindling water levels affecting it quality. The water it is not clean and safe for human and livestock consumption bearing in mind that the communities largely depend on untapped water for their domestic uses. There is need to connect the communities in the villages to clean water supply to minimize infections resulting from water-borne diseases.

By interviewing the community and observation it was noted that swamps and wetlands were a common sight in places like Bududa district which is located at headwaters of River Manafwa. However these are no existent as they have been impacted by brick making. This has affected the ability to provide freshwater services as regulatory and support services to the Mt.Elgon ecosystem as a whole. The degradation of freshwater ecosystems in the watershed is affecting its ability to provide sustainable freshwater ecosystem services. Sand mining in the river beds has affected the ability for rivers to provide habitat for freshwater microorganisms which are vital for the fish and other aquatic life. It is affecting the ability of water retention in the rivers. This accelerates evaporation drying up of rivers resulting in crop failure and reduced crop yield for crops grown along the river sides for livelihood further stressing the finite natural resource. This was observed as the communities realized crop failure due to reduced water levels in river beds.

The socio-economic benefits lost are; loss of income generating activities resulting in loss of livelihood and loss of opportunity for carbon sink, loss of other food sources, reduced irrigated agricultural production and reduced production in rain-fed agriculture. There is also lost opportunity for energy power generation due to reduced runoff in the rivers reducing the availability of job opportunities in the industrial sector and small business enterprises and loss of Gross Domestic Product (GDP). Lastly insufficient water resources for domestic and industrial use. All the above lead to more pressure on the ecosystem in search of alternative livelihoods exerting more pressure on freshwater ecosystems hence reduced freshwater ecosystem services.

4.5.5 Responses

There are currently efforts by both governments towards adaptation and mitigation to climate change. There is deliberate effort towards tree planting through community and school awareness and tree planting campaigns as seen in Figure 48 (i) page 52. According to the local leaders efforts are being made to sensitize the communities about farming up to the river banks and trying to put in place committees to management river management. However due to the nature of land tenure system were people own land individually it is still a challenge that will require government intervention with penalties for it to be effective.

Efforts towards availing alternative sources of livelihood are being encouraged through provision of soft agricultural loans to enhance productivity mainly through micro- finance agencies like Brac and government projects like the Third Northern Uganda Social Action Fund (NUSAF III) a programme geared towards improving access to income-earning opportunities for poor households in north and northeast Uganda. These are Eastern Uganda Districts amongst others; Manafwa, Busia, Sironko, Bulambuli, Kween, Kapworwa Bududa, Butaleja and Tororo found in the watersheds. The Mt. Elgon Regional Ecosystem Conservation Programme (MERECP) is a trans-boundary initiative towards sustainable development of the Lake Victoria Basin.

4.6 Results from Mapping Runoff Spatial Patterns and Monitoring Stations with QGIS and ArcGIS

Results from mapping as a method using GIS software tools for QGIS 2.6 and ArcGIS to illustrate the geographical extent and influence of the Mt.Elgon watersheds was achieved. The location of study area and spatial patterns of river runoff was carried out using QGIS. This depicts the watersheds as an important source for many rivers and lakes in the region. The study area is defined in the key as Elgon Eastern Uganda and Elgon Kenya region in Figure 4.9.

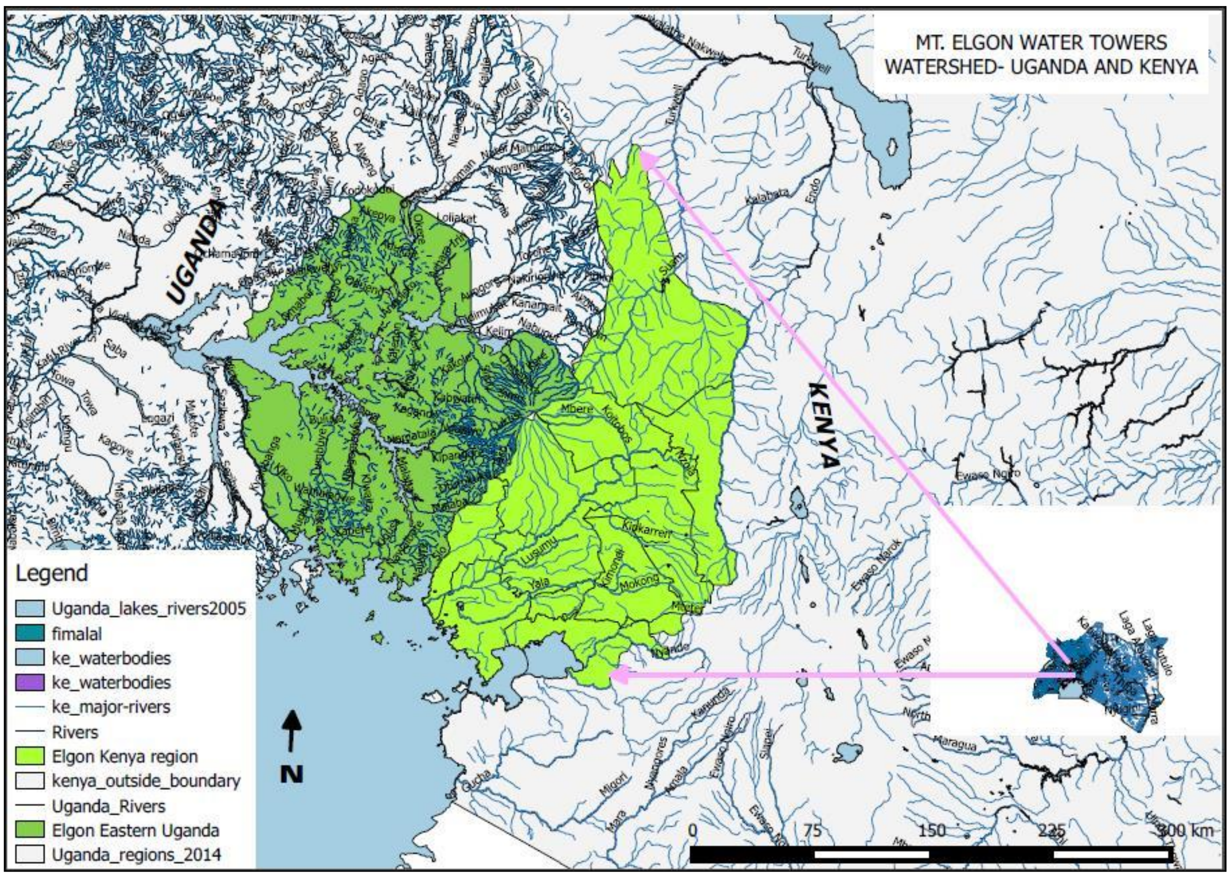

Figure 4.9: Mapping of River Runoff Spatial Patterns in the Mt.Elgon Watersheds using QGIS

Sampled water monitoring stations are presented in Table 4.6. Sampling was based on regional representation and availability of data based on the period of study and sample period. These are mapped using ArcGIS software following the same procedure, as above. While the figure above depicts a spatial patterns of very several rivers and streams. Several of these are drying up and experiencing significantly reduced water levels and drought. A visit to the area of study using observation and interview with communities confirmed this.

Table 4.6: Sampled Water Resources Monitoring Stations in Mt.Elgon Watersheds

River Gauge Station N	**River Gauge Station ID**	**Elevation**	**Area(sq_km)**	**Longitude**	**Latitude**
UGANDA					
Sio	81269	1148	1	34.05722	0.327222
Manafwa	82212	1100.2	494.2	34.15778	0.936944
Namatala	82213	1100	123.6	34.17278	1.108611
Mpologoma	82217	1078	3614	33.79028	0.826944
Sironko	82240	1118	265	34.25694	1.236111
Simu	82241	1091	165	34.28722	1.298333
Sipi	82243	1081	92	34.31444	1.382778
KENYA					
Nzoia	1BB01	1800	-	35.133333	0.920833
Rongai	1BG07	1660	-	34.925	0.773611
Kuywa	1DB01	1460	-	34.7	0.623611
Nzoia	1EE01	1180	-	34.225	0.177778
Nzoia	1DD01A	0	-	34.4875	0.372222
Suam	2B07		-	35.008333	1.481944

Location of sampled water resource monitoring stations in the Elgon Sub Catchment that are within the Elgon watersheds, are marked in red ink in Figure 4.10.

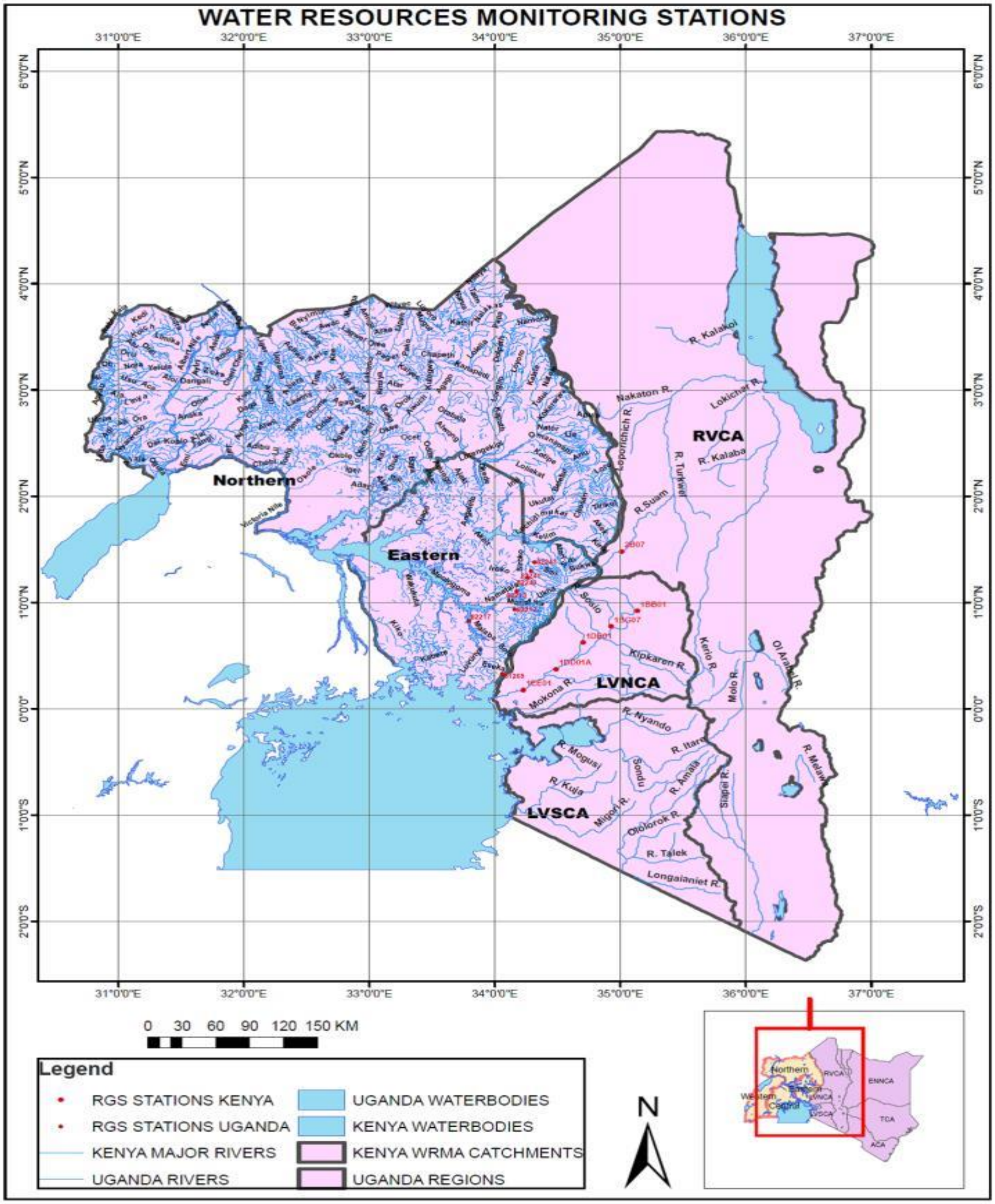

Figure 4.10: Mapping Water Resources Monitoring Stations in the Elgon Sub Catchment using ArcGIS

4.6 Trend Analysis

4.6.1 Runoff Trends

Results for the Mann-Kendal test for trend are presented in Table 4.7 and 4.8 with graphical representation of trend for categorized datasets (A,B, &C)in Figures 4.11 & 4.12 (1955-2016), Figure 4.13 & 4.14 (1963-2006) and Figure 4.15 & 4.16 (1962-1993) respectively. However individual statistics and graphical representation for selected datasets per category are presented.

Table 4.7: Summary Statistics of Datasets for Annual Mean Runoff for Selected Gauging Stations

Variable (Stream Annual Mean Runoff)	Observa tions	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Manafwa River	62	0	62	3.7753	30.8218	8.9744	4.4836
Namatala River	62	0	62	0.8518	4.5053	2.7274	0.7990
Mpologoma River	62	0	62	7.6465	52.9177	28.1549	10.5829
Sironko River	62	0	62	1.7677	15.6554	4.6425	1.9382
Simu River	62	0	62	0.7620	7.5403	3.7052	1.1652
IGB07 Rongai River	62	0	62	1.6160	41.6188	6.8457	7.2624
IBB01 Nzoia River	44	0	44	1.2984	6.6283	3.4473	1.6135
IEE01 Nzoia River	44	0	44	45.3090	146.5981	95.4928	23.7875
2B07 Suam River	32	0	32	5.3120	30.6070	12.7162	4.6302

Table 4.8: An illustration of Mann-Kendall Trend Test / Two-tailed Test (Annual Mean Runoff) for Streamflow in the Mt.Elgon Watersheds for the Period (1945-2016)

	Sample Period	Kendall's tau	S	Var(S)	p-value (Two-tailed)	alpha	Sen's slope:	Confidence interval:
Manafwa	1955-2016	0.0218	41.0000	27056.3333	0.8079	0.05	0.0009	(-1.1494 , 1.0373)
Namatala	1955-2016	-0.1487	-280.0000	27076.0000	0.0900	0.05	-0.0083	(-0.2346 , 0.2233)
Mpologoma	1955-2016	0.0581	108.0000	26922.6667	0.5143	0.05	0.0317	(-2.3260 , 2.9603)
Sironko	1955-2016	0.1492	269.0000	26286.3333	0.0983	0.05	0.0095	(-0.3884 , 0.4330)
Simu	1955-2016	0.0064	12.0000	26939.3333	0.9466	0.05	0	(-0.3649 , 0.3154)
IBG07 Rongai	1955-2016	-0.0762	-143.0000	27039.0000	0.3878	0.05	-0.0078	(-1.3898 , 1.2854)
IBB01 Nzoia	1963-2006	-0.1839	-174.0000	0.0000	0.0802	0.05	-0.0288	(-0.7166 , 0.5670)
IEE01 Nzoia	1963-2006	0.1311	123.0000	9747.0000	0.2166	0.05	0.3551	(-8.9279 , 9.1932)
2B07 Suam	1962-1993	-0.2823	-140.0000	0.0000	0.0234	0.05	-0.1548	(-2.1292 , 2.0169)

4.6.1.1 Category A Period 1955-2016

A Mann-Kendall Trend analysis was carried out for the Annual mean runoff for category A period 1955-2016 for datasets of gauging stations. The results from the Mann-Kendal test presented in Table 4.8 above showed that ties were identified in the data and suitable corrections applied, As the exact p-value could not be computed and an estimate was used to compute the p-value. The result for the p-value are as follows; Manafwa: 0.8079, Namatala: 0.0900, Mplogoma: 0.5143, Sironko: 0.0983, Simu:0.9466, Rongai:0.3878 respectively. These results depicted that for all datasets the computed p-value is greater than the significance level alpha of 0.05 and therefore one cannot reject the null hypothesis H0 that there was no trend in the time series. Below is a graphical representation of hydrographs of the analysis in Figures 4.11 and 4.12.

The hydrographs show a relatively similar pattern in increase and decrease of values for runoff in the same periods. Between 1958 to 1976 shows a reducing pattern, 1977 to 1991 an increasing pattern followed by an reducing pattern between 1992 to 2006 and finally an increasing pattern to 2016 depicting a similar climatic impacts on total annual runoff levels. The significant prolonged decreasing pattern imply drop in water levels overtime stressing freshwater ecosystem services exacerbated by increased human activities along river channels and the whole watershed

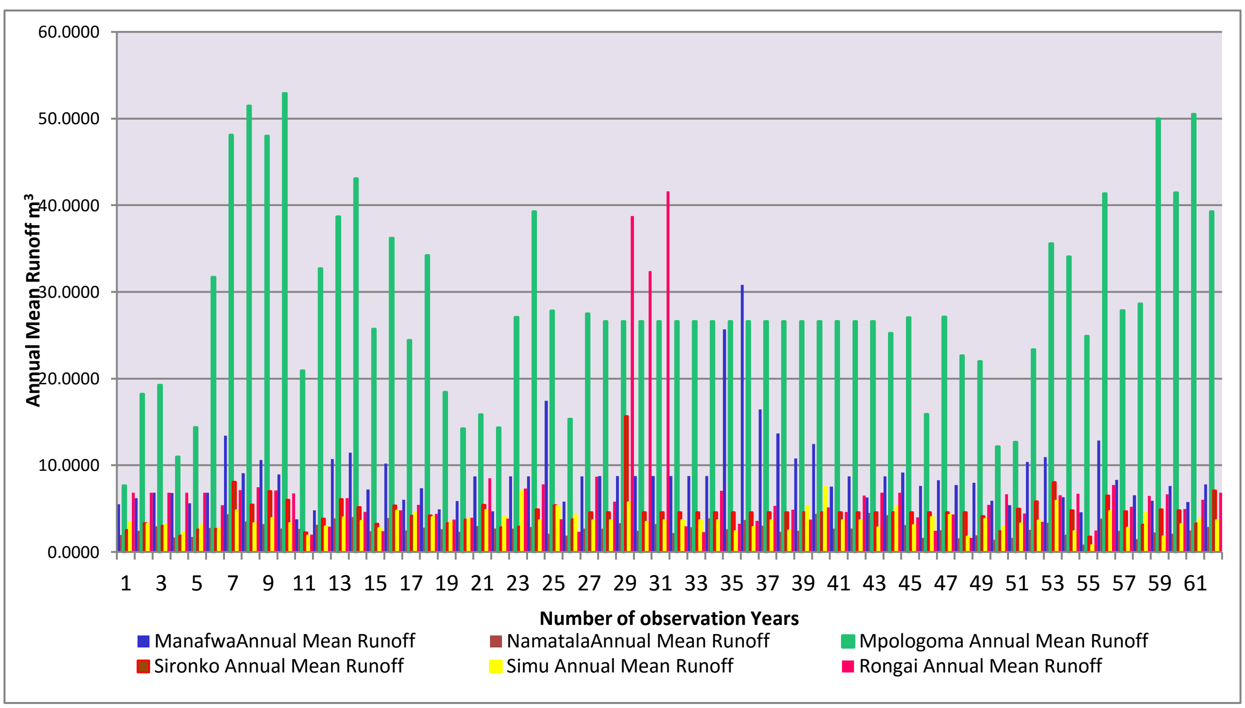

Figure 4.11: Annual Mean Runoff for Category A Stations for the Period (1955 2016)

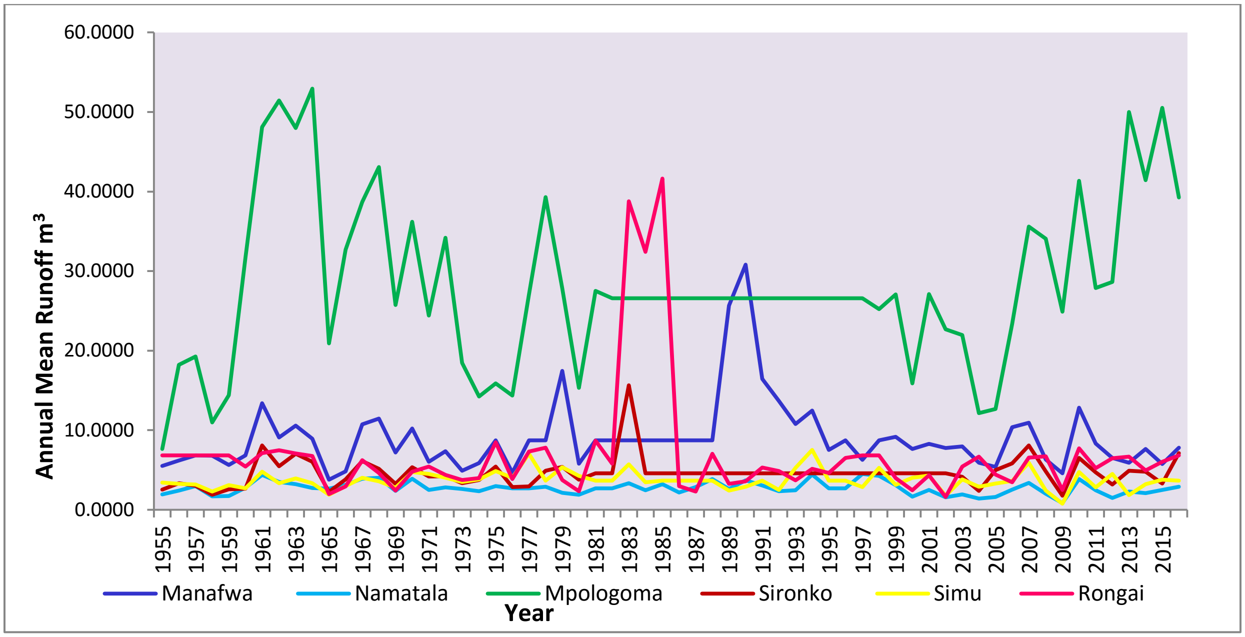

Figure 4.12: Hydrographs for Trend for Annual Mean Runoff for Category A-Manafwa, Namatala, Mpologoma, Sironko, Simu and Rongai Gauging Stations for the Period 1955-2016)

as a whole. A more detailed analysis for each station was done by breaking the datasets into 5 intervals period of 15-16 years in order to access the trend for shorter periods of time. Category A is represented by dataset for Namatala gauging station 82213 below.

A Mann-Kendall Trend analysis was carried out for Annual mean runoff dataset for Namatala gauging station. Data was sub-divided into 5 periods of 15, 16, 62 years as follows; 1955-1970 (16), 1971-1985 (15), 1986-2000 (15), 2001-2016 (16), 1955-2016 (62). This was done so as to identify trends observed in shorter period of years as in graphical plots in Figure 4.13. The graphical plot for period 1955-1970 shows an initial oscillating positive increasing pattern in values followed by a negative pattern Coefficient of determinant (R^2) rate of 30.08% ranging between 1.6 m^3- 4.3m^3 at the highest depicting an upward trend see Fig.4.13. Interval 1971-1985 continued to depict an oscillating increasing pattern in values with R^2 rate of 4.03% of 2.4m^3 dropping to 1.9m^3 to 3m^3 at the highest recording of 1971, 1980, and 1983 depicting a upward trend in the series, see Fig.4.14. In comparison to the previous interval this was a negative upward trend. The third interval of 1986-2000 depicted R^2 rate of 1.03% with oscillating value pattern between 2.2m^3- 4.5m^3 in the period dropping to 1.6m^3 at the lowest recording in this period of 1986, 1997 and 2000 respectively depicting a negative upward trend in comparison to the previous interval in the time series, see Fig.4.15. The period 2001-2016 is upward positive trend with R^2 rate of 5.73%, from $2.5m^3$ to $1m^3$ at the lowest recorded value in the whole sample rising to $3.8m^3$ at the highest recording later depicting a reducing pattern in values of $3m^3$ of 2001, 2009, 2010 and 2016 respectively still depicting an upward trend, see Fig.4.16. The full sample period of 1955-2016 depicts downward trend R^2 rate of 3.86% with the lowest record at $1m^3$ to $4.5m^3$ at the highest recording and $3m^3$ of 2009, 1997, and 2016 respectively depicting downward trend, see Fig.4.17.

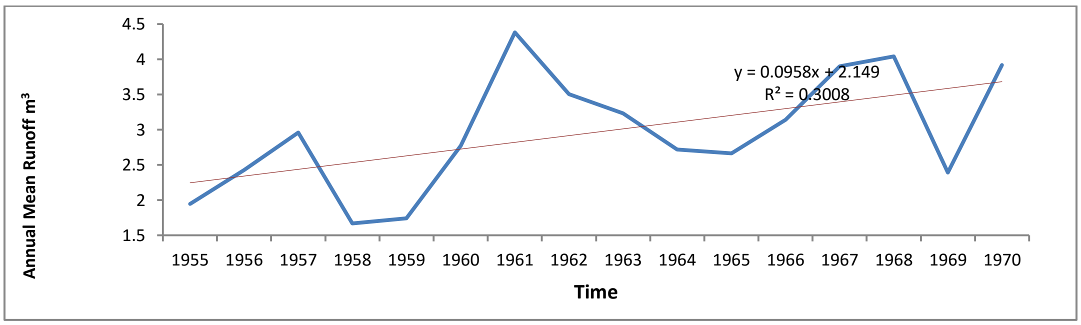

Figure 4.13: Trend for Runoff for Namatala Gauging Station for the Period 1955-1970

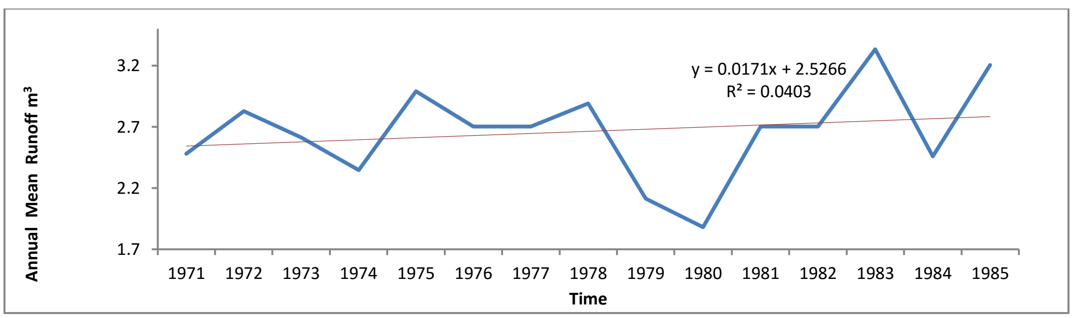

Figure 4.14: Trend for Runoff for Namatala Gauging Station for the Period 1971-1985

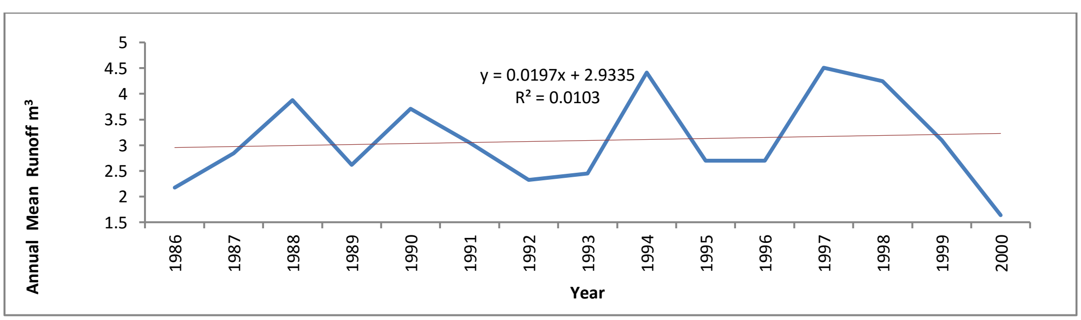

Figure 4.15:Trend for Runoff for Namatala Gauging Station for the Period 1986-2000

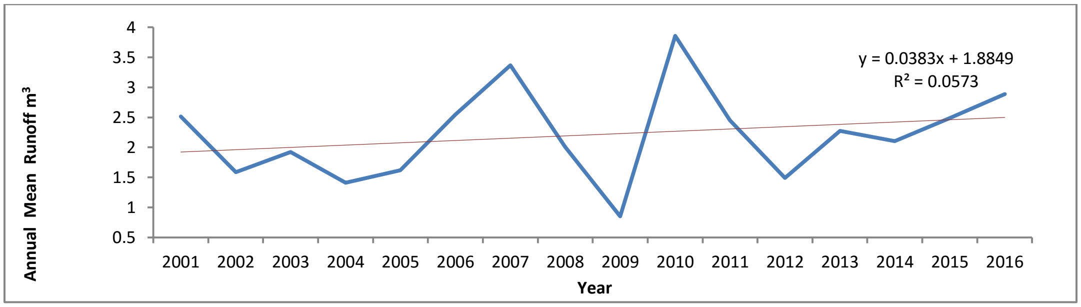

Figure 4.16: Trend for Runoff for Namatala Gauging Station for the Period 2001-2016

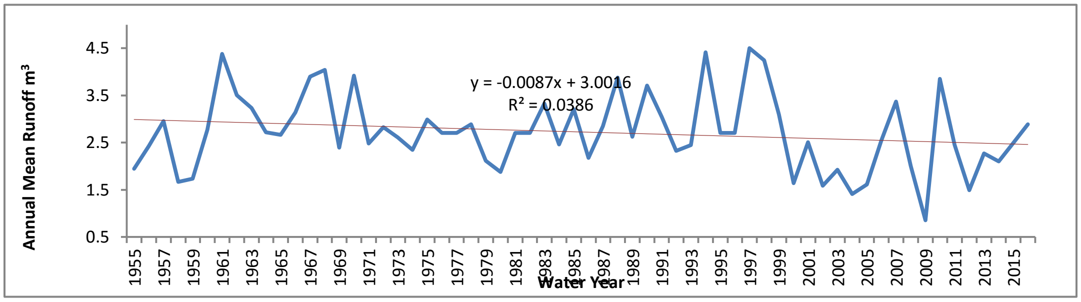

Figure 4.17: Trend for Runoff for Namatala Gauging Station for the Period 1955-2016)

The p-value was computed and result was as follows; 1955-1970: 0.0641, 1971-1985: 0.5483, 1986-2000: 0.5857, 2001-2016: 0.3057, 1955-2016: 0.0900 respectively. Based on these results, p-value for all data sets is greater than the significant level alpha of 0.05. Therefore one cannot reject the null hypothesis H0 that there is no trend in the time series. This implies that the runoff levels over the trend period were unstable and unpredictable. Rainfall being the source for all stream flow, this indicates unstable rainfall occurrence an indicator of impacts of climate change. Results are summarized in the Table 4.9 below.

Table.4.9: Result for Mann-Kendall Trend Test for Namatala Gauging Station Annual Mean Runoff Dataset for Intervals (1955-1970, 1971-1985, 1986-2000, 2001-2016, 1955-2016)

Guaging Station	**Discharge Period**	**Kendall's tau**	**S**	**Var(S)**	**p-value**	**alpha**	**Sen's slope:**	**Confidence interval:**
Namatala	1955-1970	0.3500	42.0000	0.0000	0.0641	0.05	0.1025	(-0.5558, 0.6242).
Namatala	1971-1985	0.1275	13.0000	399.6667	0.5483	0.05	0.0113	(-0.2728, 0.3981).
Namatala	1986-2000	0.1148	12.0000	407.3333	0.5857	0.05	0.0294	(-0.9353, 0.8907),
Namatala	2001-2016	0.2000	24.0000	0.0000	0.3057	0.05	0.0499	(-0.9265, 0.7831).
Namatala	1955-2016	-0.1487	-280.0	27076.0000	0.0900	0.05	-0.0083	(-0.2346, 0.2233).

4.6.1.2 Category B Period 1963-2006

Nzoia River is a major river in the Mt. Elgon watersheds that contributes significantly to the Nile river system through Lake Victoria. It is comprised of several tributaries and river gauging stations. Nzoia gauging station 1BB01 is located 0.92^0N, 35.13^0E on a tributary at the headwaters of Nzioa river. While Nzoia gauging station 1EE01 is located 0.18^0 N, 34.22^0 E on the main Nzoia river, lower Nzoia sub-basin towards Lake Victoria. A Mann-Kendal Trend analysis was carried out for datasets for the Annual mean runoff for Nzoia River gauging station 1BB01 and 1EE01 for the period 1963-2006 plotted in Figure 4.18 and 4.19.

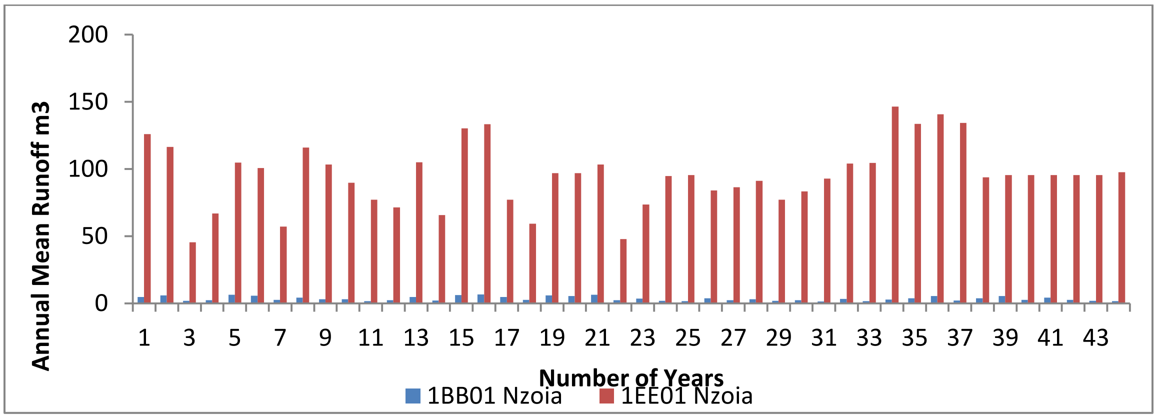

Figure 4.18: Annual Mean Runoff for Category B Stations for the Period (1963-2006)

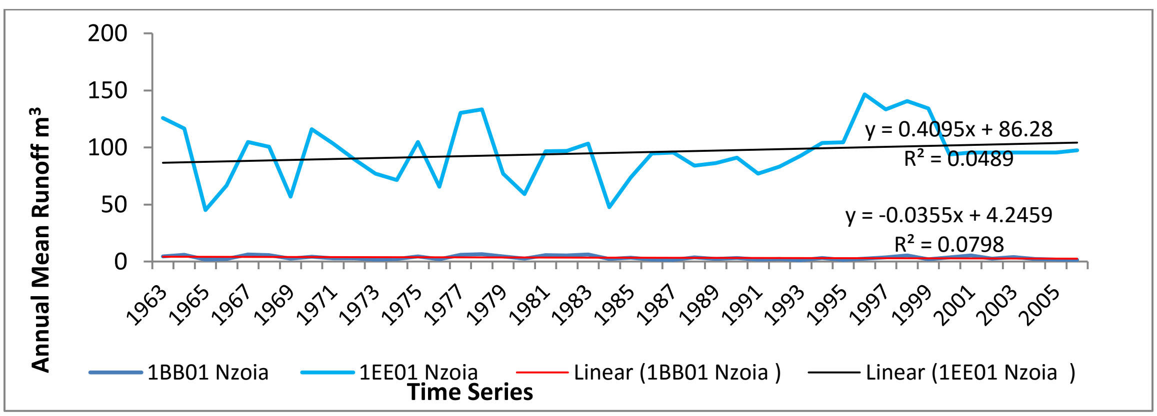

Figure 4.19: Hydrographs for Trend for Annual Mean runoff for Category B-Nzoia Gauging Stations 1BB01 and 1EE01 for the Period 1955-2016)

The hydrographs show a relatively similar pattern in increase and decrease of values in the of same periods. Between 1963 to 1966 shows a significant decreasing pattern in values, for both stations and similarly at other points. The illustration show oscillating pattern of values throughout the sample period. An overall observation shows a oscillating negative decreasing pattern from 1963 to 1984 and a positive increasing pattern of values between 1986 to 1997. A decreasing pattern is observed towards the end of sample period. The implication of decreasing trends in stream flow are reduced freshwater ecosystem services and water resources thus increased pressure on the ecosystem resulting to degradation and climate change. Unstable trends make it difficult to plan and prepare for disasters.

The result from the Mann-Kendal trend analysis showed that ties were detected in the data for Nzoia gauging station 1EE01 and appropriate corrections applied, and an approximation was used to compute the p-value whereas for Nzoia gauging station 1BB01, an exact method was applied. The result for the p-value are as follows; Nzoia 1BB01: 0.0802, Nzoia 1EE01: 0.2166, respectively, depicting that for both datasets the computed p-value is greater than the significance level alpha of 0.05 and therefore one cannot reject the null hypothesis Ho that there is no trend in the data sets. Results for Mann-Kendal trend analysis is presented in Table 4.10. For a detailed trend analysis data were sub-divided into 4 periods of 14,15 and 44 years;1963-1977 (15yrs), 1978-1992 (15yrs), 1993-2006 (14yrs), 1963-2006 (44yrs), for both gauging stations. An example illustrated is presented for Nzoia gauging station 1EE01 below.

Mann-Kendal trend analysis was carried out for the Annual mean runoff for Nzoia gauging station 1EE01 and is graphically plotted in Figures 4.20-4.23. Data for period 1963-1977 showed a slight negative downward trend with a Coefficient of determinant (R^2) rate of 0.01%, followed by continued downward trend a R^2 rate of 3.8% for period 1978-1992. Period 1993-2006 showed an initial significant upward trend 93m^3 in 1993 to 147m^3 in 1996. This is followed by significant downward trend from 134m^3 in 1997 to 98m^3 in 2006 with a R^2 rate of 14.7%.

The full sample period of 1963-2006, in Figure 4.17 depicts significant up-down oscillating pattern of values that ranges from 126m^3 to 45m^3 to 147m^3 ending 98m^3 with a R^2 of 4.89% depicting a gradual upward trend. Decreasing and unstable runoff is a signal of impacts of climate change. This being a gauging station on the main Nzoia river is an indicator that there is a significant decreasing trend of runoff from contributing tributaries upstream. It can also mean that the increased human activities upstream are impacting runoff levels through diversion. However with limited data, the study was not able to ascertain the continued upward trend up to 2016 the end of the sample period. Below are summary statistics for the Mann-Kendal trend test.

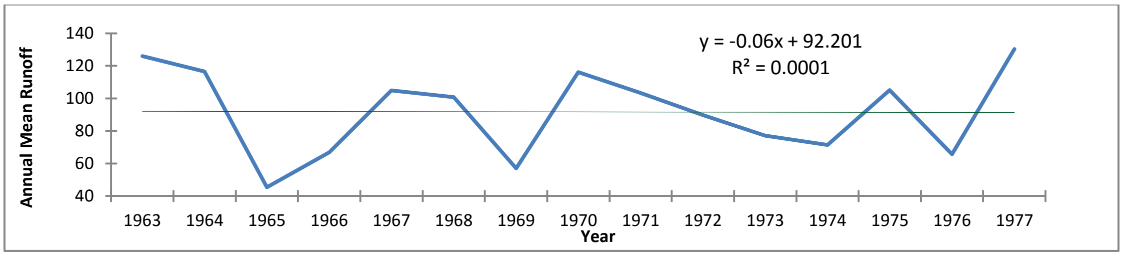

Figure 4.20: Trend for Runoff for Nzoia Gauging Station 1EE01 for the Period 1963-1977

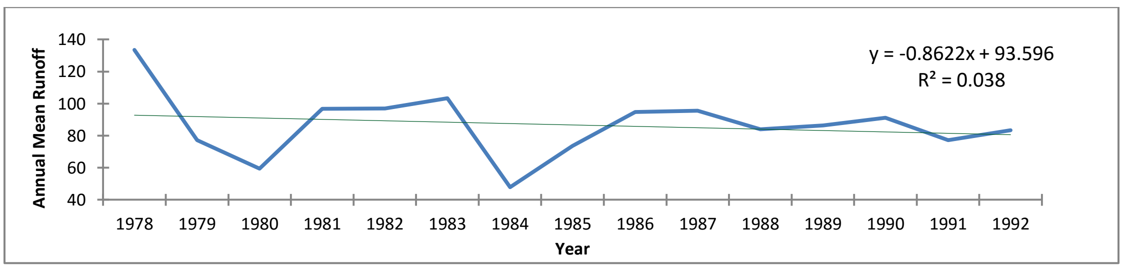

Figure 4.21: Trend for Runoff for Nzoia Gauging Station 1EE01 for the Period 1978-1992

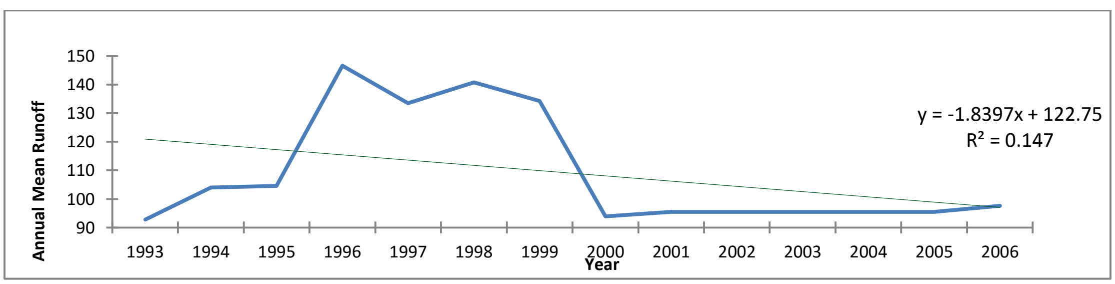

Figure 4.22: Trend for Runoff for Nzoia Gauging Station 1EE01 for the Period 1993-2006

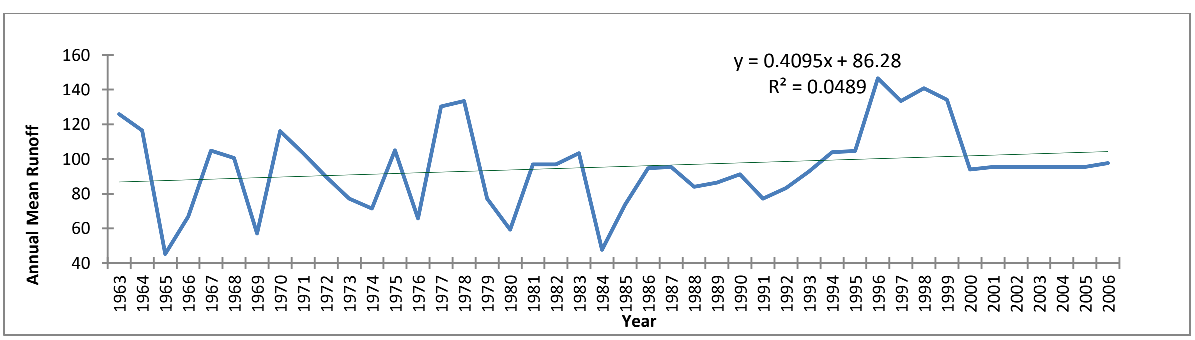

Figure 4.23: Trend for Runoff for Nzoia Gauging Station 1EE01 for the Period 1963-2006)

The p-value was computed for period 1963-1977 and 1978-1992 using an exact method while for the period 1963-2006 and 1963-2006 an approximation was used. The result was 1963-1977: 0.7705, 1978-1992: 0.3795, 1993-2006: 0.5744, 1963-2006: 0.2166 respectively. Based on these results, it is depicted that for all periods the p-value is greater than the significance level of alpha of 0.05 and therefore one cannot reject the null hypothesis H0 that there is no trend in this data. However, this does not necessarily imply we accept it. It may mean either H0 is true that there is no trend in the data set or that H0 is false but our the experiment and statistical test were not strong enough to lead to a p-value lower than alpha. Table 4.10 below is a summary of result for the statistical trend test.

Table 4.10: Result Mann-Kendall Trend Test / Two-tailed Test (Annual Mean Runoff) for Nzoia Gauging Station 1EE01 for the Period (1963-1977, 1978-1992, 1993-2006, 1963-2006)

	Discharge Period	Kendall's tau	S	Var(S)	p-value (Two-tailed)	alpha	Sen's slope:	Confidence interval:
1EE01 Nzoia	1963-1977	-0.0667	-7.0000	0.0000	0.7705	0.05	-1.0481	(-23.0845 , 22.8630)
1EE01 Nzoia	1978-1992	-0.1810	-19.0000	0.0000	0.3795	0.05	-0.8851	(-16.0683 , 15.6752)
1EE01 Nzoia	1993-2006	-0.1281	-11.0000	317.0000	0.5744	0.05	-0.5305	(-13.1929 , 11.5905)
1EE01 Nzoia	1963-2006	0.1311	123.0000	9747.0000	0.2166	0.05	0.3551	(-8.9279 , 9.1932)

4.6.1.3 Category C Period 1963-1993

Suam river is one of the few major rivers flowing north wards in the Upper Elgon watersheds. It flows into Turkwell river which drains into Lake Turkana. Suam river gauging station 2B07 is located on 1.48^0 N, 35.01^0E on Suam River. Trend analysis for the Annual mean runoff for Suam gauging station 2B07 for the period 1962-1993 was carried out. Data was subdivided into 3 periods of 16, 16, and 30years; 1962-1977, 1978-1993, 1962-1993 respectively and graphically plotted in Figure 4.24 and 4.25-4.27. The histogram showed a general outlook of the annual mean runoff for the sample period of 32 years for the period 1962-1993. It depicted undulating level patterns in runoff levels through the period. The lowest being $5.32m^3$ in the 23^{rd} water year and the highest being $30.61m^3$ in 20^{th} water year. The beginning of the sample period of the 1^{st} water year recorded $9.46m^3$ while the 32^{nd} water year recorded $9.43m^3$ with a mean record of $12.72m^3$ for the full sample period. A decreasing pattern in values is observed. The hydrographs show that the period 1962-1977 depicted an increasing pattern in values of $9m^3$ to $19m^3$ dropping to $8m^3$ increasing to $18m^3$ of 1962, 1971, 1973 and 1993 respectively. It is to be noted however that though the value levels increased steadily by $10m^3$ between 1962 and 1971 a period of 10 years, the levels dropped significantly by $11m^3$ within a period of 2 years. This period observed an upward trend with a Coefficient of determinant (R^2) rate of 1.59%. Implying increased intensity in drivers of impact on freshwater ecosystem services being either significantly reduced rainfall levels as a result climatic changes or intensified human activities at head waters most likely irrigation for rice cultivation, fish farming and deforestation.

The period 1978-1993 on the other hand depicted an oscillating decreasing pattern of values of $13m^3$ to $10m^3$ rising to $31m^3$ in 1981 dropping to $5m^3$ in 1984. This is followed by a gradually increasing pattern in values to $9m^3$ in 1993depicting a R^2 rate of 1.436%. The full sample period depicted a downward trend with a R^2 rate of 8.14%. The implications of a decreasing trend in runoff is an indicator of climate change. The challenge of reduced freshwater levels in an already semi-arid area poses a high probability in future occurrence of reduced water levels in Lake Turkana, drought and reduced freshwater ecosystem services in region important for wild life and livestock farming.

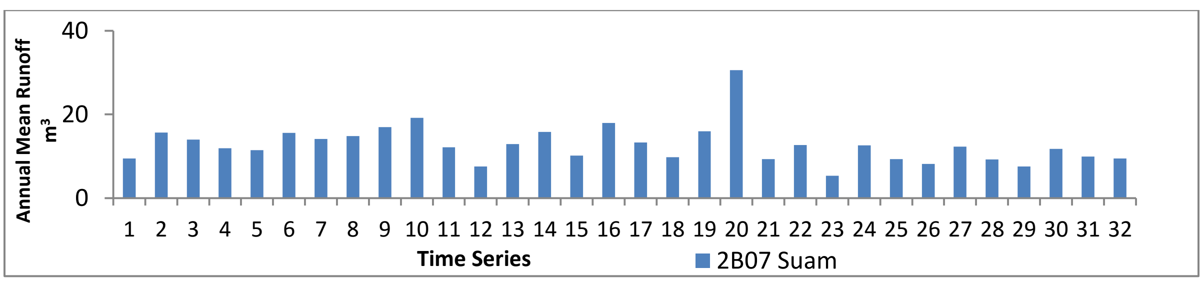

Figure 4.24: Annual Mean Runoff for Category C Station for the Period (1963-1993)

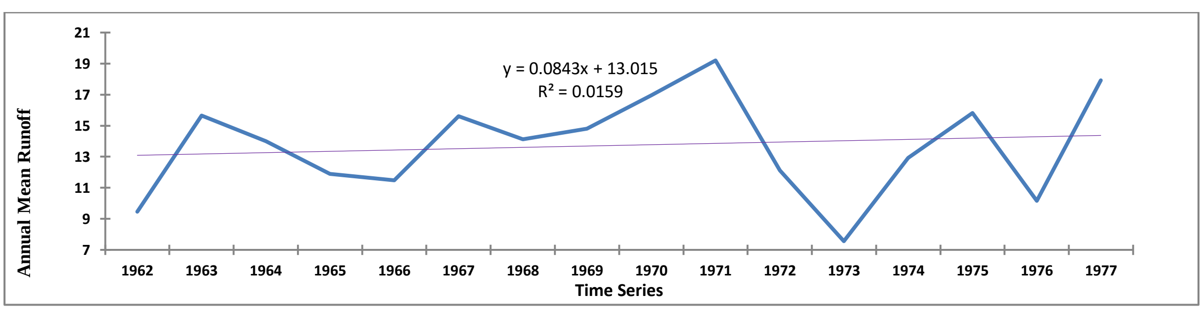

Figure 4.25: Trend for Runoff for Suam Gauging Station 2B07 for the Period 1962-1977

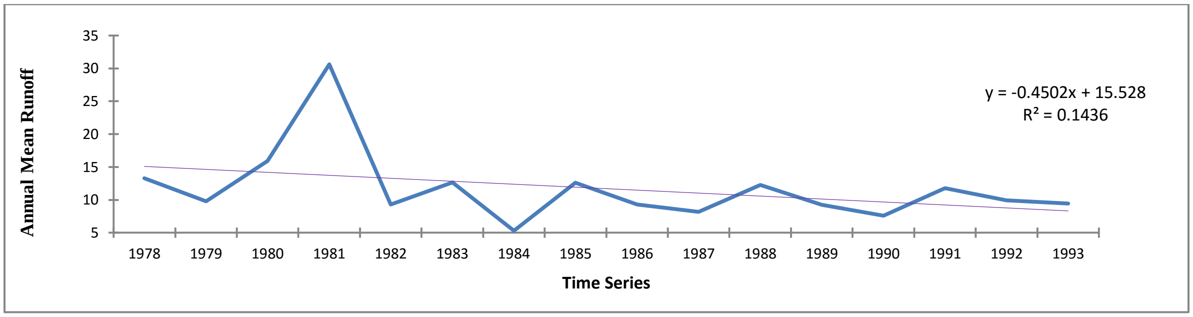

Figure 4.26: Trend for Runoff for Suam Gauging Station 2B07 for the Period 1978-1993

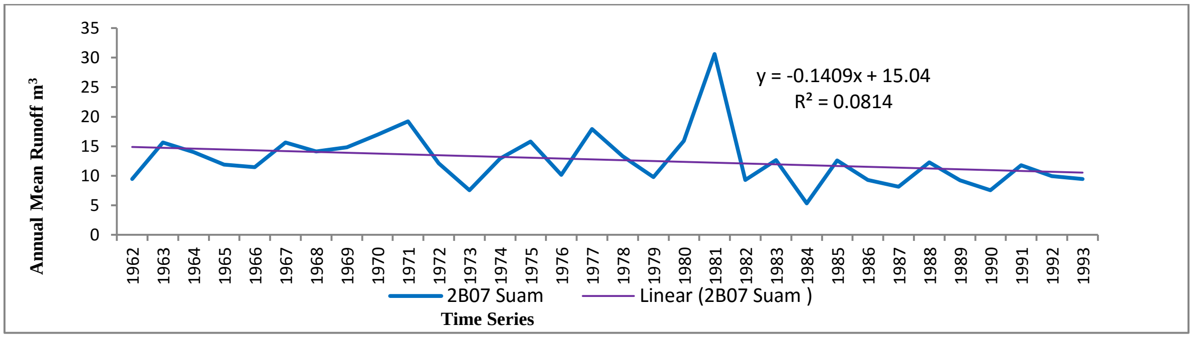

Figure 4.27: Trend for Runoff for Suam Gauging Station 2B07 for the Period 1962-1993)

As the data was analysed based on the 3 periods, results are thus presented in like manner in the trend statistical test result are presented in Table 4.11. The p-value was computed for the periods 1962-1977, 1978-1993 and 1962-1993 using an exact method. The result was; 1962-1977: 0.4503, 1978-1993: 0.0960, 1962-1993 : 0.0234. Based on these results, periods 1962-1977, 1978-1993 depicted p-value to be greater than the significance level alpha of 0.05, and therefore one cannot reject the null hypothesis H0 that there is no trend in the data sets for both periods. For the period 1962-1993 with p-value of 0.0234 depicted that the p-value was lower than the

Table 4.11: Mann-Kendall Trend Test / Two-tailed Test (Annual Mean Runoff) for Suam Gauging Station 2B07 for the Period (1962-77, 1978-1993, 1962-2008)

	Discharge Period	Kendall's tau	S	Var(S)	p-value (Two-tailed)	alpha	Sen's slope:	Confidence interval:
2B07 Suam	1962-1977	0.1500	18.0000	0.0000	0.4503	0.05	0.163	(-2.1168 , 2.6087)
2B07 Suam	1978-1993	-0.3167	-38.0000	0.0000	0.0960	0.05	-0.2081	(-3.7660 , 4.1103)
2B07 Suam	1962-1993	-0.2823	-140.0000	0.0000	0.0234	0.05	-0.1548	(-2.1292 , 2.0169)

significance level of alpha of 0.05. Based on this result, one should reject the null hypothesis H0 and accept the alternative hypothesis Ha that there is a trend in the data. Based on the graphical observation, this conforms a decreasing trend in runoff, a signal of climate change, and hence a negative impact on freshwater ecosystem services sustainability in the Mt.Elgon watersheds.

4.6.2 Precipitation Trends

Graphical plots for of Mann-Kendal Trend analysis for datasets for Buginyanya and Tororo monitoring station as illustrated in Figure 4.28 and 4.29. The result for the Mann-Kenadal trend analysis for Buginyanya shows that the initial 6 years between 1995-2001 depict an oscillating upward pattern of values and followed by a reducing pattern of values ranging between 174-192mm. In 2002 a significant negative downward reducing pattern of values is observed of up to 103mm at the lowest recording. This is followed by a significant positive upward increasing pattern to the highest recording of 372mm in 2007. The value drops to 138mm by 2009 followed by a gradual upward pattern for the remaining period to 188mm by 2016. The period 2001-2010 depict significant upward increasing and reducing pattern of values recording both the lowest and highest recorded annual mean precipitation values.

The graph also demonstrates uncertainty in expected precipitation in that particular period. The full sample period illustrates a positive upward trend with a Coefficient of determinant (R^2) rate of 1.04%. Significant changes in precipitation over prolonged periods is a signal of climate change. Precipitation being the source for all water including streamflow, uncertainty of expected precipitation inhibits planning for every aspect of the economy as water is paramount in every sector of development and most importantly planning for drought and flood management.

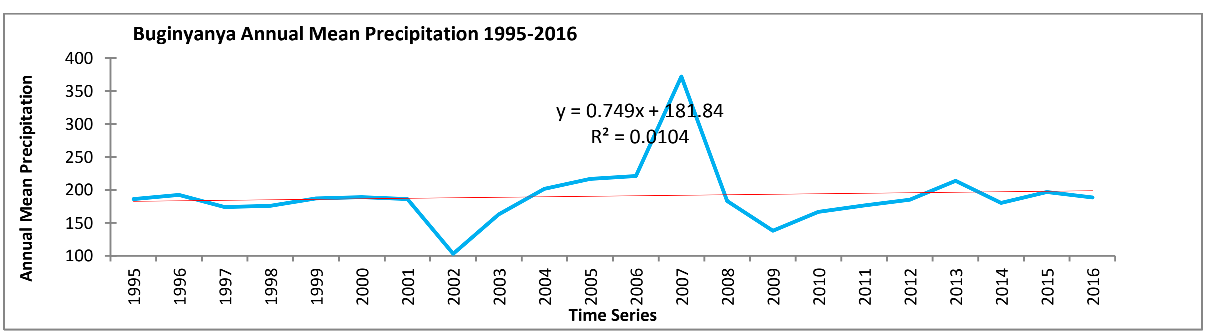

Figure 4.28: Trend for Precipitation for Buginyanya, Gauging Station for the Period 1962-1993

The result for Mann-Kennadal trend test presented in graphical figure for data for Tororo gauging station for the period 1960-2011, depicts oscillating downward pattern in mean annual precipitation values. It illustrates 138mm at the beginning of sample period (1960) with a positive increasing pattern to 165mm in 1961 which is the highest recorded value in the sample period. The figure illustrates an oscillating decreasing pattern n values with the lowest recorded value at 85mm in 1973 and 135mm by 2011. While the initial 25years from 1960-1986 illustrate a oscillating downward pattern, the following 26 years of 1987-2011 show and upward oscillating pattern in values though with less annual mean precipitation values by end of sample period depicting a negative downward trend with a Coefficient of determinant (R^2) rate of 0.06%. An increasing pattern of values could imply shift in climatic conditions however given the observed pattern of sudden decrease in values within the same sample period, is a signal of unpredicted climatic changes. The implications in the future being sudden flooding of wetlands and destruction of infrastructure as well as hydrological drought affecting livelihoods, the quality and quantity of freshwater ecosystem services due to pollution, silting and shortage.

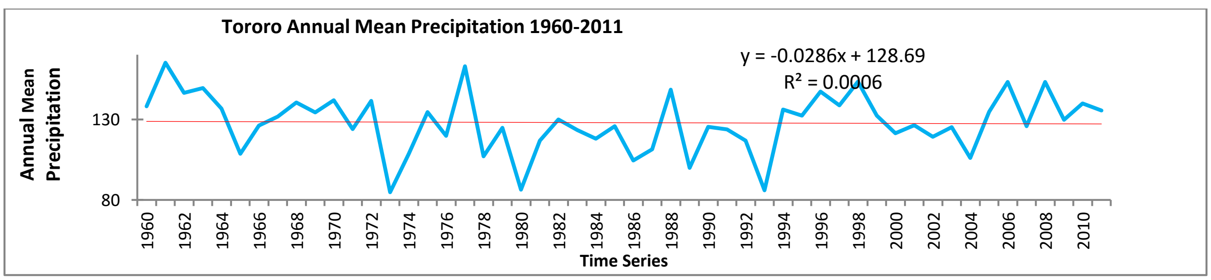

Figure 4.29: Trend for Precipitation for Tororo Gauging Station for the Period 1960-2011

The result graphical representation for data for Kitale gauging station for the period 1986-2016, depicts a steady oscillating upward pattern of values rising from 86mm in 1986 which is the lowest annual mean precipitation value recorded to 131mm in 2007 which is the highest record. However, the annual mean precipitation value drops in the preceding years over time to 122mm in 2015 depicting an overall upward trend with a Coefficient of determinant (R^2) rate of 33.53% depicting an gradual increasing upward trend for the full sample period. An increasing trend in precipitation implies an increase in streamflow. Increased water resources means increased possibility of freshwater ecosystem services. This can only be sustainable if other factors are in place. For example responsible management of freshwater ecosystems, resources and associated natural resources like controlled harvesting of timber curbing deforestation, good land-use/ land-cover management practices to avoid degradation especially along river channels to minimizing evapotranspiration and responsible livelihood activities for conservation and sustainable freshwater ecosystem services. Graphical representation is plotted in Figure 4.30.

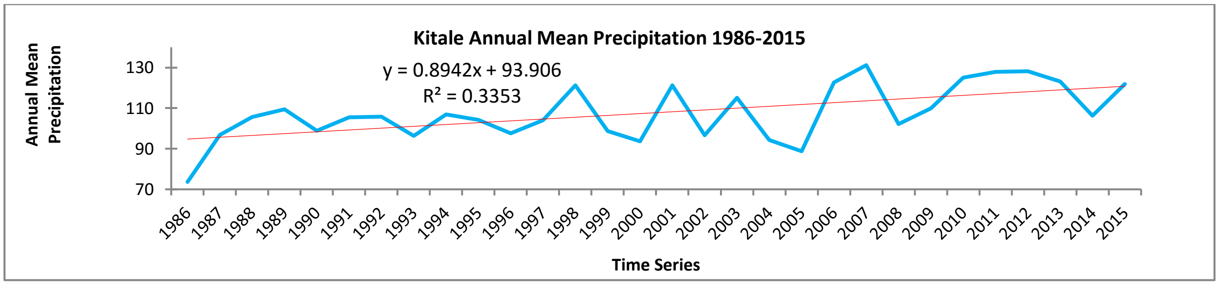

Figure 4.30: Trend for Precipitation for Kitale Gauging Station for the Period 1986-2015

Results from the Mann-Kendal trend analysis of data for Kakamega rain gauging station for period 1961-2008, depicts a gradually reducing pattern of values from 256mm in 1961 which is the highest annual mean precipitation value recorded to 116mm in 2000 at the lowest recorded value. A continued decreasing pattern of values to 157mm in 2008 as the last recorded value in the sample period is observed. It is however noted there was a significance increasing pattern from 167mm in 1987 to 217mm in 1988 dropping to 166mm in 1989 depicting downward trend with a Coefficient of determinant (R^2) rate of 0.0629. The full sample period in Figure.31 showed a gradual decreasing trend. Increased human activities in the region and cutting of trees, shrubs and medicinal plants for cultural and medicinal products as well as clearing land for livelihoods activities is leading to reduced annual mean precipitation. Continued decreasing precipitation levels will greatly impact the forest reserve as well as surrounding areas that depend on the climatic benefits it provides as well as impact freshwater ecosystem services negatively.

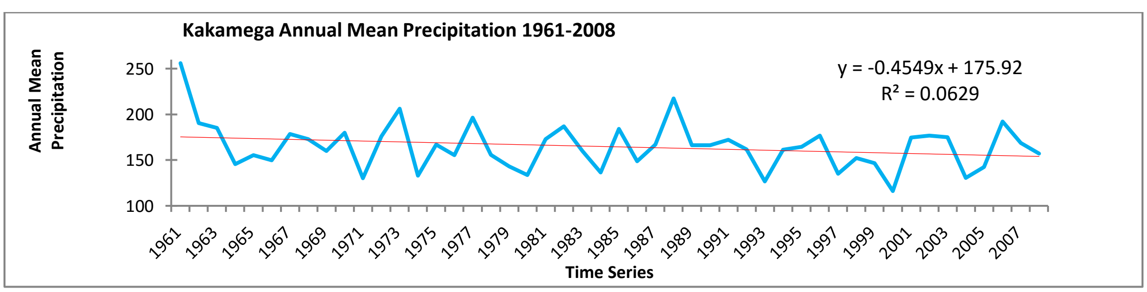

Figure 4.31: Trend for Precipitation for Kakamega Gauging Station for the Period 1961-2008

Summary statistics for annual mean precipitation for all datasets was computed and results presented. The p-value was computed for datasets for Buginyanya, Kitale and Kakamega rain gauging station using an exact method. While for Tororo rain gauging station as the exact p-value could not be computed and an approximation was used. The results was as follows; Buginyanya 1995-2016: 0.5779, Tororo 1960-2011: 0.8190, Kitale 1986-2015: 0.0075, Kakamega 1961-2008: 0.1987 respectively**.** The result is discussed below in Table 4.12 and 4.13. The results showed that data for Buginyanya, Tororo and Kakamega rain gauging stations depicted that the computed p-value was greater than the significance level alpha of 0.05 and therefore one cannot reject the null hypothesis Ho that there was no trend in the data. The trend analysis for data for Kitale rain gauging station showed that the computed p-value was lower than the significant level alpha of 0.05 and therefore depicting that one should reject the null hypothesis H0 and accepted the alternative hypothesis Ha that there is a trend in the data. However as observed all graphical plots depicted both a decreasing and increasing trend at certain periods of time.

Table 4.12: Summary Statistics of Datasets for Annual Mean Precipitation for Selected Rain Gauging Stations

Variable (Annual Mean Precipitation)	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Buginyanya	22	0	22	103.0260	371.6000	190.4574	47.7104
Tororo	52	0	52	84.8000	165.1635	127.9365	18.0622
Kitale	30	0	30	73.6000	131.1417	107.7665	13.5948
Kakamega	48	0	48	116.1917	256.2000	164.7715	25.4015

Table. 4.13: Mann-Kendall Trend Test / Two-tailed Test (Annual Mean Precipitation) for Sampled Rain Gauging Stations in the Mt.Elgon Watersheds for the Period (1960-2016)

	Trend Period	Kendall's tau	S	Var(S)	p-value (Two-tailed)	alpha	Sen's slope:	Confidence interval:
Buginyanya	1962-1993	0.0909	21.0000	0.0000	0.5779	0.05	0.5005	(-26.8512 , 28.7854)
Tororo	1960-2011	-0.0226	-30.0000	16059.3333	0.8190	0.05	-0.0232	(-6.3434 , 5.5956)
Kitale	1986-2015	0.3425	149.0000	0.0000	0.0075	0.05	0.8202	(-4.6170 , 7.1662)
Kakamega	1961-2008	-0.1294	-146.0000	0.0000	0.1987	0.05	-0.329	(-11.0075 , 7.6401)

In conclusion, all regions experience varying climatic conditions influencing the precipitation levels differently. It is also observed that station near forest reserve record higher precipitation levels emphasizing the importance of forest/tree vegetation cover in the formation of rainfall the source of streamflow.

4.7 Impacts of Climate Change: Opportunity Cost

This subsection is composed of results from Waterworld v.2 [.92] and Costingnature v.3 [.2] model simulations. This modelling and simulation exercise was carried out to assess socio-economic impacts on freshwater ecosystem services. The opportunity cost for conservation of freshwater ecosystems for sustainability against consumption of benefits at current state, in the Mount Elgon watersheds under a changing climate was also done.

4.7.1 Modelling and Simulation for the Opportunity Cost for Conservation

Modelling and Simulation for the opportunity cost for conservation of freshwater ecosystems with their associated ecosystems for freshwater ecosystem services sustainability using Co$tingnature model was done. In this case, modelling was carried out based on current baseline data statistically computed in percentage for current land-use and cover change, presented in form of output maps in relation to the opportunity cost of conserving the entire Mt.Elgon watershed to achieve full ecosystem benefits. The activities carried out in this exercise are mentioned and a summary explanation of what was done is given. Summary analysis for simulation scenarios for both Upper and Lower Elgon is presented in Table 4.14.

The result is presented in output maps figures with a key to define the percentage values of activity done. The opportunity cost of consumption of natural resources at current state as realised services and the priority to conserve based on the potential services. The conservation of the natural resources is to enhance the provision of full benefits of freshwater ecosystems and its associated ecosystem in the Mt.Elgon watersheds, for sustainable freshwater ecosystem service provision. Modelling enabled testing the effects of modifications in the climate system as a result of anthropogenic drivers of climate change. The results aid inform strategic planning for policy development and implementation as well as decision making regarding conservation of ecosystem services in the region.

Table 4.14: Summary Analysis Simulation Result for Scenario Outputs for Opportunity Cost

S/N	Name of activity	Explanation
1	Relative aggregate development priority index (realised services)	Pressured with low conservation priority and realised service provision
2	Relative aggregate development priority index (potential services)	Pressured with low conservation priority and potential service provision
3	Relative pressure index	Current pressure according to population, wildfire frequency, grazing intensity, agricultural intensity, dam density, infrastructure (dams, mines, oil and gas, urban) density
4	Relative threat index	Future threat according to accessibility, proximity to recent deforestation (MODIS), projected change in population and GDP, projected climate change, current distribution of nighttime lights
5	Relative total potential bundled services index	Total potential services including water, carbon, nature based tourism and hazard mitigation services
6	Relative total realised bundled services index	Total realised services including water, carbon, nature based tourism, hazard mitigation services
7	Greatest relative total realized bundled service	Greatest realised service from: water, carbon, nature and cultural-based tourism, hazard mitigation, timber (commercial and domestic), fuelwood, grazing, wildlife services, Non-wood forest products, wildlife dis-services, aquatic fisheries (commercial and artisanal) and environmental quality.

Results are presented as result scenario outputs illustrated in figures as Upper and Lower Elgon. A discussion on the opportunity cost to realise full benefits from the Mt.Elgon watersheds. This is in terms of development priority to conserve, the extent of pressure on the watersheds, the threats, the realised ecosystem services and potential services projected. Simulation results for relative aggregate development priority index for realized services, showed a significant highly pressured ecosystem with low conservation priority and realised service provision, for both Upper and Lower Elgon. This ranged between 0.500-1.000 at a local scale covering up approximately 90% of the total area. The result illustrated that the areas mostly under protected forest reserves provided the highest realized services, under a scale of 0-0.459. Only an area of up-to 1% depicted in grey-black experiences fully realised ecosystem services.

Ecosystem services are not fully realized due to land degradation. This is resulting from over exploitation and overuse. Land degradation resulting from poor land management practices lead to loose soils and exposed land cover due to destroyed vegetation. This results in soil erosion during rainy season which drains in the freshwater systems impacting freshwater ecosystem resources causing discoloration and silting in river systems. This affects the ability to provides clean and safe water for domestic and industrial use. Poor land management practices of cultivation especially along riparian zones affects the ability of provision of regulatory and flood control of freshwater ecosystem services. Areas highly affected are those with intensive agricultural regions of Bulambuli, Sironko and the Nzioa river basin as depicted in the figures below, with little or no measures towards conservation priority and sustainability of natural resources. This is illustrated in Figure 4.32 and Figure 4.33.

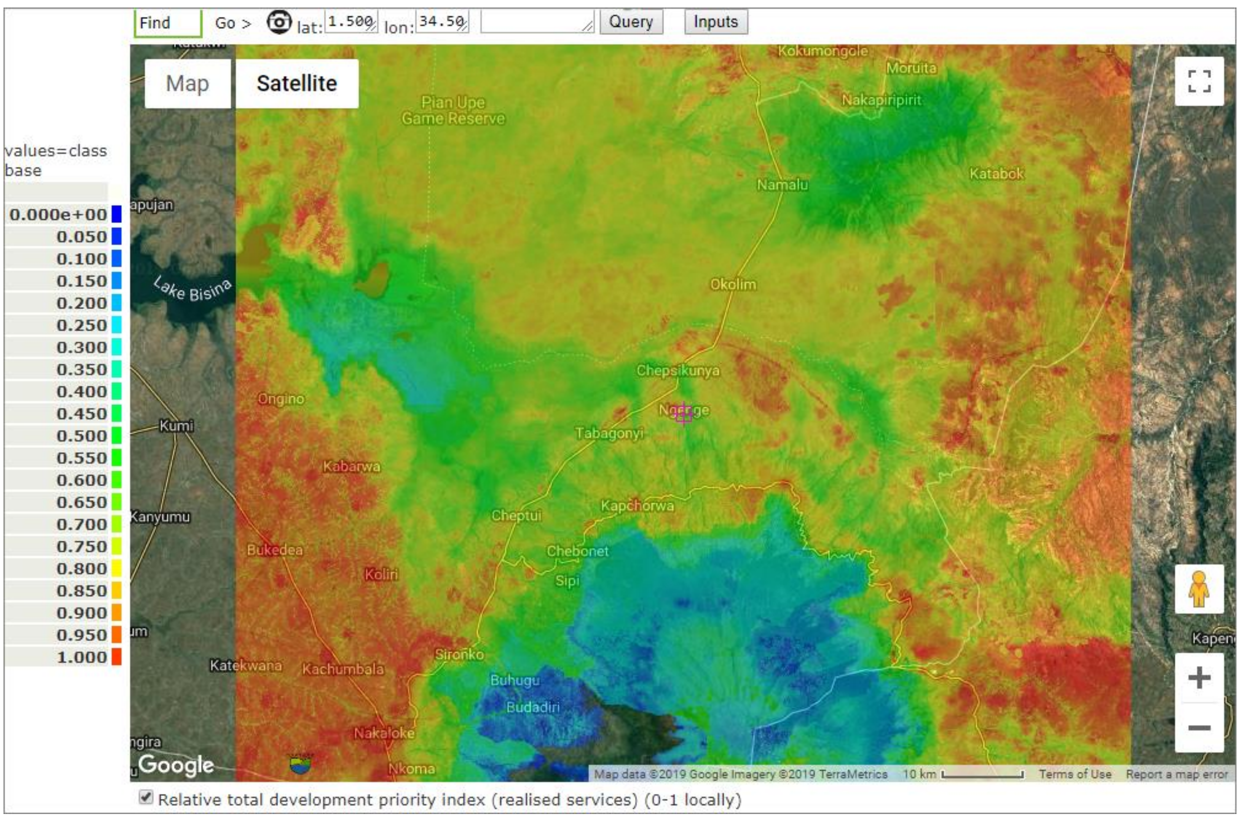

Figure 4.32: Relative Aggregate Development Priority Index for Realised Services in the Mt.Elgon Watersheds in Upper Elgon

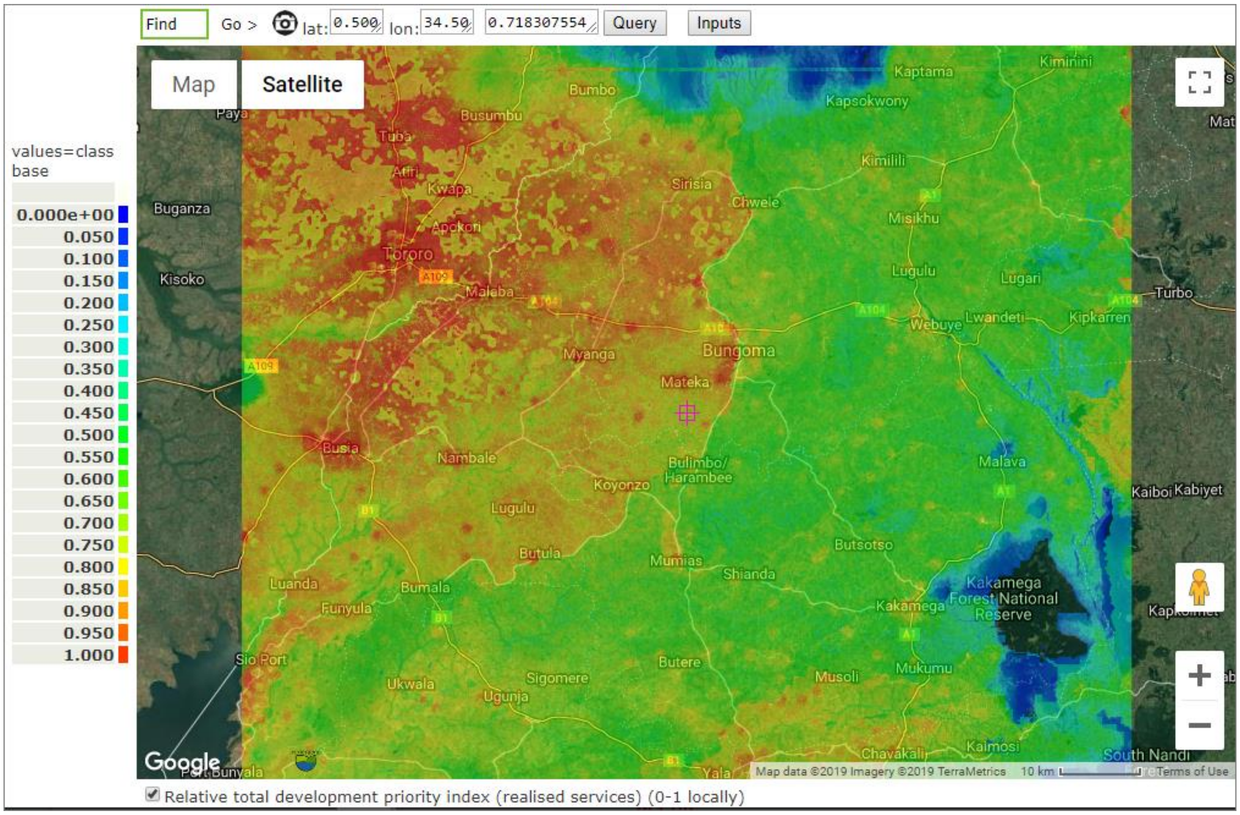

Figure 4.33: Relative Aggregate Development Priority Index for Realised Services in the Mt.Elgon Watersheds in Lower Elgon

Results for relative aggregate development priority index for potential services, depicted highly pressured and endangered conservation priority areas. High potential service delivery of relative and nature conservation priority index was observed in the results. This was mainly realized in protected forest reserves, along rivers and water bodies highest ranging 0.750-1.000 at a local scale. Over 80% of the ecosystem is pressured with low conservation priority as in Figure 4.34 and Figure 4.35 below. There is higher and wider spread for development priority for potential services in Lower Elgon than Upper Elgon which largely under gazzeted protection.

However the Upper Elgon too indicates high development priority for potential services in the river basins of Suam, Upper Nzoia basin, Sironko, Nakaloke and in Mpologoma river basin wetlands. There is urgency for total ecosystem nature conservation priority development, for areas with high potential to realise full benefits of supporting others ecosystems flora and fauna, filtration and flood control freshwater ecosystem services as depicted below.

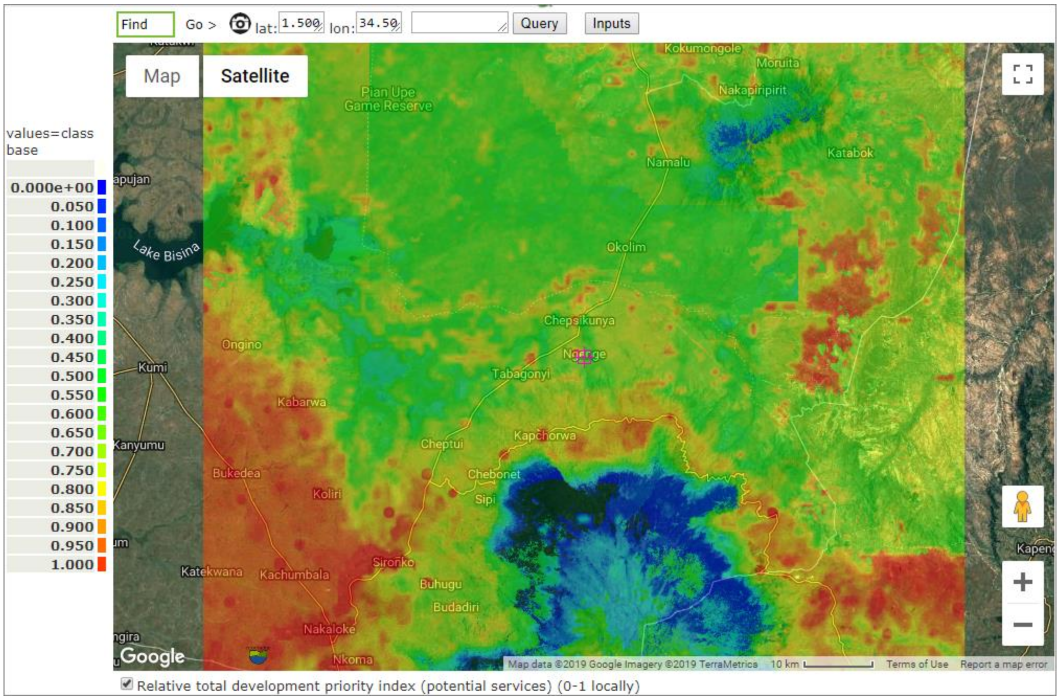

Figure 4.34: Relative Aggregate Development Priority Index for Potential Services in the Mt.Elgon Watersheds–Upper Elgon

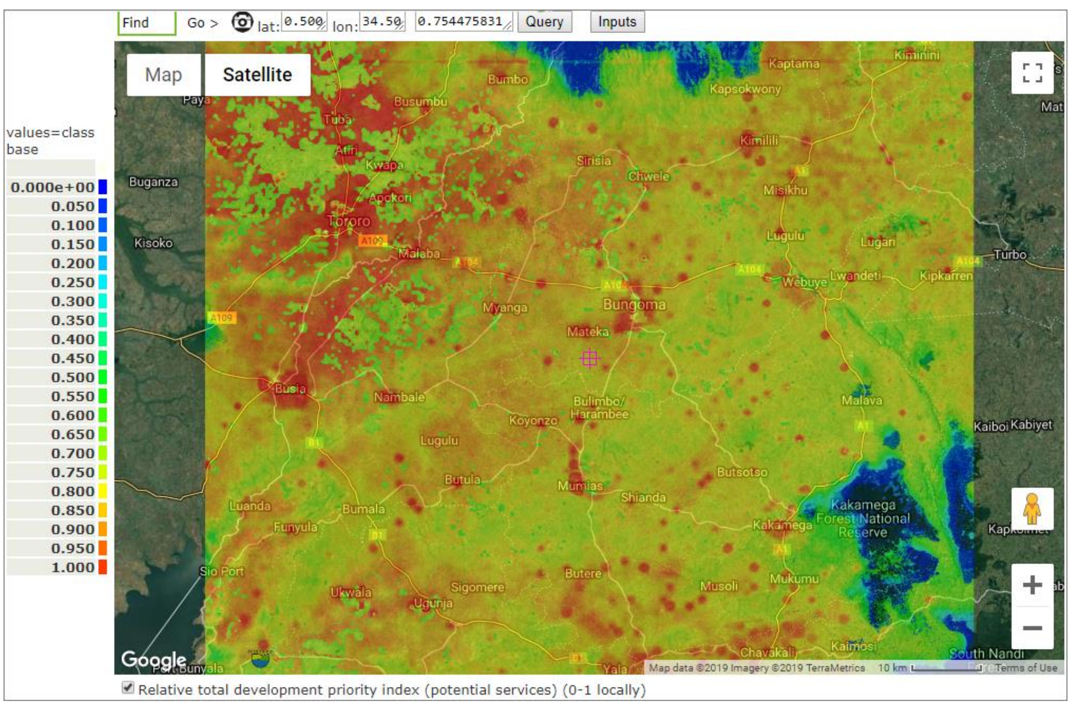

Figure 4.35: Relative Aggregate Development Priority Index for Potential Services in the Mt.Elgon Watersheds–Lower Elgon

Relative pressure index results showed most pressured areas ranging between 0.700-1.000 at a local scale. In Upper Elgon areas most pressured are Bulambuli, Sironko, Simu, Bukwo and Suam and areas towards Turkwell and Namatale forest reserve within watersheds. In Lower Elgon areas depicted are; Mt. Elgon forest reserve frontiers, Kitale and along the Nzoia river, Bungoma, areas neighboring Kakamega forest reserve, Busia, Bududa and Budaka. Also affected are along river Sironko, Manafwa Mpologoma, Namatala areas towards lake Kyoga, as illustrated in Figure 4.36 and Figure 4.37. This depicts the current realized pressure in respect of population, wildfire occurrence, grazing concentration, agricultural intensity, dam concentration. It also depicts realized pressure in terms of infrastructure density, that is dams, mines, oil and gas as well as urbanization. These areas among the most populated, raising demand for land, leading to land cover change and its impacts affecting freshwater ecosystems and services.

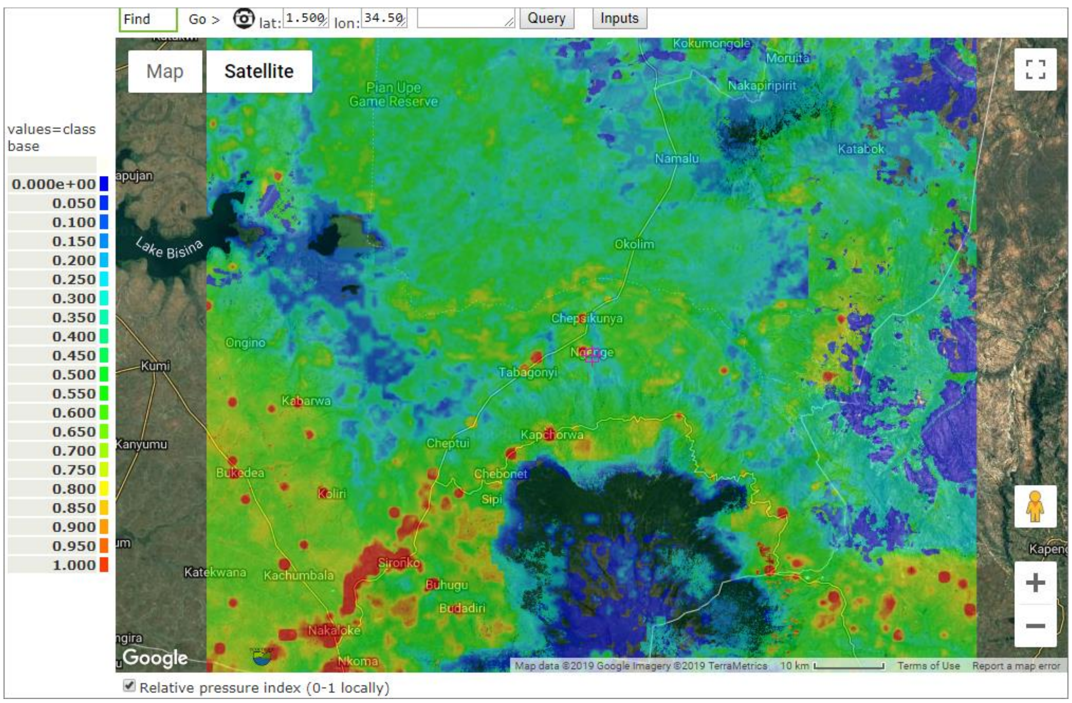

Figure 4.36: Relative Pressure Index in the Mt.Elgon Watersheds –Upper Elgon

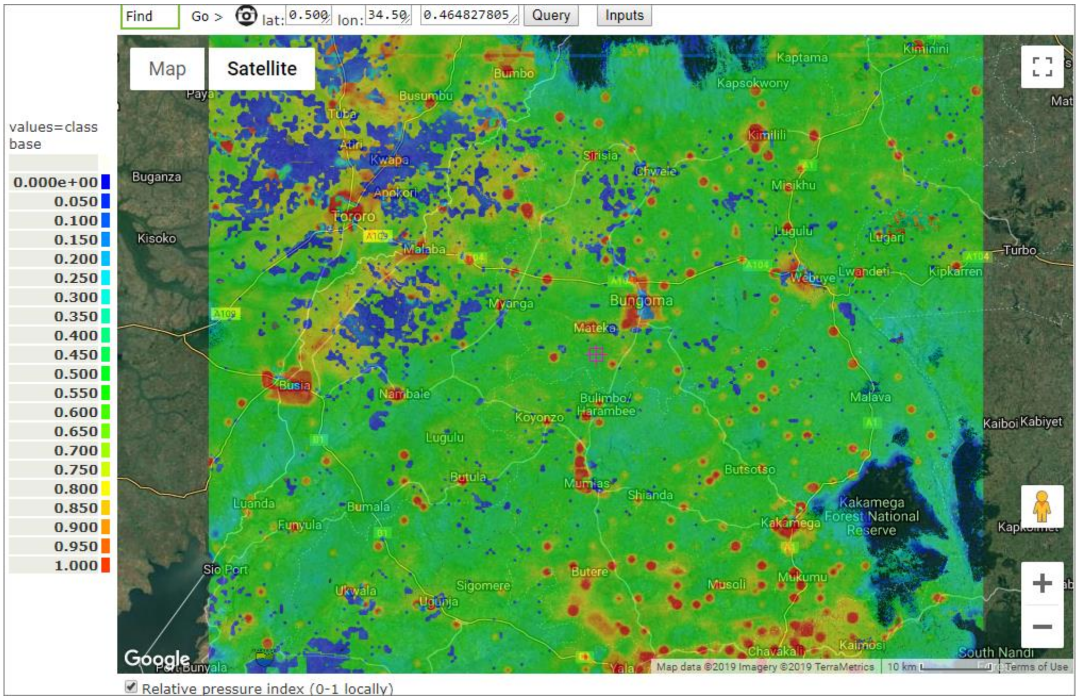

Figure 4.37: Relative Pressure Index in the Mt.Elgon Watersheds –Lower Elgon

The relative threat index result in Figure 4.38 and Figure 4.39 below, indicated future threat according to ease of access, nearness to recent deforestation, predicted change in populace and Gross Domestic Product (GDP). It also indicated projected climate change and present distribution and presence of nighttime lights. The highest future threats are in Buhugu, Nakaloke,

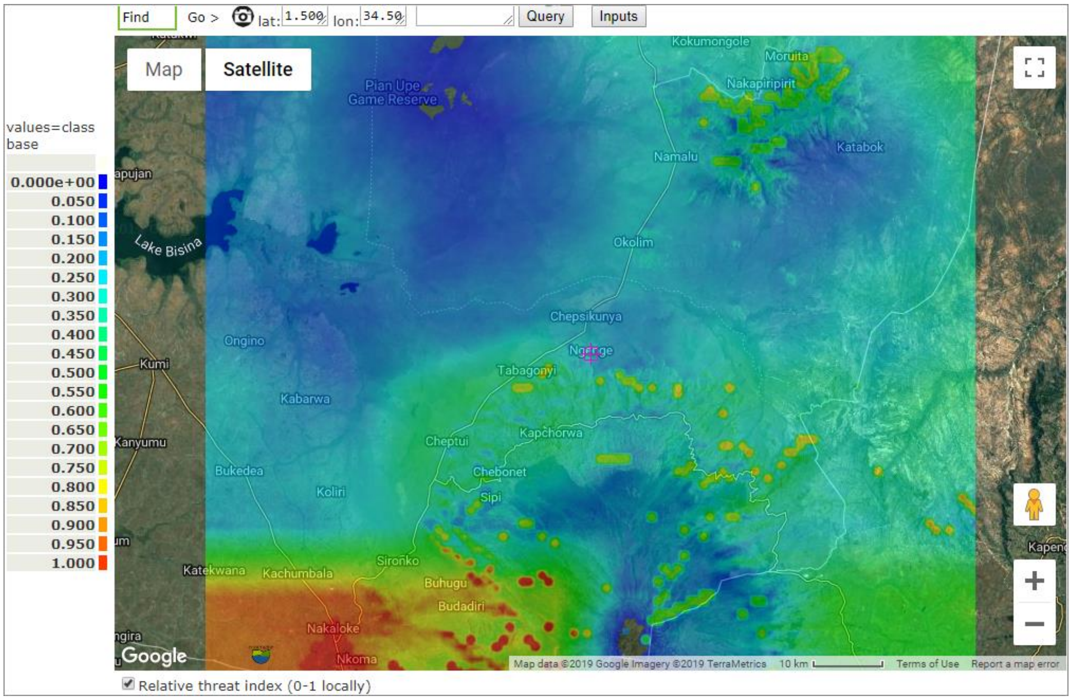

Figure 4.38: Relative Threat Index in the Mt.Elgon Watersheds Upper Elgon

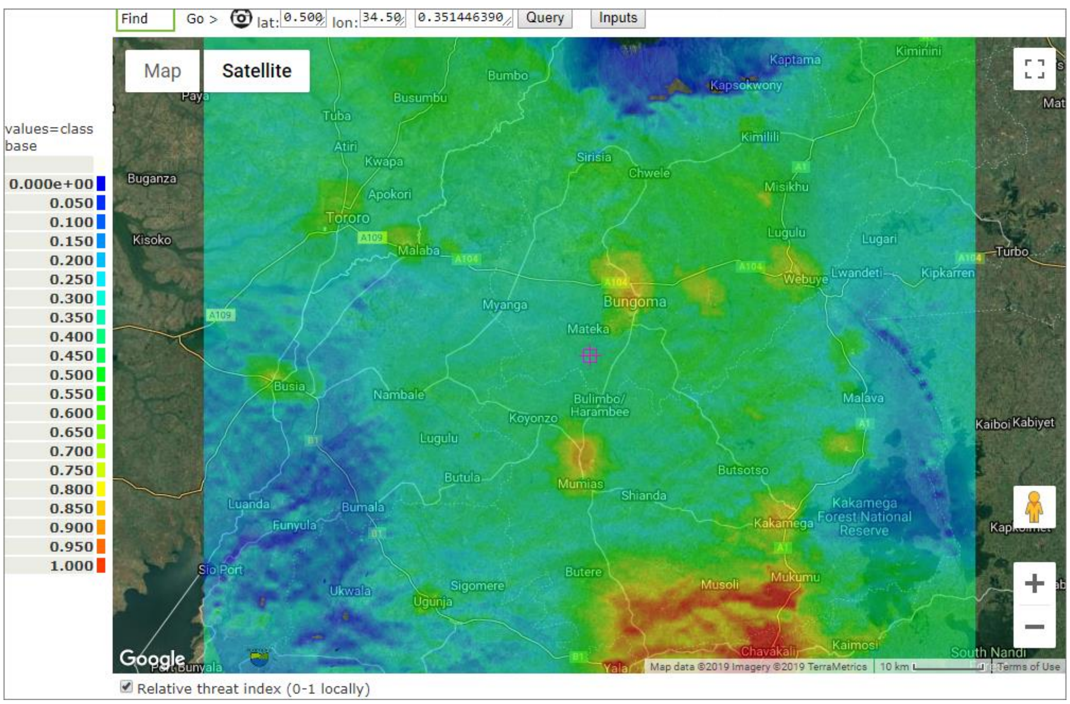

Figure 4.39: Relative Threat Index in the Mt.Elgon Watersheds Lower Elgon

Nkoma, upper Nzoia river basin, Kakamega, Musoli, Yala, Bungoma, Mumias and Webuye. Increased urbanization, rising population, unchecked increased human activity and the demand for freshwater ecosystem services for agriculture, irrigation, industry and domestic use, will affect their sustainability.

Results for relative potential bundled services for water, carbon, nature based tourism and hazard mitigation services in Figure 4.40 and Figure 4.41, showed relative total potential bundled services index highest along the rivers and protected forest reserves of Mt. Elgon and Kakamega forest reserve, ranging 0.600 – 1.000 an area of approx. 10% of total area emphasizing the urgent need resettlement for reforestation as conservation priority to enhance precipitation so as to enhance ecosystem health improved land cover. This will avoid impacts of poor watersheds management for sustainability freshwater ecosystem services. Other relative bundled services represented in timber for commercial and domestic use, fuelwood, grazing, wildlife dis-services, aquatic fisheries both commercial and artisanal and environmental quality for both Upper and Lower Elgon.

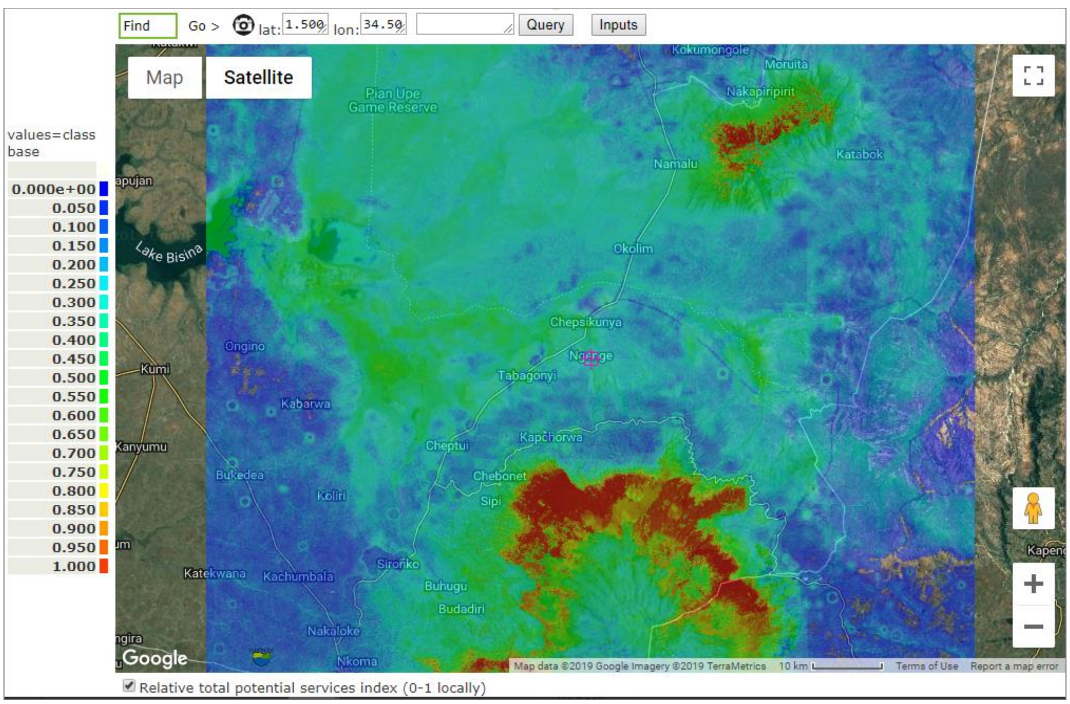

Figure 4.40: Relative Total Potential Bundled Services Index in the Mt.Elgon Watersheds-Upper Elgon

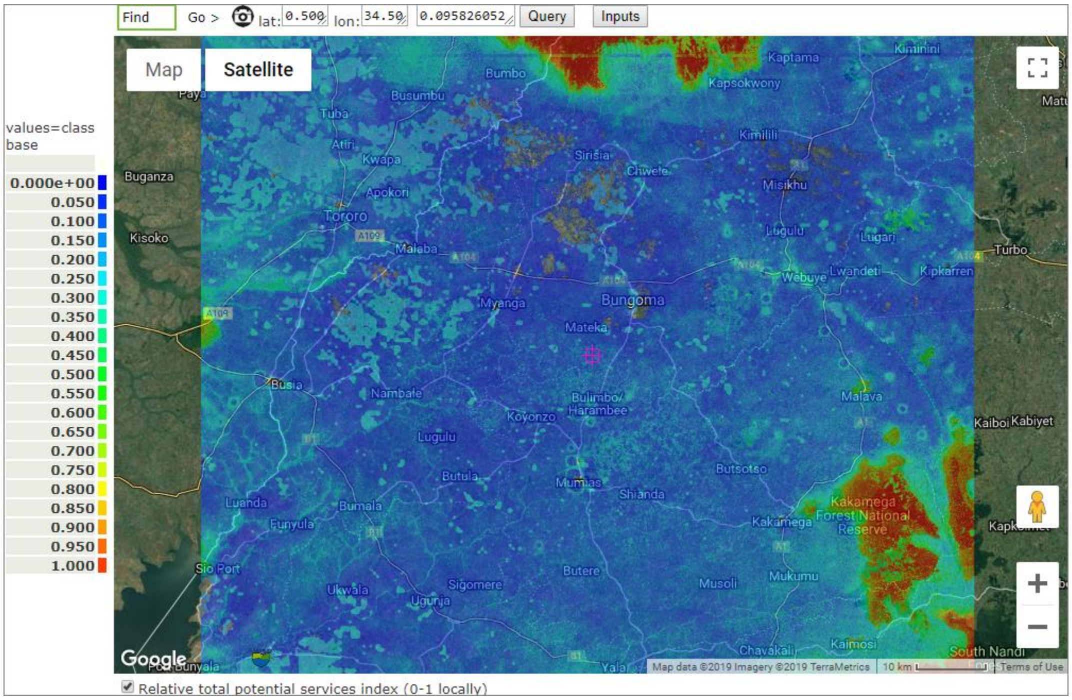

Figure 4.41: Relative Total Potential Bundled Services Index in the Mt.Elgon Watersheds-Lower Elgon

Results for Total realized bundled services illustrated in Figure 4.42 and Figure 4.43, showed that relative total realised bundled services index was observed highest within the protected forest reserves. This ranged 0.236-0.260 reducing along the river systems and less on bare land, mainly where human activites were more intensified in agricultural production. It is also observed that within the forest reserve where cattle grazing is takes place less relative total realised bundled services index is observed. Implying the largest area of the whole upper Elgon Watershed realised less bundled services bundled services are not realized along the rivers and water bodies of the Lower Elgon. The rest of the area covering 95% showed a scale of only 0.181-0.228 of relative total realized bundles service index. With the increasing human activity this is likely to drop further. Other total realized bundled services within those areas included carbon, nature based tourism and hazard mitigation. Also realized services are timber for commercial and domestic use, fuelwood, grazing wildlife dis-services, aquatic fisheries for both commercial and artisanal purposes as well as environmental quality ecosystem services.

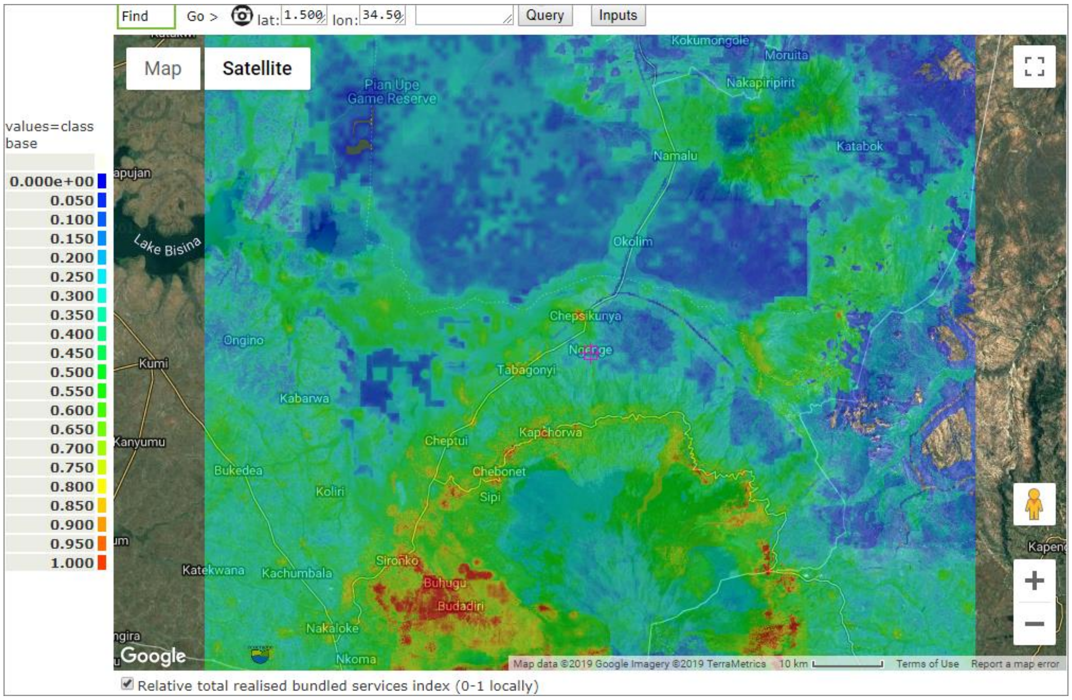

Figure 4.42: Relative Total Realised Bundled Services Index in the Mt.Elgon Watersheds- Upper Elgon

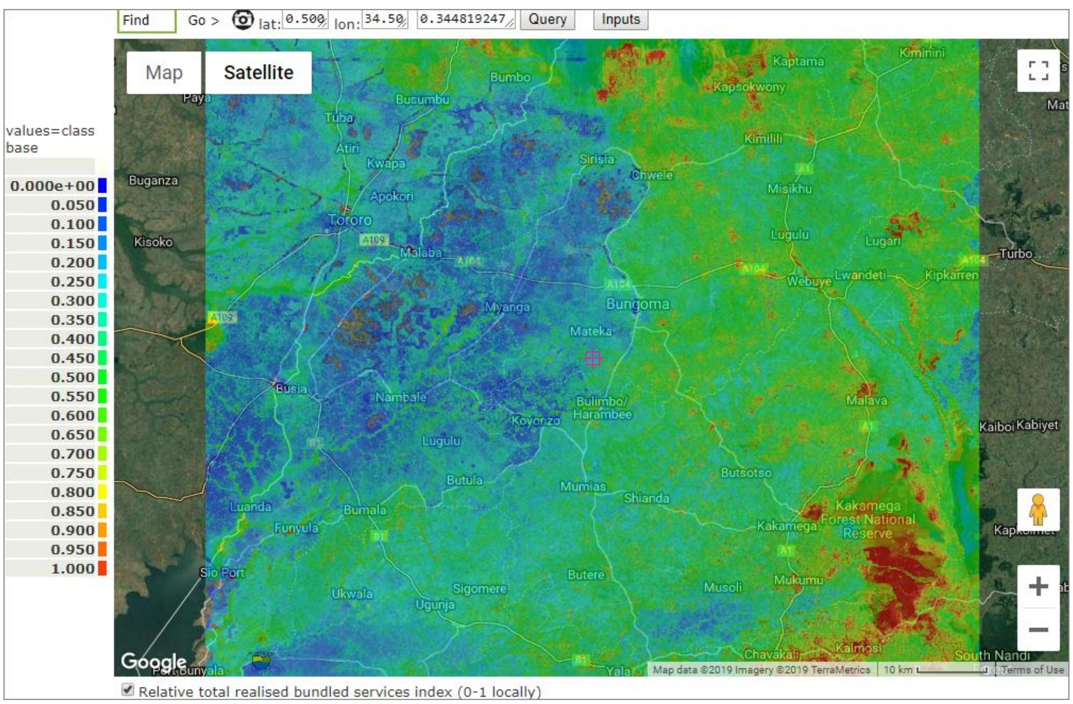

Figure 4.43: Relative Total Realised Bundled Services Index in the Mt.Elgon Watersheds- Lower Elgon

A representation of the greatest relative total realised bundled services as illustrated in Figure 4.44 and Figure 4.45 below was modelled. Results depicted carbon and water as the greatest realised services in Upper and Lower Elgon respectively, while hazard mitigation services and environmental quality is among the least realized ecosystem services. This compromises ecosystem health and its ability to offer sustainable ecological services. Conservation is a priority to achieve full benefits of the freshwater ecosystem services and associated ecosystem services. Other Greatest realised services include nature based tourism. Timber for both commercial and domestic purposes is another of the realised services Others are hazard mitigation services, fuelwood, grazing, wildlife dis-services, aquatic fisheries (commercial and artisanal) and environmental quality

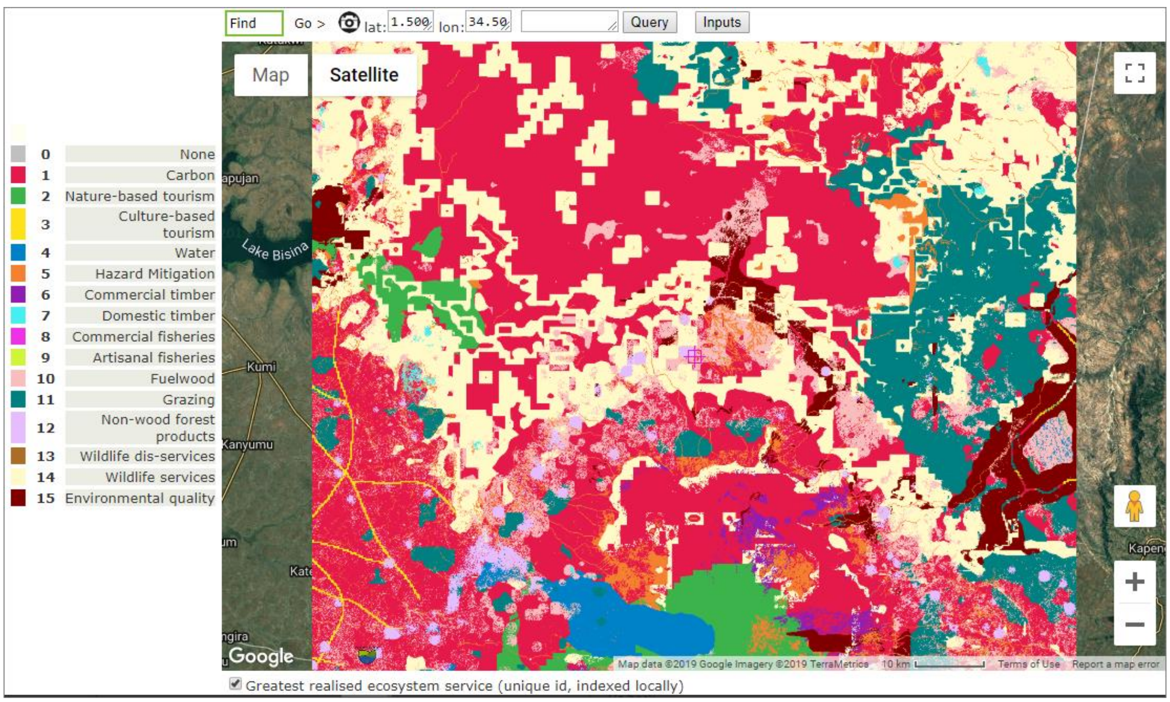

Figure 4.44: The Greatest Relative Total Realised Bundled Services Index in the Mt.Elgon Watersheds Upper Elgon

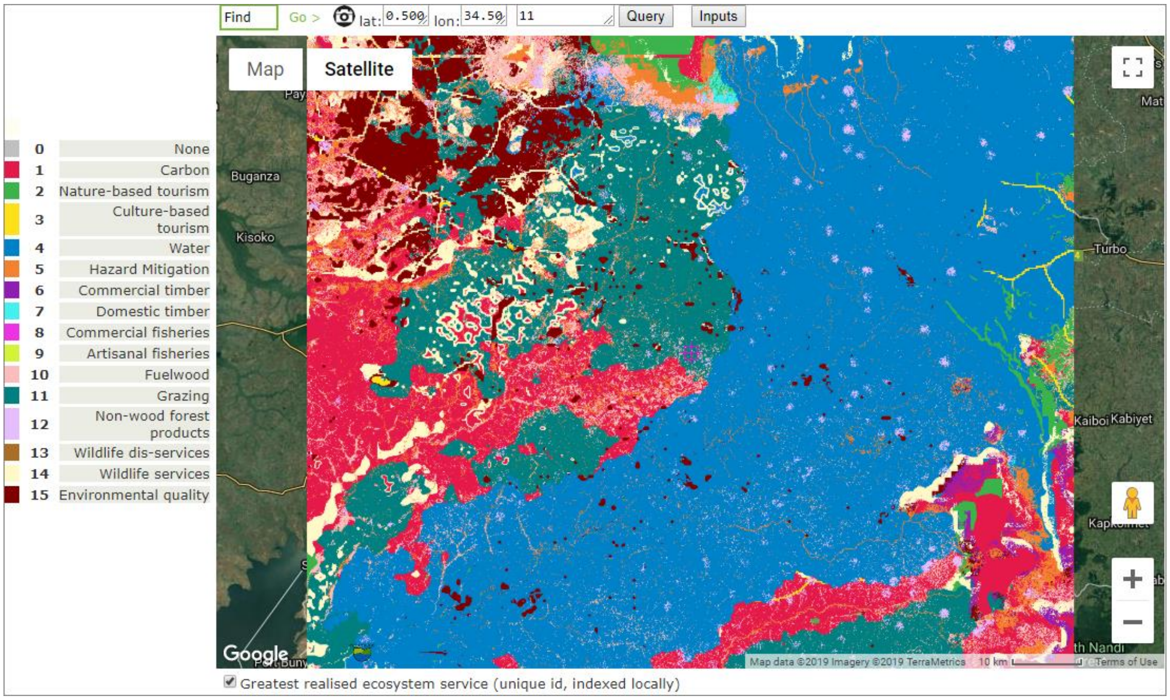

Figure 4.45: The Greatest Relative Total Realised Bundled Services Index in the Mt.Elgon Watersheds Lower Elgon

4.7.2 Analysis for New outputs for Simulation Vegetation and Agriculture Upper Elgon

A simulation exercise was carried out for vegetation and agriculture. This focused on Paying for Global Ecosystem Services (P4GES) Land use and Total defecating population. A corresponding activity to evaluate the recent land cover and land use and how it impacts freshwater ecosystems and their ability to provide services as well as using the results to identify possible solutions for climate change adaptation. A summary of activities carried are presented below in Table 4.15. Output maps were generated illustrating current state of the study area and results are presented in figures below with discussion.

Table 4.15: Summary Analysis of New Key Outputs Simulation of Current State of Land Cover and Land Use for Vegetation and Agriculture for the Mt. Elgon Watersheds

S/N	Variable	Explanation
1	P4GES Land use	Produced P4GES categorical land use map from the maps used by the PSS: #1 Native closed canopy forest; #2 Plantation; #3 Tree or shrub Savoka (fallow); #4 Degraded land (Tany Maty);#5 Irrigated rice
6	Total defecating population	Calculated defecating population (humans and livestock)

A P4GES (Paying for Global Ecosystem Services) categorical land use map, was produced, from the PSS (Policy Support System). Results showed vegetation categories depicting the highest percentage of the ecosystem as degraded with very little re-afforestation represented, and of the major benefits of enhancing forest cover is streamflow regulation. This aspect of modeling and simulation was based on forest-water linkages in relation to the positive and negative hydrological effects of trees and forests at the scale relevant to environmental policy as illustrated in Figure 4.46 and 4.47.

While the presence of trees along rivers banks and watershed is important to prevent soil erosion and control evapotranspiration, literature shows forests tend use much more water than rain-fed agriculture. Replanting of trees to enhance levels of streamflow during the drought periods is only improved when the level of intake due to permeation of runoff under trees surpasses the level of water lost in the streamflow through evapotranspiration. Rice and maize growing are a major livelihood activities in the Mt.Elgon Watersheds and wetlands. By simulating and modelling for P4GES will enable identify interventions of increasing forest cover as a strategy to increase streamflow levels during dry seasons.

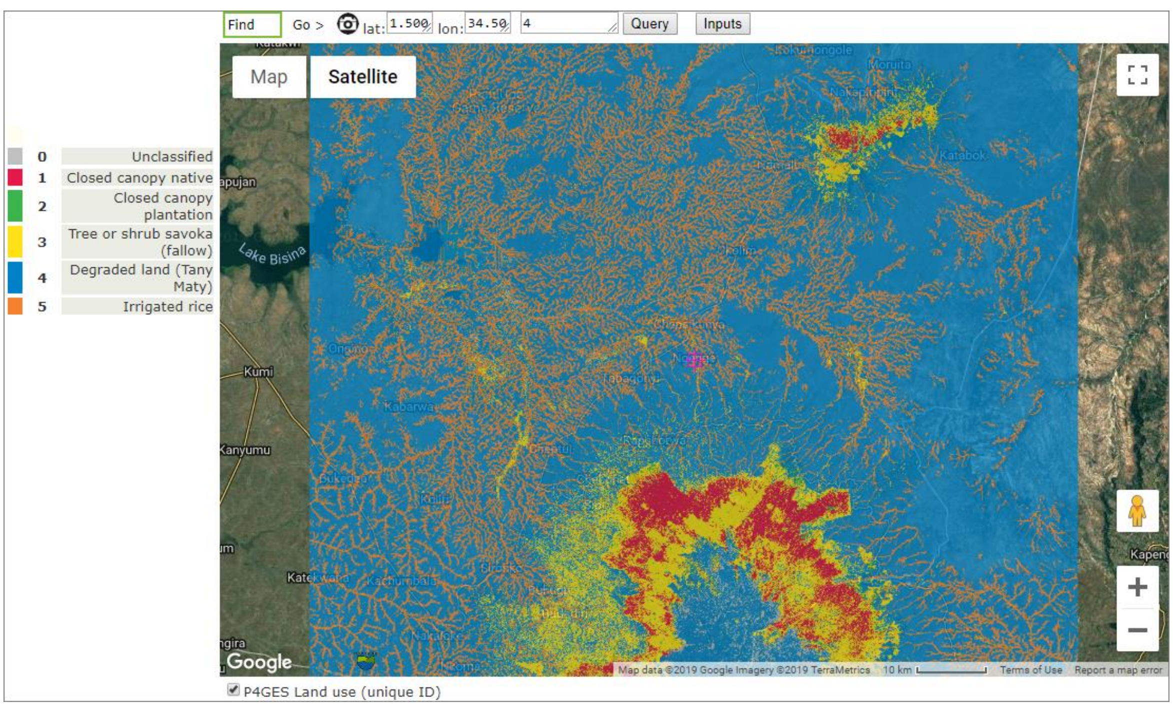

Figure 4.46: Simulation Results for Paying for Global Ecosystem Services (P4GES) Land Use Depicting Vegetation and Agriculture in the Mt. Elgon Watersheds Upper Elgon

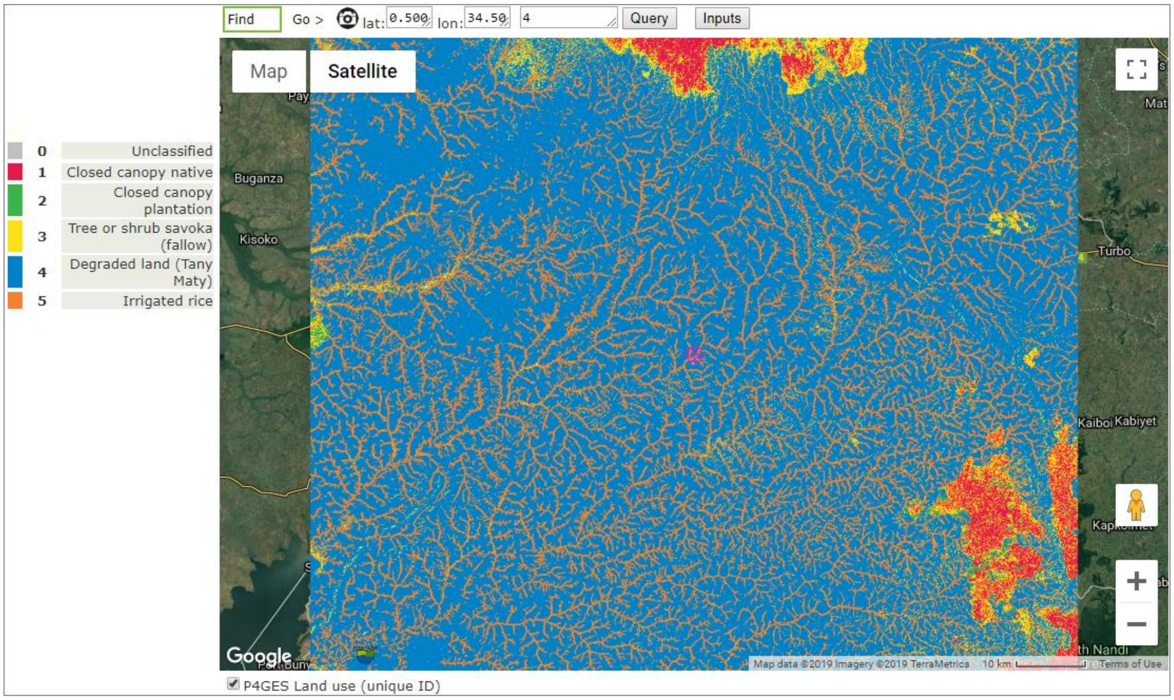

Figure 4.47: Simulation Results for Paying for Global Ecosystem Services (P4GES) Land Use Depicting Vegetation and Agriculture in the Mt. Elgon Watersheds Lower Elgon

This will enable farmers grow and benefit from a second crop from the degraded land given the current variation in climate, terrain and land cover state. Solar panels can also be installed within the rice gardens to harness solar energy. This as a source of renewable energy that will reduce use of bio fuels as a solution to land cover change and contour emissions of GHGs from rice field.

Total defecating population comprising of humans and livestock was calculated. Results showed defecation most intensified at the headwaters bordering protected mountain forest reserves. It depicted a defecating population with the highest range between 7,000-31,083 with least impact realised in the lower protected reserves. Results depicted the rest of the area covering a defecating population of 98% of 1, 420,465. The implication of defecation at the headwaters is increased pollution by contamination of freshwater ecosystems and increased footprint as illustrated in Figure 4.48 and 4.49 confirming study visit findings.

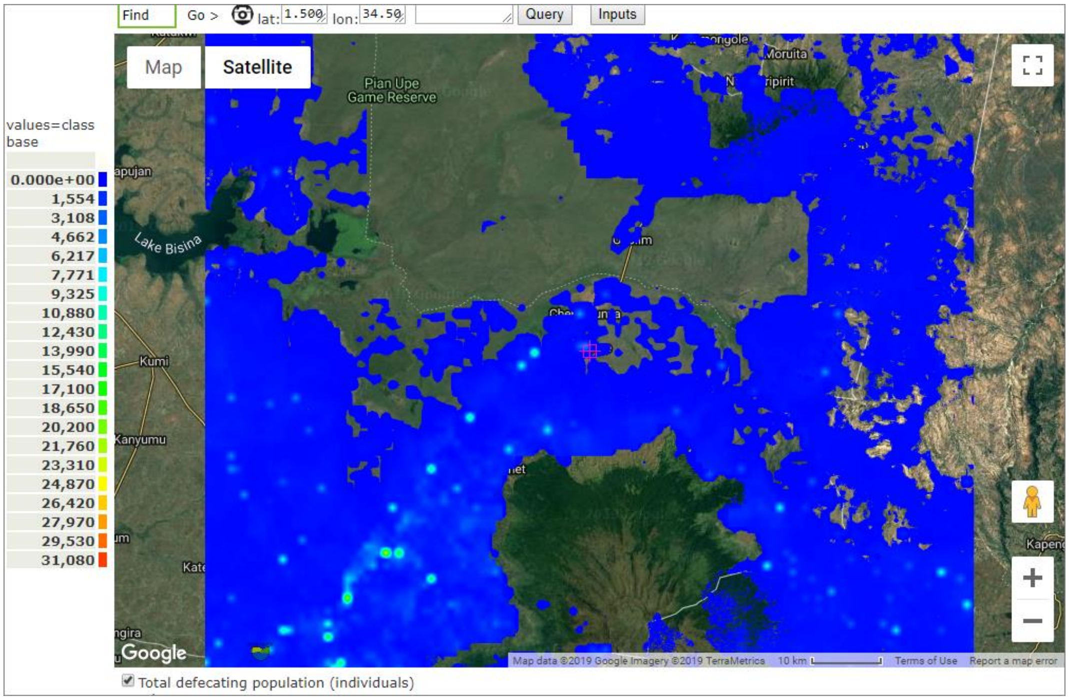

Figure 4.48: Simulation Results for Total Defecating Population in the Mt. Elgon Watersheds-Upper Elgon

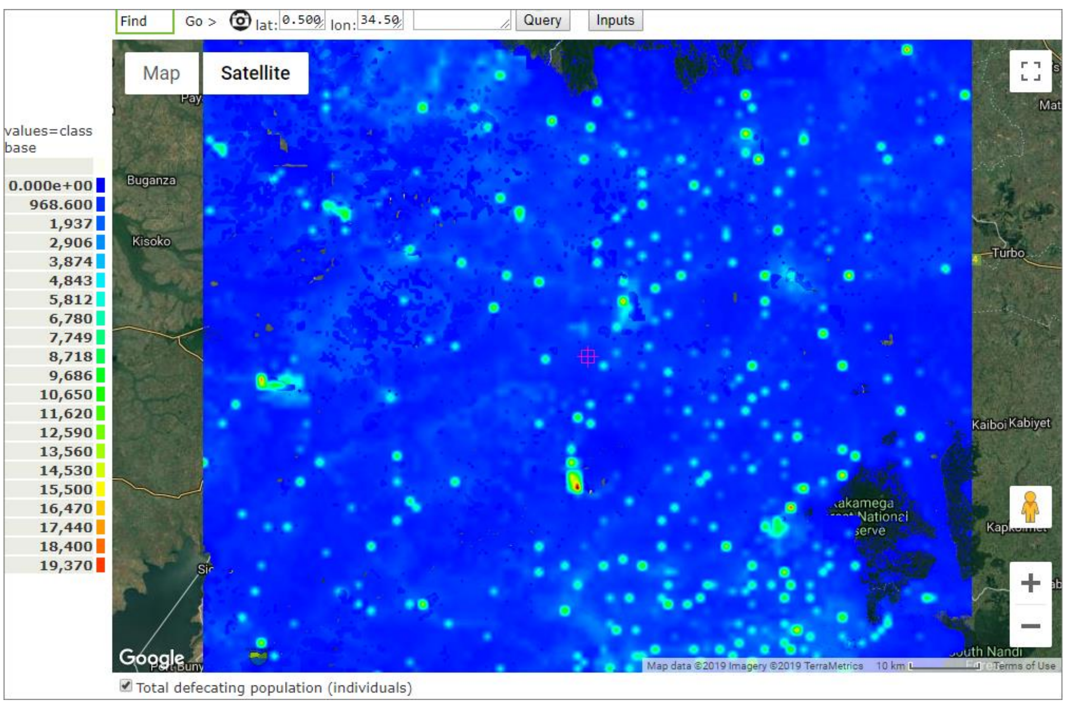

Figure 4.49: Simulation Results for Total Defecating Population in the Mt. Elgon Watersheds-Lower Elgon

4.7.3 Modelling and Simulations for Policy Exercise for Land Use and Land Cover Change

Results for modelling and simulation for the application of a Policy exercise for land use and land cover change, for recent deforestation percentage, of the percentage of land deforested in Upper Elgon, depicted at a Global Forest Cover (GFC) percent deforested, at a maximum of 100% and mean of 0.7% at a frequency of a sum of 1,000,000hectares per1,400,000hectares and a net percent deforested at a minimum of -80%, a maximum of 100% and mean of 0.5% deforested at a frequency of a sum of 720,000hectares per 1,400,000hectares. While results for Lower Elgon land use and cover change for recent deforestation percentage, of the percentage of land deforested at Global Forest Cover (GFC) percent deforested at a maximum of 100% and mean of 1.2% at a frequency of a sum 1,800,000hectares per 1,400,000hectares and a net percent deforested at a of minimum of -80%, maximum of 100% and mean of 0.8% at a frequency of a sum of 1,100,000hcctares per 1,400,000hectares. Results depicted a wide spread of deforestation from baseline in both the Upper and Lower Elgon. It showed that most of the land cover was herbaceous summarised in Table 4.16 and 4.17with results illustrated in Figure 4.50- 4.53.

Table 4.16: Simulation for Policy Exercise: Land Use and Land Cover Change: Assessed Impacts of Land Use and Cover Change on the Ecosystem: Recent Deforestation Percentage, of Land

Simulation	Minimum	Maximum	Mean	Sum	Count
GFC percent deforested, Hansen/UMD/Google/USGS/NASA (calculated by Co$tingNature) (% of land) (Upper Elgon)	0	100	0.7	1,000,000	1,400,000
GFC percent deforested, Hansen/UMD/Google/USGS/NASA (calculated by Co$tingNature) (% of land) (Lower Elgon)	0	100	1.2	1,800,000	1,400,000
GFC net percent deforested, Hansen/UMD/Google/USGS/NASA (calculated by Co$tingNature) (% of land) Upper Elgon	-80	100	0.5	720,000	1,400,000
GFC net percent deforested, Hansen/UMD/Google/USGS/NASA (calculated by Co$tingNature) (% of land) Lower Elgon	-80	100	0.8	1,100,000	1,400,000

Table 4.17: Simulation Result Scenario for Policy Exercise Outputs: Land Use and Cover Change

Upper Elgon **Variable:** Recent deforestation percentage, % of land GFC percent deforested, Hansen/UMD/Google/USGS/NASA (calculated by costingnature) (% of land) • Min: 0 • Max:100 • Mean:0.7 • Sum:1,000,000 • Count: 1,400,000	**Upper Elgon** **Variable:** Recent deforestation percentage, % of land :GFC net percent deforested, Hansen/UMD/Google/USGS/NASA (calculated by costingnature) (% of land) • Min: -80 • Max:100 • Mean:0.5 • Sum:720,000 • Count: 1,400,000
Lower Elgon :GFC percent deforested, Hansen/UMD/Google/ USGS/NASA (calculated by costingnature) (% of land) • Min: 0 • Max:100 • Mean:1.2 • Sum:1,800,000 • Count: 1,400,000	**Lower Elgon** :GFC net percent deforested, Hansen/UMD/Google/USGS/NASA (calculated by costingnature) (% of land) • Min: -80 • Max:100 • Mean:0.8 • Sum:1,100,000 • Count: 1,400,000

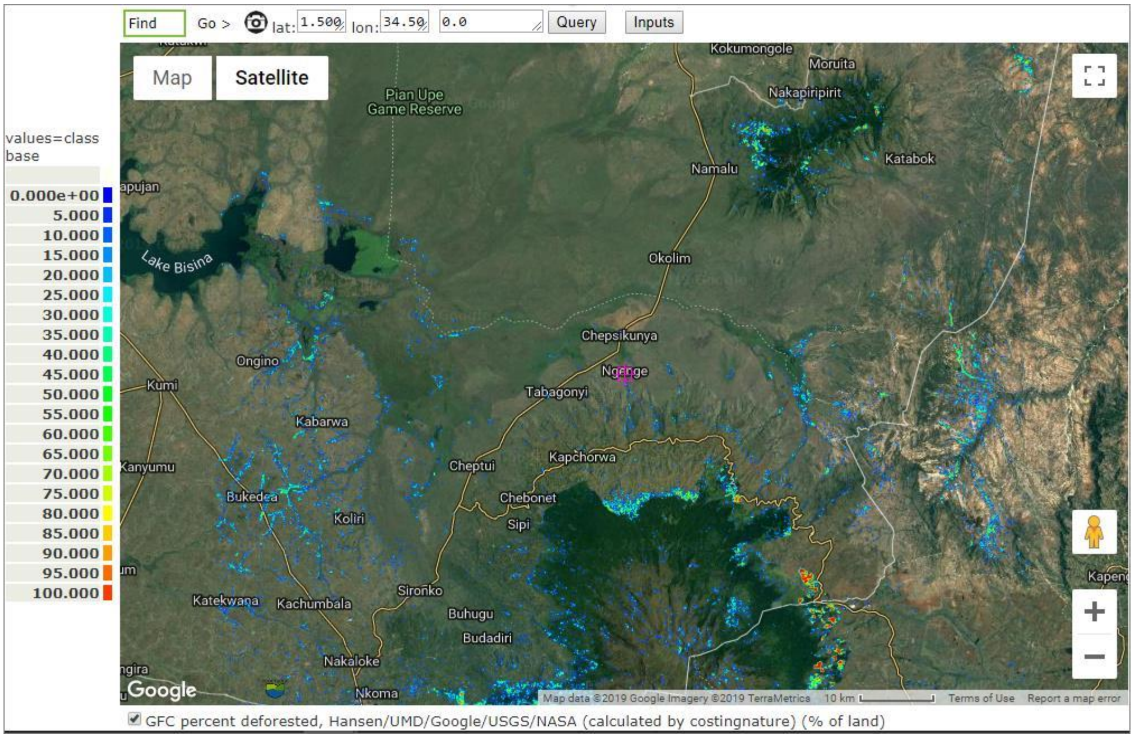

Figure 4.50: Simulation Result Scenario for Policy Exercise Outputs: Land Use and Cover Change-GFC Percent Deforested Upper Elgon

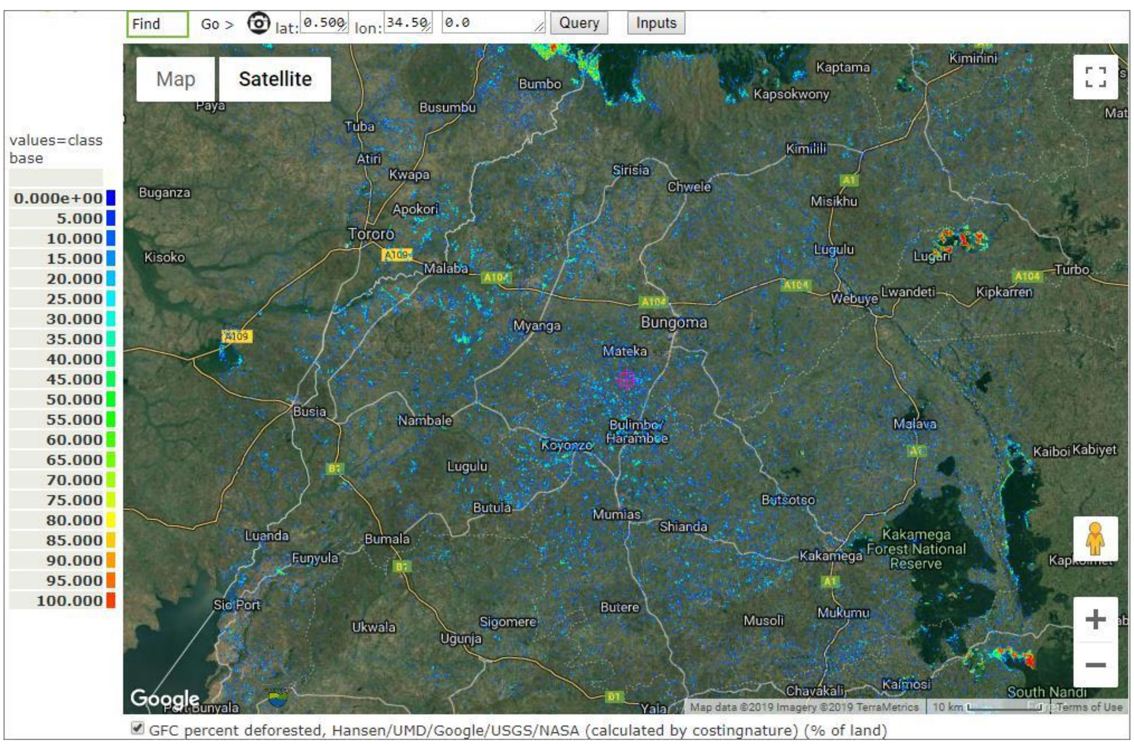

Figure 4.51: Simulation Result Scenario for Policy Exercise Outputs: Land Use and Cover Change GFC Percent Deforested Lower Elgon

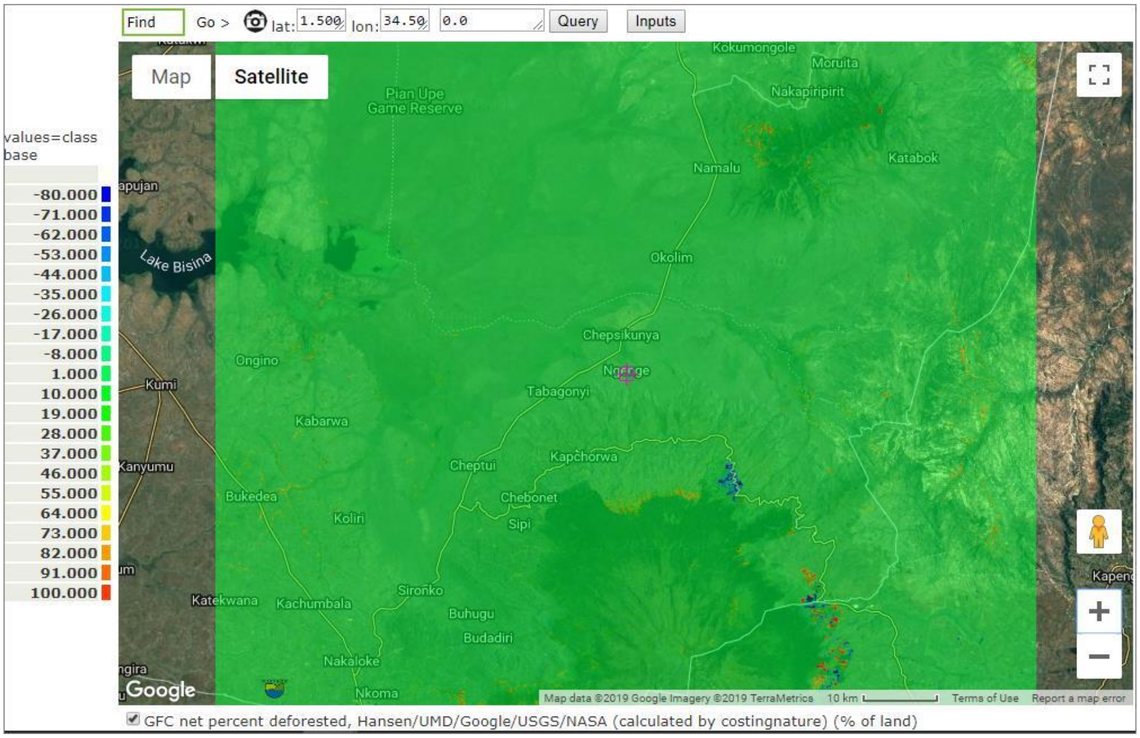

Figure 4.52: Simulation Result Scenario for Policy Exercise Outputs: Land Use and Cover Change GFC Net percent deforested –Upper Elgon

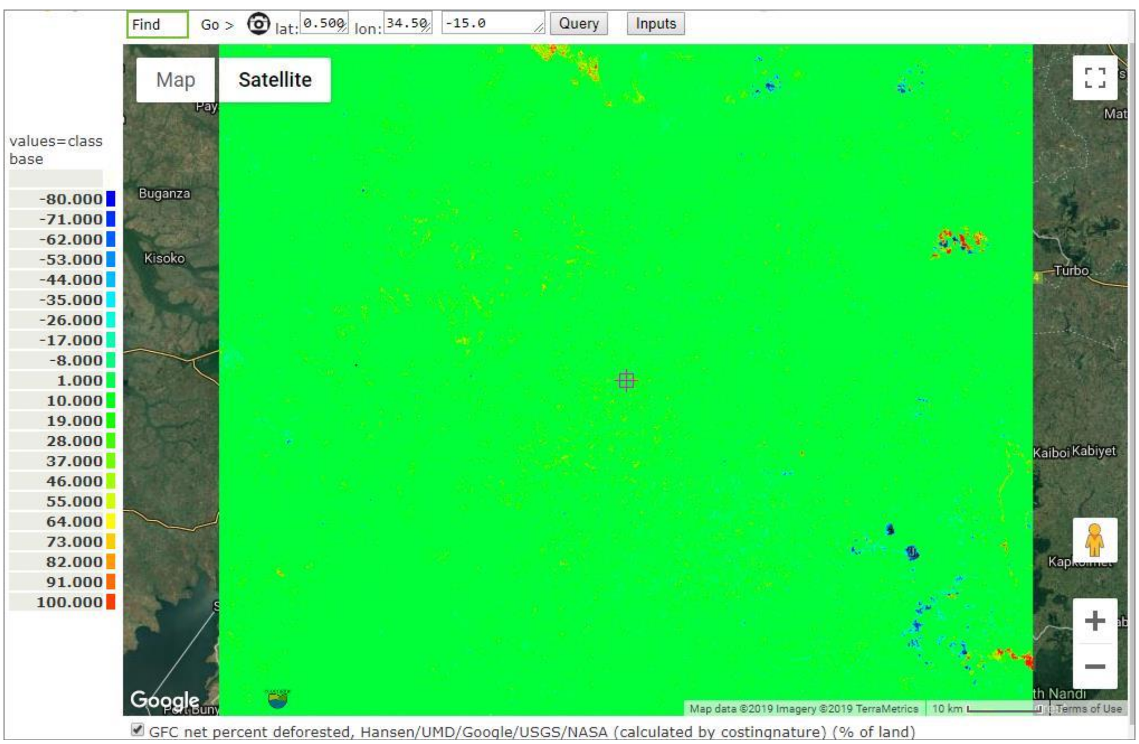

Figure 4.53: Simulation Result Scenario for Policy Exercise Outputs: Land Use and Cover Change GFC Net percent deforested –Lower Elgon

Simulations for Policy exercise to assess land use and changes in land cover and how it affects Ecosystems (ES), was carried out for recent deforestation rate percentage of land. Results for Upper Elgon depicted land use and land cover change at a Global Forest Cover (GFC) deforestation rate of minimum of 0%, maximum of 8.3% and mean of 0.058% at a frequency of a sum of 84,000 hectares per 1,400,000hectares with net deforestation rate of a minimum of -6.7%, maximum of8.3% and mean of 0.042% at a frequency of a sum of 60,000hectares per 1,400,000hectares percentage of land per year. While results for Lower Elgon depicted changes in land use and changes in land cover at Global Forest Cover (GFC) deforestation rate of a minimum of 0%, maximum of 8.3% and mean 0.01% at a frequency of a sum of 150,000 hectares per 1,400,000hectares and a net deforestation rate of minimum of -6.7%, maximum 8.3% and mean 0.066 at a frequency of a sum of 96,000hectares per 1,400,000hectares percentage of land per year on the ecosystem. Results are summarised in Table 4.18 and 4.19. Results showed intensity of recent deforestation rates mainly around the Elgon forest reserve at the headwaters of Nzoia and Suam in the watersheds and around Kakamega forest reserve as shown in the Figures 4.54-4.57. The implication of this being a reducing forest cover leading to more degradation of the ecosystem affecting its ability to provide services and hence intensifying climate change impacts.

Table 4.18: Simulations for Policy Exercise: Land Use and Land Cover Change: Assess Impacts of Land Use and Cover Change on the Ecosystem: Recent Deforestation Rate, of Land

Simulation	Minimum	Maximum	Mean	Sum	Count
GFC deforestation rate, Hansen/UMD/Google/USGS/NASA (calculated by costingnature) (% of land/yr) Upper Elgon	0	8.3	0.058	84,000	1,400,000
GFC deforestation rate, Hansen/UMD/Google/USGS/NASA (calculated by costingnature) (% of land/yr) Lower Elgon	0	8.3	0.1	150,000	1,400,000
GFC net deforestation rate, Hansen/UMD/Google/USGS/NASA (calculated by costingnature) (% of land/yr)	-6.7	8.3	0.042	60,000	1,400,000
GFC net deforestation rate, Hansen/UMD/Google/USGS/NASA (calculated by Co$tingNature) (% of land)	-6.7	8.3	0.066	96,000	1,400,000

Simulation results output maps, for scenario for policy exercise for land use and changes in land cover to assess its impacts on Ecosystem (ES) for recent deforestation percentage of land and recent deforestation rate percentage of land are presented in Figure 4.54 – 4.57. Results showed that deforestation was wide spread for both Upper and Lower Elgon intensifying around protected forest reserves frontiers, mountain regions, urban areas and along river channels. This is a great threat to freshwater ecosystems and services sustainability.

Table 4.19: Simulation Result Scenario for Policy Exercise Outputs: Land Use and Cover Change

Upper Elgon **Variable:** Recent deforestation rate, % of land/yr :GFC deforestation rate, Hansen/UMD/Google/ USGS/NASA (calculated by costingnature) (% of land/yr) • Min: 0 • Max:8.3 • Mean:0.058 • Sum:84,000 • Count: 1,400,000	**Upper Elgon** **Variable:** Recent deforestation rate, % of land/yr :GFC net deforestation rate, Hansen/UMD/Google/USGS/NASA (calculated by costingnature) (% of land) • Min: -6.7 • Max:8.3 • Mean:0.042 • Sum:60,000 • Count: 1,400,000
Lower Elgon :GFC deforestation rate, Hansen/UMD/Google/ USGS/NASA (calculated by costingnature) (% of land/yr) • Min: 0 • Max:8.3 • Mean:0.1 • Sum:150,000 • Count: 1,400,000	**Lower Elgon** :GFC net deforestation rate, Hansen/UMD/Google/USGS/NASA (calculated by costingnature) (% of land) • Min: -6.7 • Max:8.3 • Mean:0.066 • Sum:96,000 • Count: 1,400,000

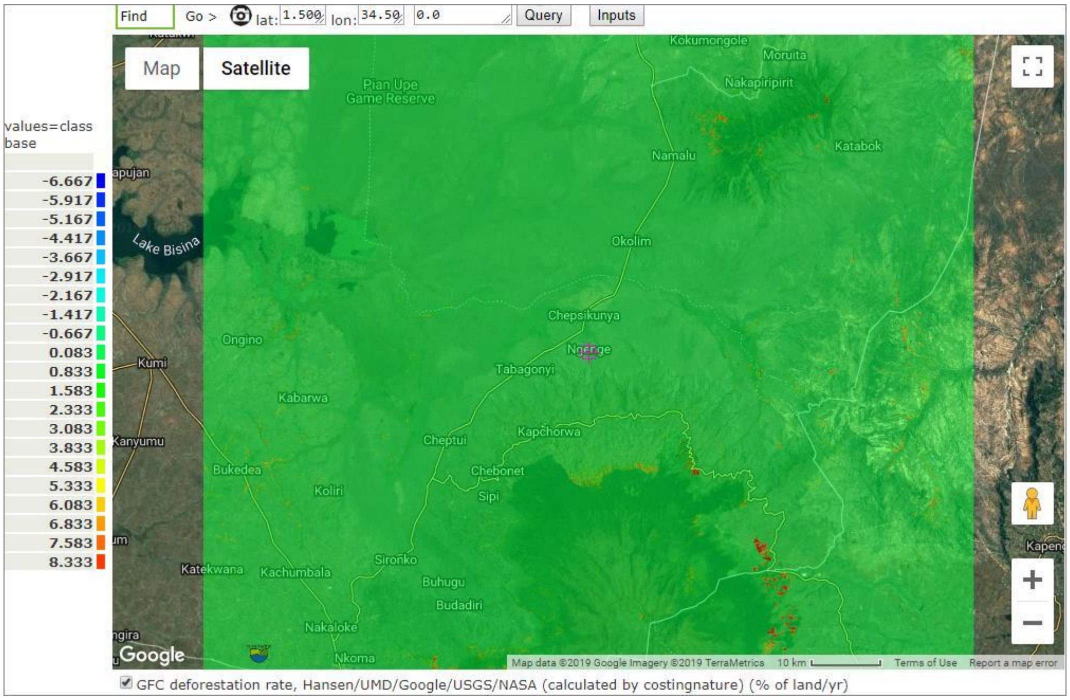

Figure 4.54: Simulation Result Scenario for Policy Exercise Outputs: Land Use and Cover Change GFC Deforestation Rate-Upper Elgon

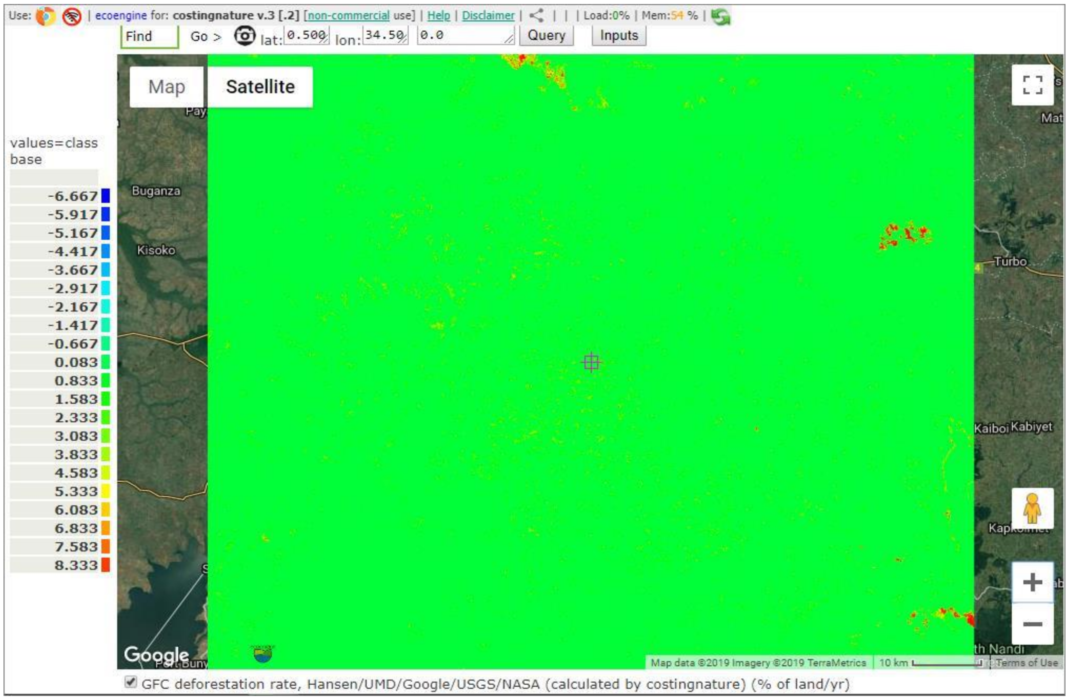

Figure 4.55: Simulation Result Scenario for Policy Exercise Outputs: Land Use and Cover Change GFC Deforestation Rate-Lower Elgon

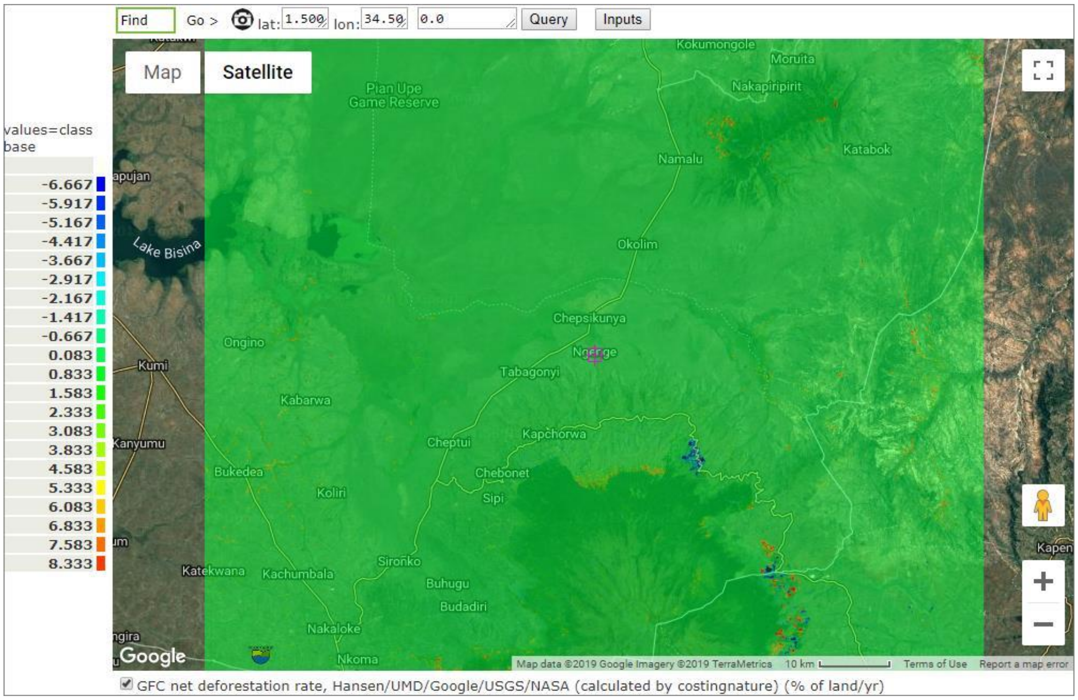

Figure 4.56: Simulation Result Scenario for Policy Exercise Outputs: Land Use and Cover Change GFC Net Deforestation Rate-Upper Elgon

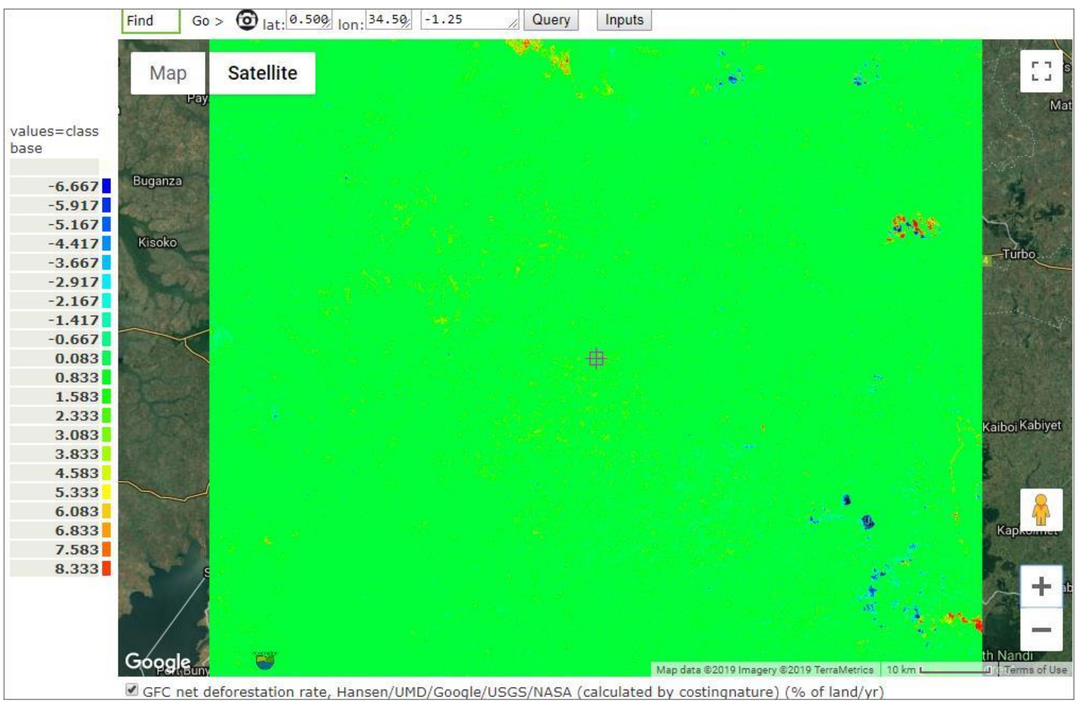

Figure 4.57: Simulation Result Scenario for Policy Exercise Outputs: Land Use and Cover Change GFC Net Deforestation Rate-Lower Elgon

To examine the opportunity cost for conserving freshwater ecosystems, for freshwater ecosystem services sustainability, results from costing nature for realized services, potential services and development priority for conservation showed that, other than the watersheds within the protected forest reserves, freshwater ecosystem services and associated ecosystem services are no fully realized. These ranged between 0.500-1.000 percent at a local scale. Results also depicted high rates of the need for development priority for conservation for the entire study area if potential services are to be realized. Results based on scenarios of land use and cover change using costing nature ecoengine model was based on recently observed rates. They were also based on the assumption of ineffective protected areas for recent deforestation and management of private woodlots. Results showed increased agricultural cultivation of irrigated rice and wetland destruction for rice cultivation, diverting stream flow at head waters fish farming. It also depicted water pollution due to contamination by defecation and soil erosion by siltation, along the rivers and water bodies affecting water quality and quantity, environmental quality and hazard mitigation. Results also showed an increasing trend of presence of carbon in deforested and exposed land area hence increased emissions in the atmosphere that will impact climate resulting in climate change.

4.7.4 Modelling and Simulation to Evaluate Climate Change Effects in the Watersheds

Modelling and simulation using the Waterworld v.2 [.92] ecoengine model, for climate change to assess its impacts in Mt. Elgon watershed, for projection of potential future impacts was carried out in the Upper and Lower Elgon. The result from projection will inform policy formulation for conservation for freshwater ecosystems with their associated ecosystems, for ecosystem services sustainability. Simulation for change from baseline was also carried out. Table 4.19 is a summary of result in form of key output maps. Figures are illustrated in result narrative report.

Table 4.20: Summary Analysis of Key Output for Modelling and Simulation for Change from Baseline for Climate Change: Assessment of Impacts of Climate Change in the Mt.Elgon Watersheds

S/N	Name	Variable name	Explanation
1	Rainfall	Change in rainfall	Change in total annual (wind-driven) rainfall (mm/yr)
2	Water balance	Change in water balance	Change in local water balance (mm/yr) (rainfall+fog+snowmelt less actual evapotranspiration (AET). Where water balance is negative local actual evapotranspiration is supported by upstream watersheds and/or aquifer sources
3	Runoff	Change in runoff	Modification in total annual runoff (m^3/yr). Computed as water balance that is cumulated downstream. Negative water balance (AET>precipitation) in a cell consumes runoff from upstream.
4	Hillslope net erosion	Change in hillslope net erosion	Change in hillslope net erosion (mm/yr). Net erosion (erosion minus deposition) on hillslopes
5	Total net erosion	Change in total net erosion	Conversion in total net erosion (mm/yr). Net erosion (erosion minus deposition) from hillslopes and channels (streams/rivers)
6	Human footprint on water quality (pollution)	Change in human footprint on water quality (pollution)	Alteration in mean percentage of water that may be polluted (human footprint index, %)

4.7.5 Result from Modelling and Simulation for Policy Exercise Scenario with Waterworld

An alternative simulation was run from the baseline l for Climate Change scenarios to assess projected possible effects of climate change for the projected period 2041 to 2060 using the policy **cmip5rcp45worldclimhg20412060**. Results showed that For this alternative run for Upper Elgon, the Water balance ($mmyr^{-1}$) for the modelled area was at a medium level of 540 with 25 percentage of 180 and a 75 percentage of 780, a total minimum of -320 and maximum amount of 4,400. This reflects an area medium precipitation ($mmyr^{-1}$) level of 1,100 with a total minimum of 450 and a maximum amount of 4,600. The actual evapo-transpiration ($mmyr^{-1}$) is between 31 and 1,400 with an average of 650. Fog inputs remain low relatively to precipitation ranging 5.4 % medium, totaling an amount of 66 ($mmyr^{-1}$) at medium level but stretching from 19 to 340 ($mmyr^{-1}$).

While for Lower Elgon for this alternative run, the Water balance ($mmyr^{-1}$) for the modelled area was of a medium level of 1,100 with 25 percentage of 860, a 75 percentage of 1,300, a total minimum of -230 and maximum of 2,900. This reflects an area medium precipitation ($mmyr^{-1}$) of

1,600 with a total minimum of 870 as well as a maximum of 3,000. The actual evapo-transpiration ($mmyr^{-1}$) is between 38 to 1,300 with an average of 630. Fog inputs remain low relatively to precipitation at 4.8 % averagely, totaling to 80 ($mmyr^{-1}$) at a medium level but extending from 46 to 330 ($mmyr^{-1}$). Resulting in Total annual runoff of a maximum of 3,900,000,000 m^^{3}, 5,700,000,000 m^^{3} and human footprint on water quality of maximum 99%, 78% for Upper and Lower Elgon respectively, as in Table 4.20 illustrated in Figure 4.58 and 4.65

Table 4.21: Result of Outputs for Alternative Run for Change from Baseline for Impacts of Climate Change

Upper Elgon: Alternative: Annual total water balance $mmyr^{-1}$ • Min:-380 • Max:3,500 • Mean:480 • Sum:690,000,000 • Count: 1,400,000	**Upper Elgon: Alternative:** Total wind-corrected rainfall $mmyr^{-1}$ • Min:430 • Max:3,700 • Mean:1,100 • Sum:1,500,000,000 • Count: 1,400,000
Lower Elgon: Alternative: Annual total water balance $mmyr^{-1}$ • Min:-230 • Max:2,900 • Mean:1,100 • Sum:1,500,000,000 • Count: 1,400,000	**Lower Elgon: Alternative:** Total wind-corrected rainfall $mmyr^{-1}$ • Min: 870 • Max:3,000 • Mean:1,600 • Sum:2,300,000,000 • Count: 1,400,000
Upper Elgon: Alternative: Total annual runoff (m^3) • Min: 29 • Max:3,900,000,000 • Mean:2,500,000 • Sum:3,700,000,000,000 • Count: 1,400,000	**Upper Elgon: Alternative:** Human footprint on water quality (% contamination) • Min: 0 • Max: 99 • Mean: 3.8 • Sum: 5,500,000 • Count: 1,400,000
Lower Elgon: Alternative: Total annual runoff (m^3) • Min: 45 • Max:5,700,000,000 • Mean:5,900,000 • Sum:8,500,000,000,000 • Count: 1,400,000	**Lower Elgon: Alternative:** Human footprint on water quality (% contamination) • Min: 0 • Max: 73 • Mean: 7.6 • Sum: 11,000,000 • Count: 1,400,000

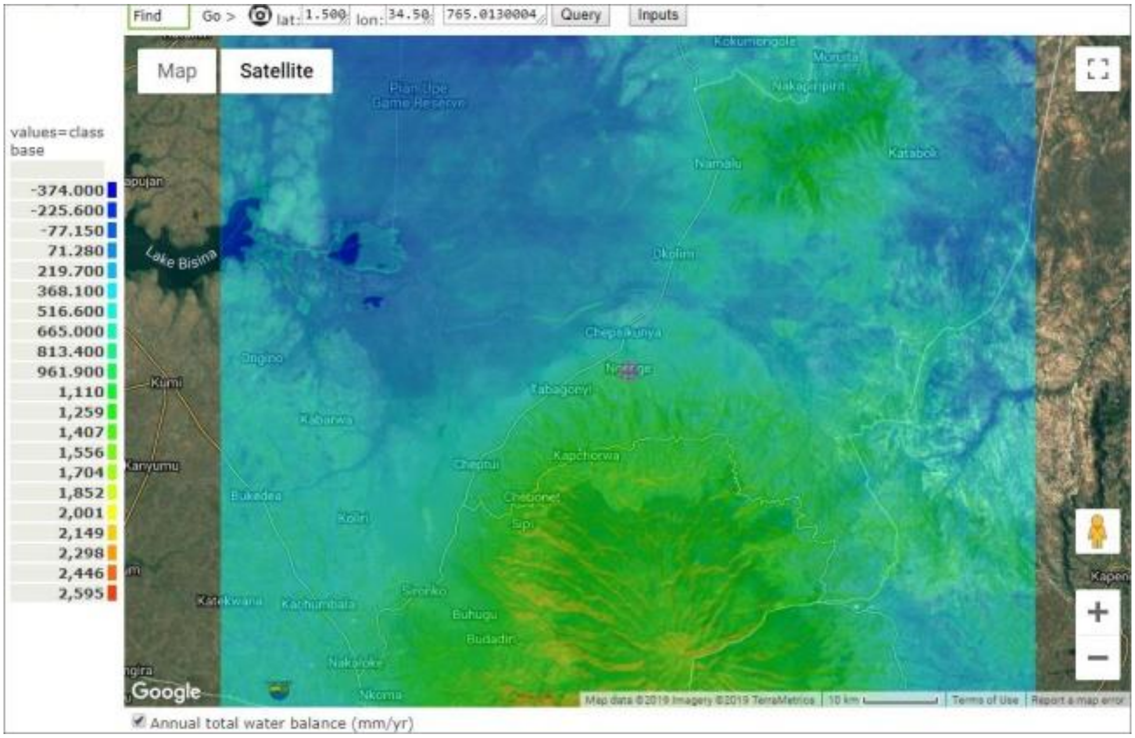

Figure 4.58: Result of Outputs for Alternative Run for Change from Baseline for Impacts of Climate Change; Annual total water Balance –Upper Elgon

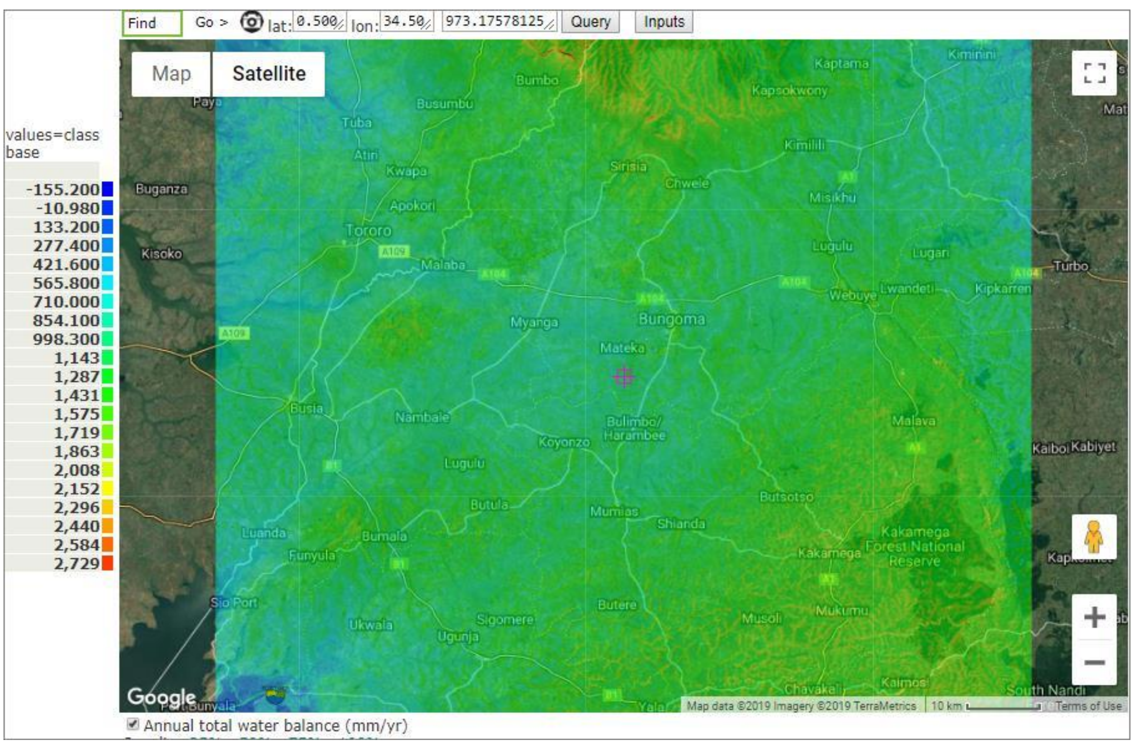

Figure 4.59: Result of Outputs for Alternative Run for Change from Baseline for Impacts of Climate Change Annual total water Balance –Lower Elgon

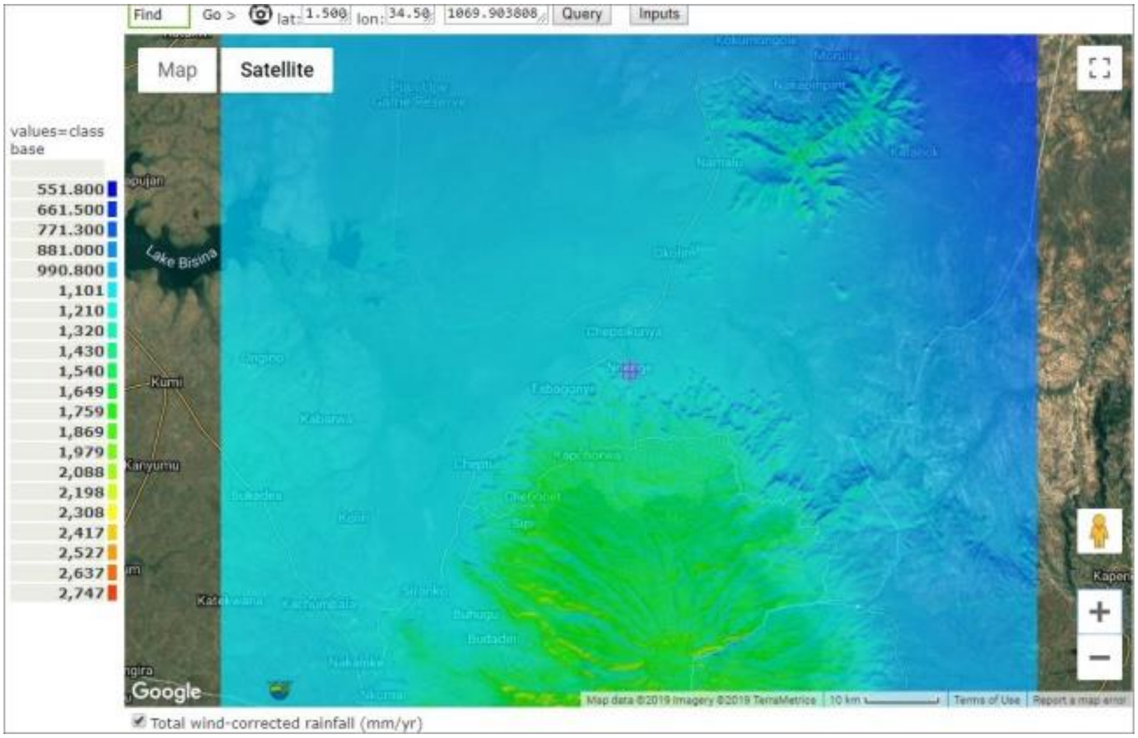

Figure 4.60: Result of Outputs for Alternative Run for Change from Baseline for Impacts of Climate Change; Total Wind-Corrected Rainfall-Upper Elgon

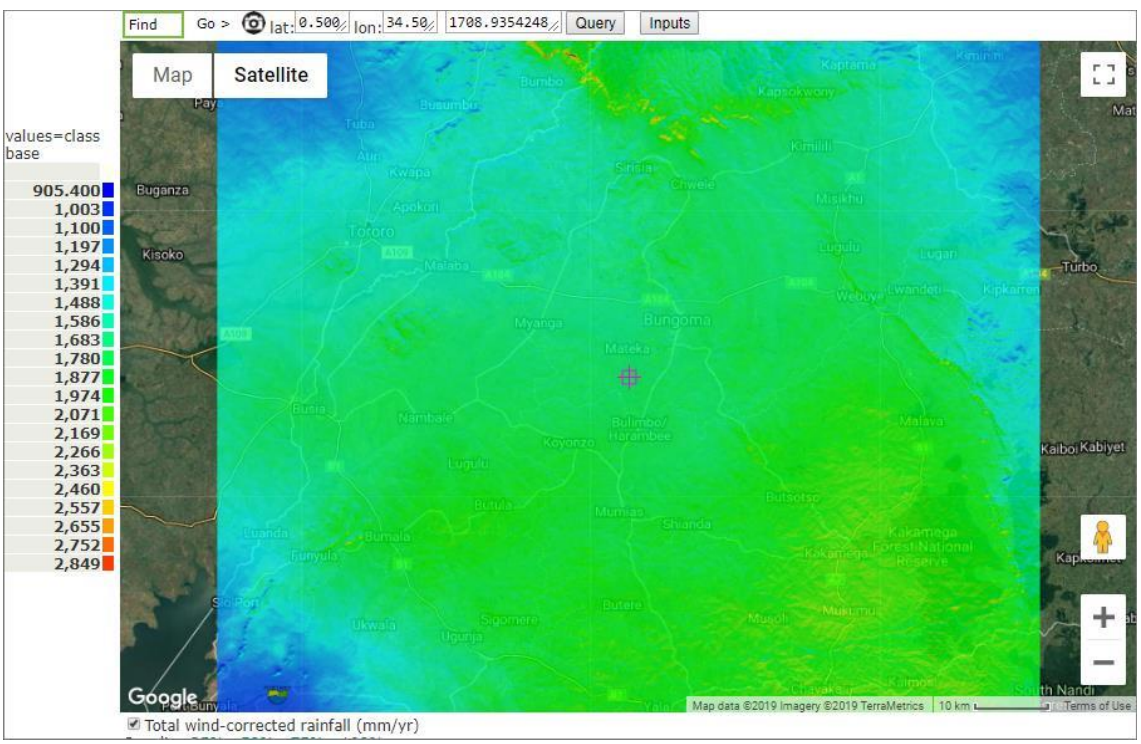

Figure 4.61: Result of Outputs for Alternative Run for Change from Baseline for Impacts of Climate Change Total Wind-Corrected Rainfall-Lower Elgon

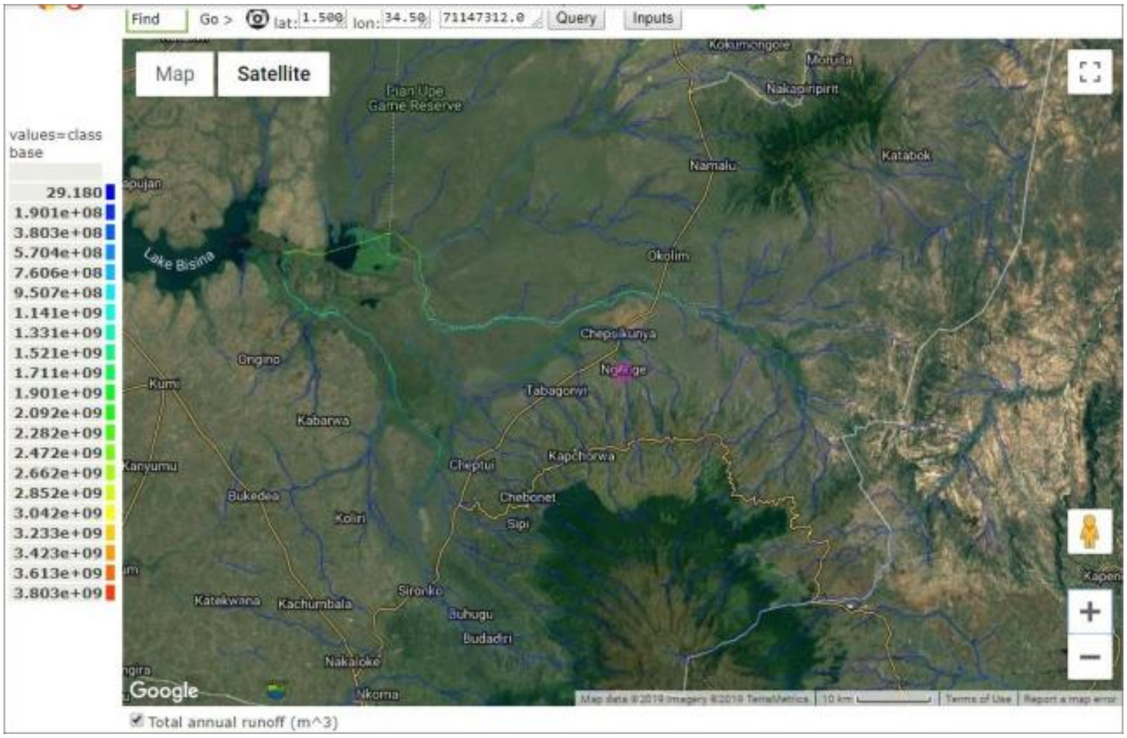

Figure 4.62: Result of Outputs for Alternative Run for Change from Baseline for Impacts of Climate Change; Total Annual Runoff- Upper Elgon

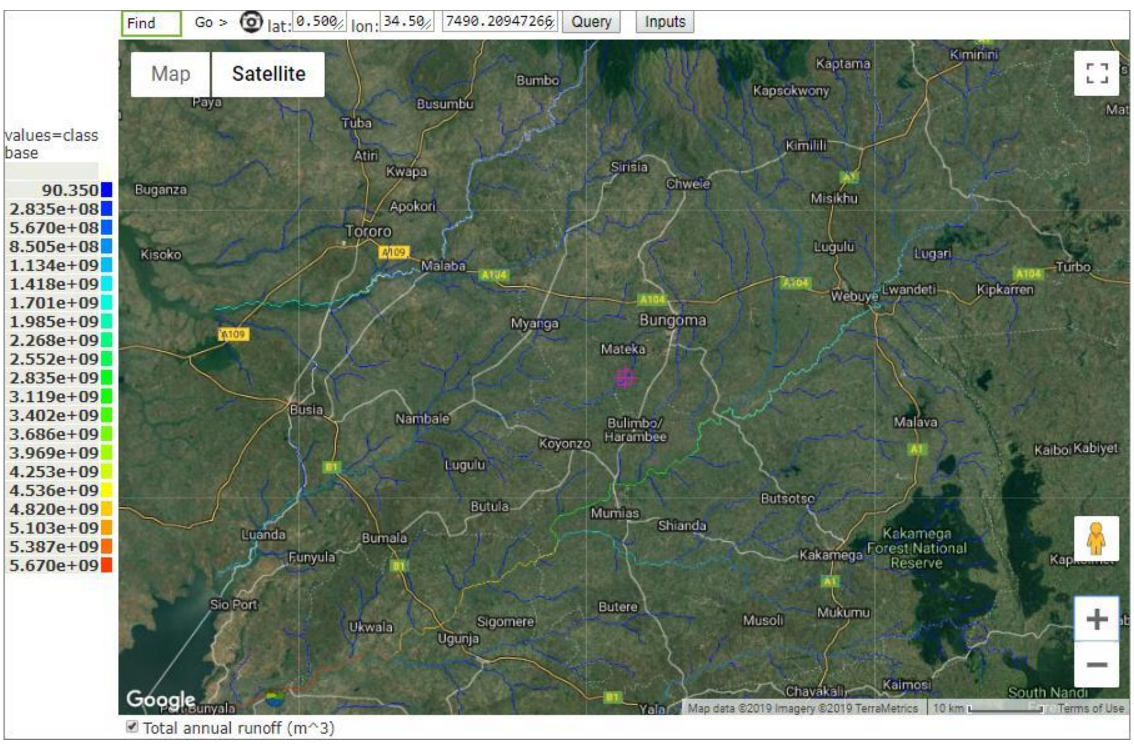

Figure 4.63: Result of Outputs for Alternative Run for Change from Baseline for Impacts of Climate Change Total Annual Runoff- Lower Elgon

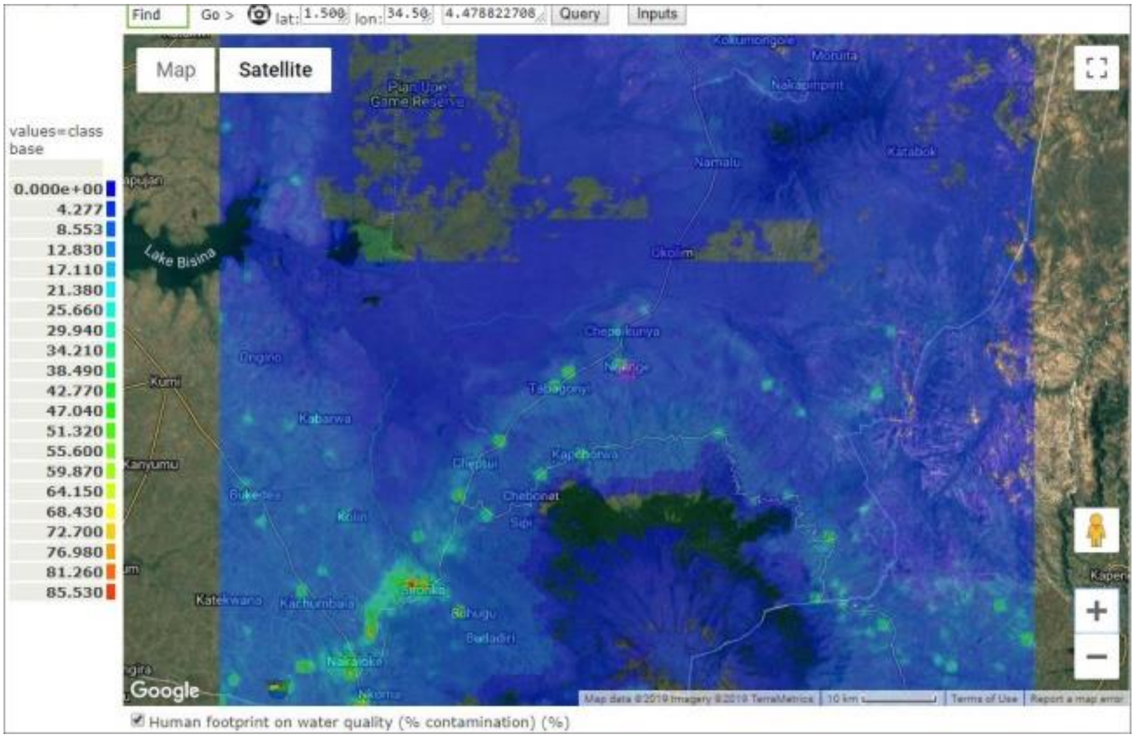

Figure 4.64: Result of Outputs for Alternative Run for Change from Baseline for Impacts of Climate Change; Human Footprint on Water Quality(% Contamination- Upper Elgon

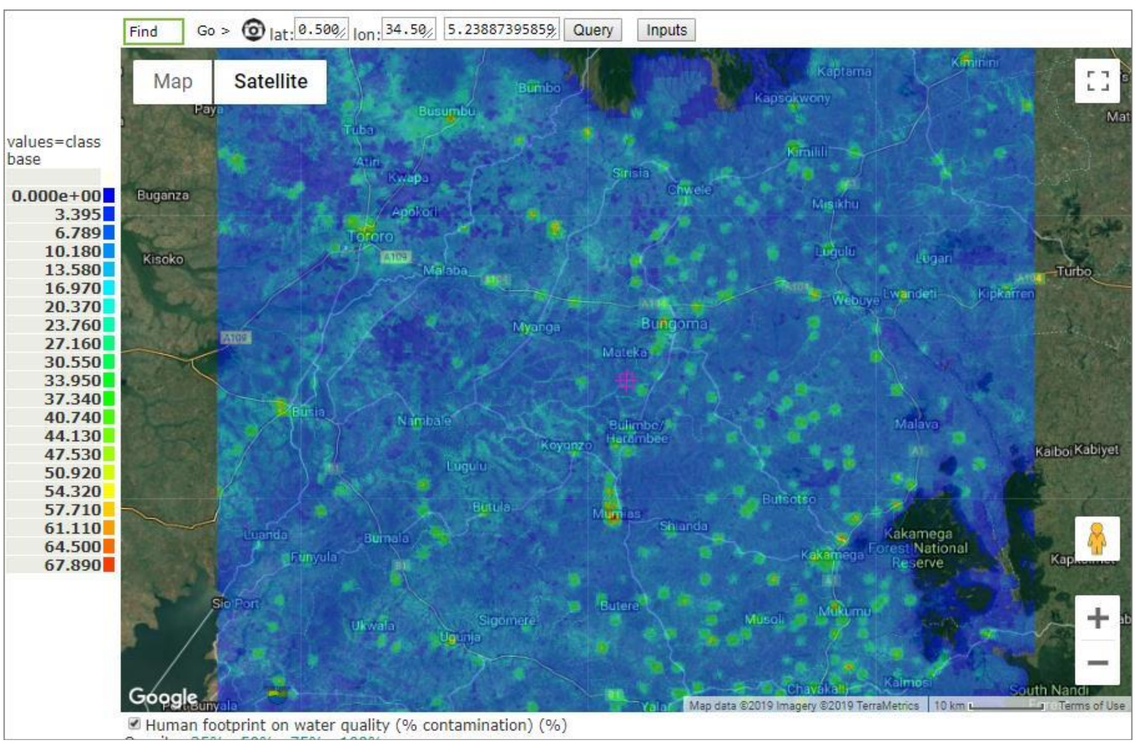

Figure 4.65: Result of Outputs for Alternative Run for Change from Baseline for Impacts of Climate Change; Human Footprint on Water Quality(% Contamination- Lower Elgon

For the baseline run for Upper Elgon, the Water balance (mmyr^{-1}) for the area was averagely 640 with a 25 percentage of 290 and a 75 percentage of 870, a total minimum of -200 and maximum of 4,000. This reflects an area medium precipitation (mmyr^{-1}) of 1,200 with a total minimum of 490 and maximum of 4,200. Actual evapo-transpiration (mmyr^{-1}) ranges from 29 to 1,400 with a medium of 620. Fog inputs are at a much lower rate relatively to that of precipitation at 5 % at medium rate, at a total of 65 (mmyr^{-1}) on average but ranging from 12 to 330 (mmyr^{-1}). While the baseline run for Lower Elgon, the Water balance (mmyr^{-1}) for the zone at medium level of 1,100, 25 percentage of 880, 75 percentage of 1,300 a total of lowest measurement at -150 and highest at 3,000. This reflects an area average of precipitation (mmyr^{-1}) of 1,600 with a total least measurement at 880 and highest measurement at3,000. The actual evapo-transpiration (mmyr^{-1}) between 34 and 1,200 with a medium range of 600. Fog inputs continued to remain low relatively compared to precipitation at 5 % averagely, totaling to 83 (mmyr^{-1}) on medium but ranging from 48 to 320 (mmyr^{-1}), depicted in Table 4.21 illustrated Figure 4.66 and 4.73

Table 4.22: Result of Outputs for Baseline Run for Change for Impacts of Climate Change

Name: Change in water balance **Explanation:** Variation in local water balance (mm/yr) (rainfall less of the actual evapotranspiration (AET). Where water balance is negative local AET is supported by upstream sources of water and/or ground water**Upper Elgon: Baseline:** Annual total water balance mmyr^{-1} • Min:-200 • Max:4,000 • Mean:640 • Sum:920,000,000 • Count: 1,400,000	**Name:** Change in rainfall **Explanation:** Change in Total wind-corrected rainfall mmyr^{-1} **Upper Elgon**: **Baseline**: Total wind-corrected rainfall mmyr^{-1} • Min:490 • Max:4,200 • Mean:1,200 • Sum:1,700,000,000 • Count: 1,400,000
Lower Elgon: Baseline: Annual total water balance mmyr^{-1} • Min:-150 • Max:3,000 • Mean:1,100 • Sum:1,600,000,000 • Count: 1,400,000	**Lower Elgon**: **Baseline**: Total wind-corrected rainfall mmyr^{-1} • Min:880 • Max:3,000 • Mean:1,600 • Sum:2,300,000,000 • Count: 1,400,000
Name: Change in runoff **Explanation:** Modification in aggregate annual runoff (m^3/yr). Computed as water balance that is cumulated downstream. Negative water balance (AET>precipitation) in a cell consumes runoff from upstream. **Upper Elgon: Baseline:** Total annual runoff (m^3) • Min: 32 • Max:4,600,000,000 • Mean:3,000,000 • Sum:4,300,000,000,000 • Count: 1,400,000	**Name:** Change in human footprint on water quality (pollution) **Explanation:** Alteration in mean percentage of water that might be polluted (human footprint index, %) total net erosion mmyr^{-1} **Upper Elgon: Baseline:** Human footprint on water quality (% contamination) • Min: 0 • Max: 99 • Mean: 3.9 • Sum: 5,700,000 • Count: 1,400,000
Lower Elgon: Baseline: Total annual runoff (m^3) • **Min: 75** • **Max:5,800,000,000** • **Mean:6,000,000** • **Sum:8,700,000,000,000** • **Count: 1,400,000**	**Lower Elgon: Baseline:** Human footprint on water quality (% contamination) • Min: 0 • Max: 72 • Mean: 7.7 • Sum: 11,000,000 • Count: 1,400,000

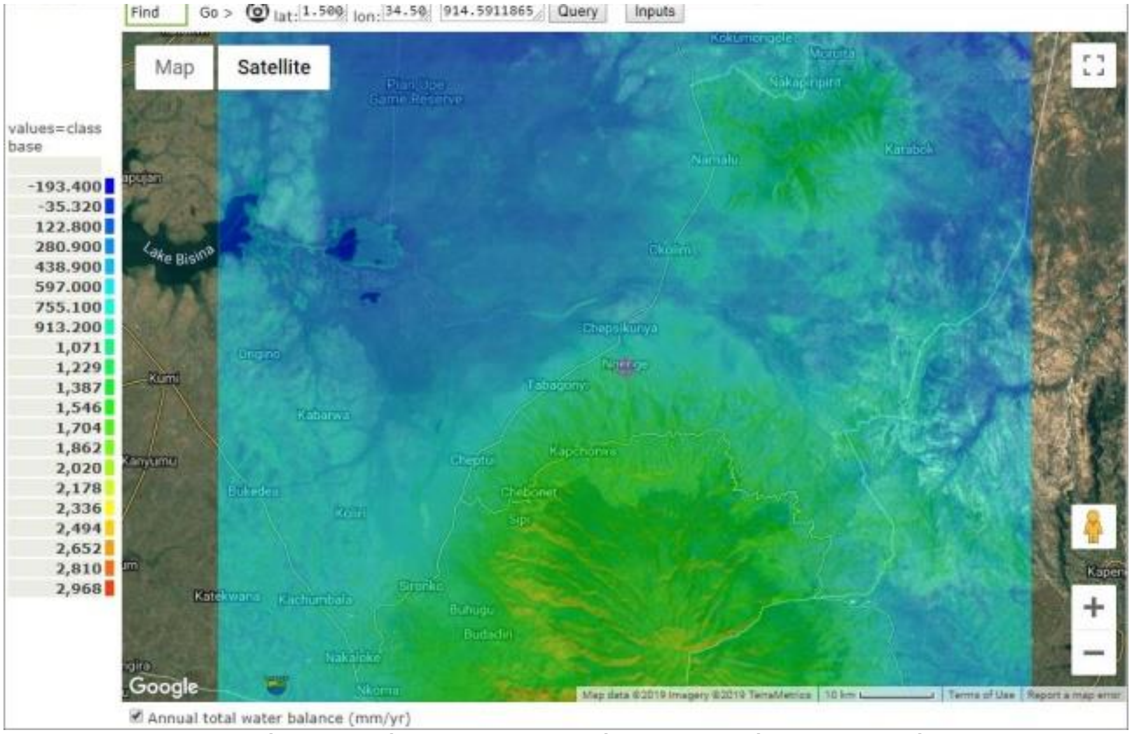

Figure 4.66: Result of Outputs for Baseline Run for Change for Impacts of Climate Change; Annual Total Water Balance-Upper Elgon

Figure 4.67: Result of Outputs for Baseline Run for Change for Impacts of Climate Change; Annual Total Water Balance-Lower Elgon

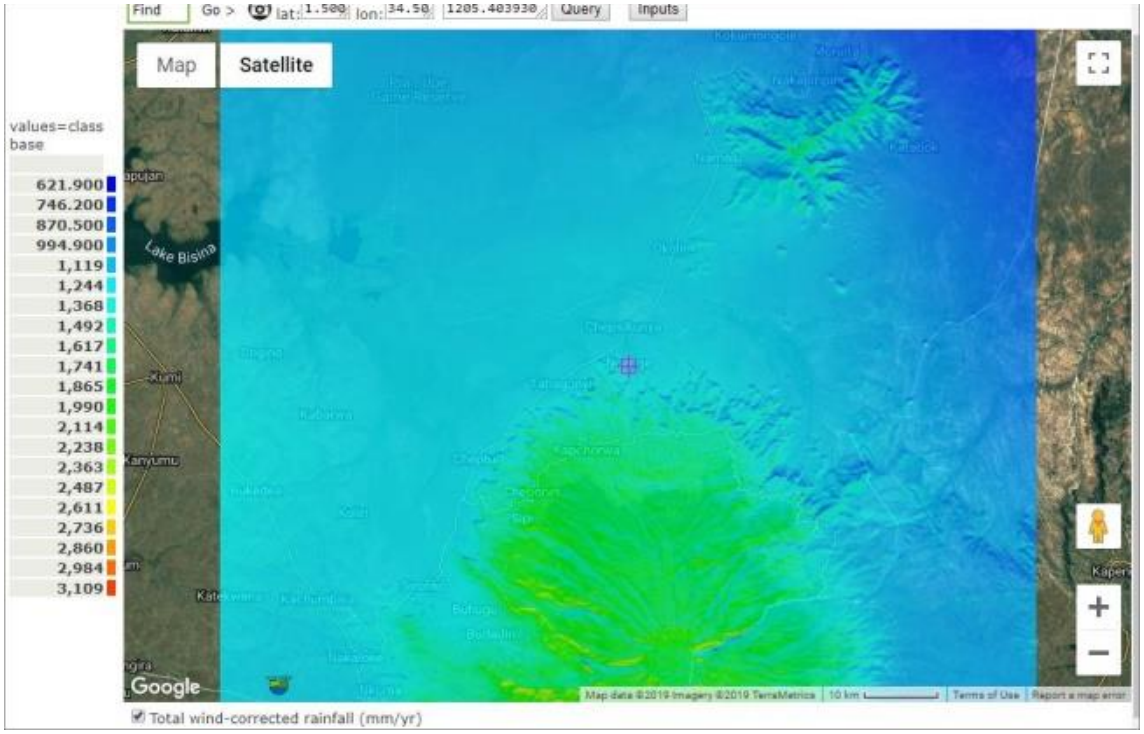

Figure 4.68: Result of Outputs for Baseline Run for Change for Impacts of Climate Change; Total Wind-Corrected Rainfall- Upper Elgon

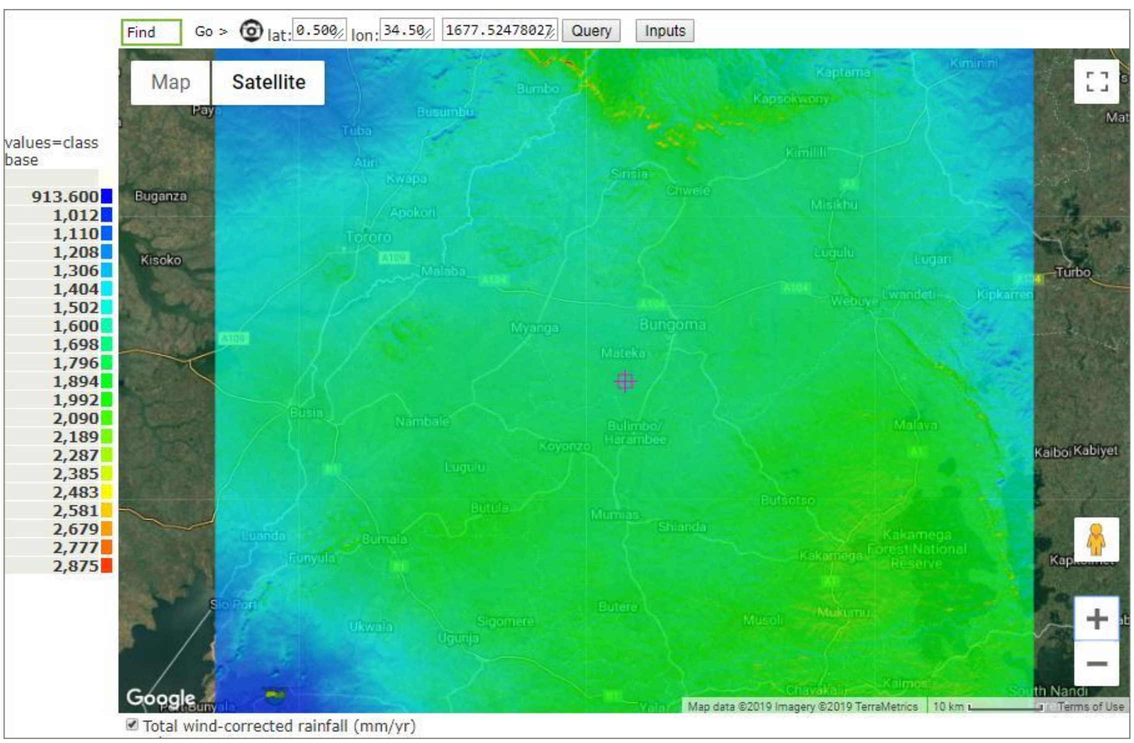

Figure 4.69: Result of Outputs for Baseline Run for Change for Impacts of Climate Change; Total Wind-Corrected Rainfall- Lower Elgon

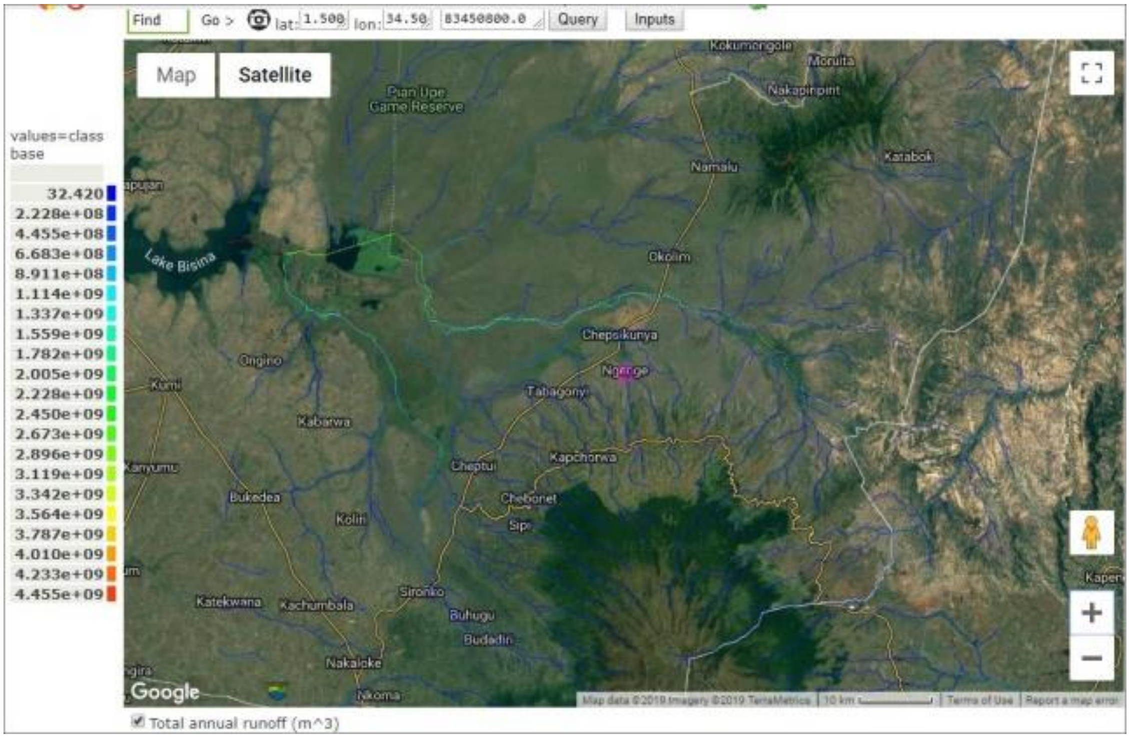

Figure 4.70: Result of Outputs for Baseline Run for Change for Impacts Resulting from Climate Change; Total Annual Runoff- Upper Elgon

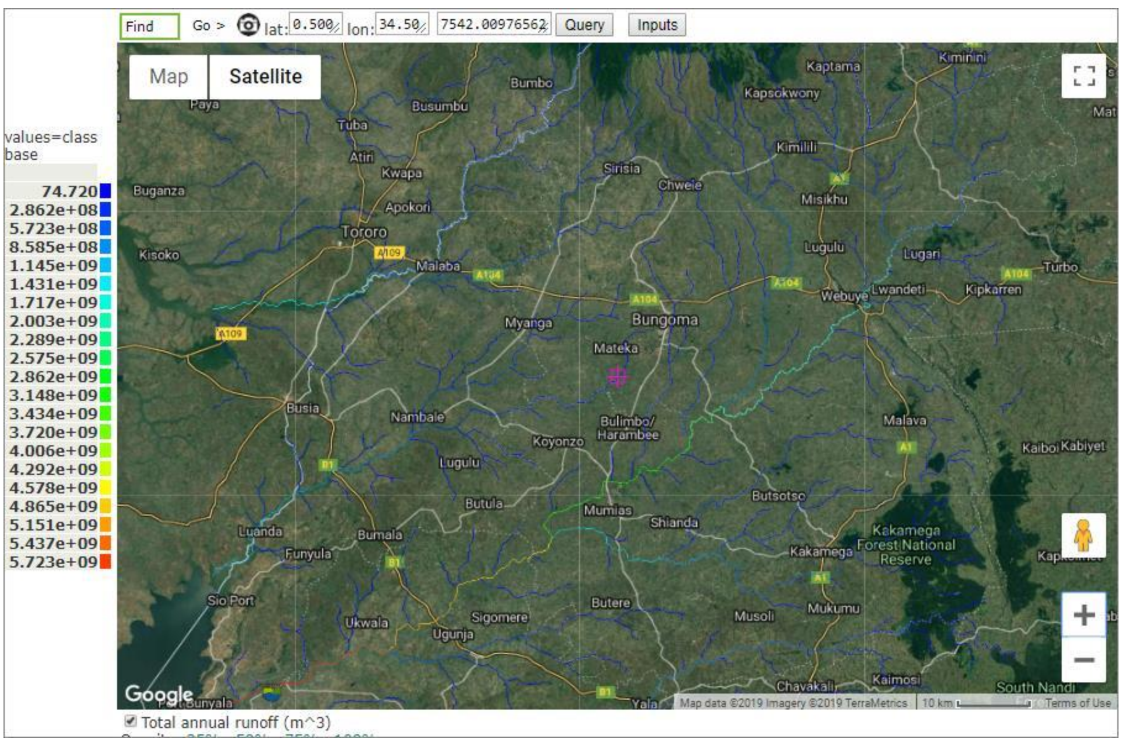

Figure 4.71: Result of Outputs for Baseline Run for Change for Impacts Resulting from Climate Change; Total Annual Runoff- Lower Elgon

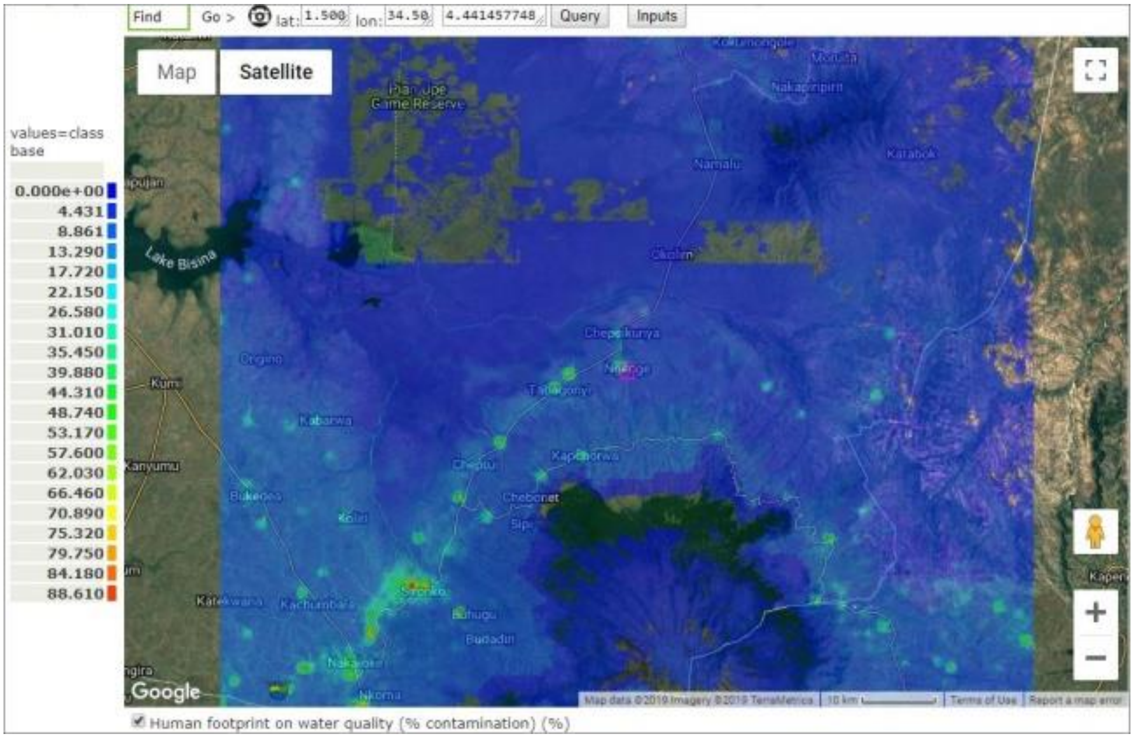

Figure 4.72: Result of Outputs for Baseline Run for Change for Impacts Resulting from Climate Change; Human Footprint on Water Quality(%Contamination)- Upper Elgon

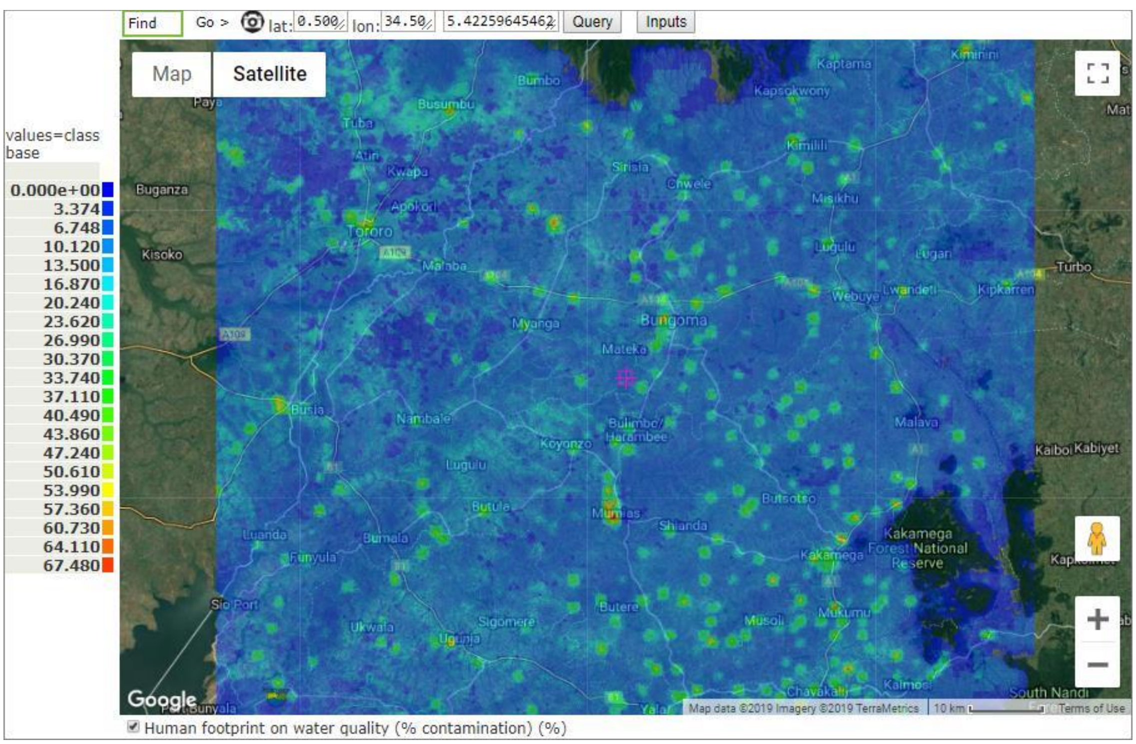

Figure 4.73: Result of Outputs for Baseline Run for Change for Impacts Resulting from Climate Change; Human Footprint on Water Quality(%Contamination)- Lower Elgon

For the Upper Elgon the alternative led to a change in tree cover of 0 % cover on average and a change of herb cover of 0 % cover with a change of bare cover of 0 % cover. This led to a rise in evapotranspiration for the area of 30 ($mmyr^{-1}$) (4.8 %) and a rise of fog interception of 0.5 ($mmyr^{-1}$) (0.76 %), resulting to an overall decline in water balance of -97 ($mmyr^{-1}$) (-15 %). While for Lower Elgon the alternative this led to a change in tree cover of 0 % cover on average and a change of herb cover of 0 % cover with a change of bare cover of 0 % cover. This led to a rise in evapotranspiration for the area of 34 ($mmyr^{-1}$) (5.7 %) and a decline of fog interception of -3.2 ($mmyr^{-1}$) (-3.9 %), resulting to an overall decline in water balance of -16 ($mmyr^{-1}$) (-1.5 %). Based on these results and illustrations in the figures, with the current status quo, it is projected climate change will have negative impacts on freshwater ecosystem services sustainability in terms of water quality and quantity.

Results from Waterworld depicted potential impacts of climate change of reduced runoff levels due to evapotranspiration resulting from increasing temperatures. It is projected increased water contamination due defecation by both human and livestock. Based on these results, it is projected that with increased human activity, there will be increased emission of anthropogenic Green House Gases (GHGs') due to poor land use practices resulting in increased temperatures. Increased temperatures will lead to increased evapotranspiration, resulting in reduced water levels and hence reduced and an unsustainable freshwater ecosystem services.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The results from the study for the period 1948-2017, show that the current cost of living and increasing population in the Mt. Elgon region, has greatly led to increasing demand for land for socio-economic activities. Land being a fixed asset, with increased pressure due to increased demand, is of increasing encroachment on forest reserves and leading to indiscriminate cutting of trees to clear land for livelihood activities. This is affecting tree cover and its ability to contribute towards enhancement of formation of precipitation and a cool climatic conditions. This has affected livelihoods which largely depends on rain-fed agriculture and thus increased irrigation putting more pressure on the limited waters resources. Limited land resources has resulted in land degradation due to over-use and exposure of top fertile soils without deliberate efforts towards conservation, improvement or even allow regeneration by fallow.

Land degradation has led to increase in loose top soils, increased soil erosion, water pollution by contamination as a result of silting and defecation by both human and non-human populations. This has affected the quality of freshwater resources. Increased runoff with limited water percolation has greatly reduced water reserves in ground aquifers resulting in limited or no river runoff during drought periods. The temperatures are warmer and rainfall unpredictable. There is increasing downward trends in precipitation and increased climate variability. Seasons are shorter with erratic rainfall. This has resulted in poor freshwater quality and quantity in river channels, and hence reduced quality and hence unsustainable freshwater ecosystem services.

Human activites for livelihoods like agriculture, fish farming, charcoal burning, sand mining, herbal medicinal plant collection, livestock farming and fuel-wood for energy production through deforestation, has led to an increased demand for freshwater ecosystem services. This has led to socio-economic impacts like, conflict among communities for land and water, land degradation due to over-exploitation, loss of soil moisture due to overuse and increasing temperatures. There is increased evapo-transpiration in rivers due to cleared riparian zones, causing increased uptake of water by crops and plants as a result of increased temperature and hydrological drought as well as exposed streamflow to high temperatures drying up river discharge. There increased wetland encroachment and loss of flood control mechanisms resulting in flooding. As a result of sand mining, more streams and rivers are drying up leading to loss of habitat for reproduction of organisms and nutrient purification cycle, and reduced water levels in the \Mt. Elgon watersheds causing rationing of water for domestic supply and industrial use in Mbale Water supply located on River Manafwa. This has also caused loss of crop during drought spells.

The increased demand for land, its use and practices has affected its state and quality in the watershed. There is increased irrigated rice growing in uplands to enhance food production to meet population demand. Poor crop production is leading to loss of income hence increased poverty and loss of food security. The opportunity cost of producing more food and utilization of natural resources for livelihood activities, without conservation measures is impacting freshwater resources negatively and as a result affecting sustainability of freshwater ecosystem services. With limited or no conservation measures taken, as well as limited conservation development priority, will continue to affect the ability of freshwater ecosystems to perform to their expected potential to provide services..

For the entire watershed for observed data analysed, annual mean precipitation levels was highest in Buginyanya gauging station and lowest in Kitale station withdownward trend. There is a general downward trend in discharge was observed. depicting severe changes in water levels. This has impacted the ability of the watersheds to deliver sufficient freshwater ecosystem services for the entire ecosystem over time, affecting the hydrological cycle and hence increased climate variability driven by socio-economic drivers in the Mt. Elgon watersheds and beyond.

By modelling and simulation results showed the opportunity cost for conserving freshwater ecosystems, for freshwater ecosystem services sustainability, results from costing nature for realized services, potential services and development priority for conservation showed that, other than the watersheds within the protected forest reserves, freshwater ecosystem services and associated ecosystem services are no fully realizeddepicting high rate of the need for development priority for conservation for the entire study area if potential services are to be realized. Forland use and cover change esults showed increased agricultural cultivation of irrigated rice and wetland destruction for rice cultivation, diversion of stream flow at head waters fish farming and increasedwater pollution due to contamination by defecation, siltation, affecting water quality and quantity, environmental quality and hazard mitigation. Results also showed an increasing trend of presence of carbon in deforested and exposed land area hence increased emissions in the atmosphere that will impact climate resulting in climate change.

Results from Waterworld depicted potential impacts of climate change of reduced runoff levels due to evapotranspiration resulting from increasing temperatures. It is projected increased water contamination due defecation by both human and livestock. Based on these results, it is projected that with increased human activity, there will be increased emission of anthropogenic Green House Gases (GHGs') due to poor land use practices resulting in increased temperatures. Increased temperatures will lead to increased evapotranspiration, resulting in reduced water levels and hence reduced and an unsustainable freshwater ecosystem services.

5.2 Recommendations

Founded on observations and challenges encountered during this study, and the results of the findings from the investigation in the Mt. Elgon watersheds, the researcher would like to make the following recommendations;

5.2.1 Government-Policy Makers

Rainfall is the source of all water. The presence of adequate forest cover is vital to enhance suitable climatic conditions to enhance precipitation levels. The presence of forest cover makes the atmosphere more humid and also store water in the occurrence of relief rainfall. They utilize mist and fog hence making the moisture in the air. This is eventually released through evapotranspiration increasing chances of the occurrence of rain when sea breezes lift land air. There is urgent need to increase forest reserves by gazette. There is need to resettle communities on loose hazardous soils to allow forestation and reaforestation at higher altitudes of the watershed and along riparian zones of the river systems. There is need for government to devise alternative livelihoods for affected communities as well as provide incentives for carbon credits and improved social services, cooperatives and market for produce and subsidies on implements to enable value addition.

Availability and sufficiency of historical climate, biophysical and socio economic data was limited. Improvement mechanism for collection and data management is a priority. This can be enhanced through reanalysis of data, modeling and simulation of future scenarios. This is imperative for economic planning, decision making for policy development and implementation for improved livelihoods, hazard mitigation, conservation of freshwater ecosystems and services. As an adaptation strategy for sustainability of freshwater ecosystem services watersheds, as a priority, there must be improved integration of statitics on contemporary climate unpredictability of water-related managegement (IPCC, 2008). This information would be useful towards long term approaches of coping with climate change.

5.2.2 Government-Ministry of Environment and Natural Resources

The Costing of nature to asseess and analyse, the opportunity cost of deriving benefits in an ecosystem is very vital. This enables the setting of development priorities, whether to conserve and improve natural resurces to realise full and potential benefits of freshwater ecosystem services and its associated ecosystem services. Or utilise a natural resource at its current state. Conservation gurantees sustainable utilisation and development of natural resourses. It also increases opportunites for alternative profitable livelihood options as decision for investment are based on data and researched information. A healthy mountain watershed enhances freshwater ecosystem service provision, providing alternative sustainable livelihoods. There is need to Cost all natural resources to know their true value in terms of the full benefits that can be derived. This will also enable priority to be taken in making investments. It will also enable efforts to be made towards conservation to attain full ecosystem value and health and as such generate more opportunities for alternative livelihood choices and investments.

5.2.3 Government-Ministry of Economic Planning and Development

Natural resource modelling and simulation enables projection for better planning and policy development. It enables mitigation, informs early warning systems, preparedness and adaptation strategies. In worst case scenarios, it informs emergency response to avert loss of life and property, restoring dignity and hope to affected communities enabling bouncing back. Adapting and utilisation of climate change models, ecosystem models, agro-metrology and hydrometerology models will inform decision making for policy development.

5.2.4 Government and Non-Governmental Organisations-Conservationist

There is need for increased sensitization on of climate change and it effects in all sectors of the society by mainstreaming climate change and mitigation in both private and public sectors and encouraging alliances for accountability. Increased funding towards innovation is an incentive to attract alternative livelihoods. Awareness through the leadership in faith-based organisations and community leaders. This will enable improved water resource management and governance. There is need for further research on mountain ecosystems and freshwater ecological services in the Mt.Elgon watersheds. Deliberate efforts to enhance precipitation to recharge groundwater aquifers should be carried out. Rainwater harvesting and utilization should be encouraged to reduce on wastage of this limited natural resource. Recycling of water and use should be practiced, this can be used for irrigation. The East African countries can learn from advanced economies in Asia like in Israel and Dubai that are adapting to climate change by sustainably utilizing the scarce freshwater resources that they have by applying the measures above. By enhancing alternative economical ways of utilizing these resources will enhance conservation and sustainability of freshwater ecosystems and the benefits we derive from them. This will greatly improve the health of other associated ecosystems.

5.2.5 Researchers and Academician

There is need for increased research in the science of climate change and climate variability and its impacts on freshwater ecosystem services and more research in sustainability of mountain freshwater ecosystem services conservation and management. There is opportunity for increased research in the benefits of costing nature verses the benefits derived from conservation of the ecosystems for sustainable services which can be replicated in other regions. However there is need for more research towards Ecosystem based adaptation approaches, alongside community based approaches so as to ensure sustainability of the ecosystem and the ecosystem services as shown in the some of the adaptation strategies carried out..

There is need for enhancement of governance rights through informed policy decision making based on evaluation of the opportunity cost of conserving the ecosystem and the services it provides. There is need to invest technology for example geospatial technologies and remote sensing for improved data collection and data analysis as a base for informed policy formulation and projection, There is great need to put in place necessary economic instruments for policy to enhance alternative livelihoods. These can be supported by creating opportunities for communities to access services from financial institutions as means of reduced interest rates on credit facilities. These were some of the suggestions from various community leaders using unstructured interviews.

There is need for urgent research on alternative sustainable livelihoods in the Elgon region, afforestation by native fruit bearing trees as a means for carbon sequestration and as source for food and livelihoods as in most especially in the highlands. The communities in the low land can be encouraged to grow woodlots. This can be a source of income inform of carbon credits earned and attained as a bonus for reducing carbon emissions due to sequestration. The use of firewood and charcoal as a source of energy is a major cause of respiratory diseases, deforestation and land degradation due to land cover change. This can be curbed by the use of tested improved cook stoves that are both domestic and institutional that have a high thermal efficiency and use less fuel wood or charcoal. Every community not only in the Mt. Elgon watershed but in the whole world using wood as a source of fuel energy, needs to adapt to the use of this improved technology to save our forests (Venkatar et al., 2010). It is another source of annual income as one can earn carbon credits by using this kind of stove. The user can register and sell their carbon credits to a registered improved cook stove supplier organization that is a buyer for example Uganda Carbon Bureau. There is also need to advance technologies in thermal efficiency in cook stoves. Improved access rights for Ecoengine models and other ecological models for scientists will enable research and use in developing economies.

REFERENCES

Abeygunawardena, P. *et al.* (2009) 'Poverty and Climate Change: Reducing the Vulnerability of the Poor through Adaptation', pp. 1–43.

Amelie, V. ., Ongoma, V. and Muthama, N. J. (2010) 'Journal of Meteorology A Journal of Kenya Meteorological Society', *J.Meteorol. Rel. Sci., 4 3 –20 (2010),* 4(December).

Aylward, B. *et al.* (2005) 'Freshwater Ecosystem Services', in *Ecosystems and Human Well-being: Current State and Trends*, pp. 213–255.

Bergkamp, G. and Cross, K. (2006) 'Groundwater and ecosystem services: towards their sustainable use', *International Symposium on Groundwater Sustainability (ISGWAS)*, pp. 177–193. Available at: http://aguas.igme.es/igme/isgwas/Ponencias ISGWAS/13-Bergkamp.pdf.

Bergkamp, G. and Cross, K. (2014) 'Groundwater and ecosystem services: towards their sustainable use', *International Symposium on Groundwater Sustainability (ISGWAS)*, pp. 177–193. Available at: http://aguas.igme.es/igme/isgwas/Ponencias ISGWAS/13-Bergkamp.pdf.

Burn, D.H. and Elnur, M.A.H. (2002) Detection of Hydrologic Trends and Variability. Journal of Hydrology, 255, 107-122. https://doi.org/10.1016/S0022-1694(01)00514-5

Byaruhanga .A., Kasoma .P., and Pomeroy .D., (2011)

Cavanagh, C. and Benjaminsen, T. A. (2014) 'Virtual nature, violent accumulation: The "spectacular failure" of carbon offsetting at a Ugandan National Park', *Geoforum*. Elsevier Ltd, 56, pp. 55–65. doi: 10.1016/j.geoforum.2014.06.013.

Costa A C, Soares A (2009 Homogenization of climate data: Review and new perspectives using geostatistics. *Mathematical Geosci.* 41: 291–305

Creswell JW., (2007), Qualitative Inquiry and Research Design: Choosing Among Five Approaches: International Student Edition. Thousand Oaks, California: Sage Publications; 2007.

Crozier M.J. and Glade T., 2005. Landslide hazard and risk: issues, concepts, and approach. In: Glade T, Anderson M, Crozier MJ (eds) Landslide hazard and risk. Wiley, New York, pp 1-40.

Crotty M..(1998), The Foundations of Social Research: Meaning and Perspective in the Research Process. Thousand Oaks, California: Sage; 1998.

Dasgupta, S. *et al.* (2009) 'Sea-level rise and storm surges: A comparative analysis of impacts in developing countries', (April), p. 41.

DFID. 2000a. *Halving world poverty by 2015, economic growth, equity and security. Strategies for achieving the international development targets.* DFID Strategy Paper. London

Dodds, W. K., Perkin, J. S. and Gerken, J. E. (2013) ‘Human impact on freshwater ecosystem services: A global perspective’, *Environmental Science and Technology*, 47(16), pp. 9061–9068.

Everard, M. (2017) *Ecosystem Services: Key Issues.* Translated from the N/A First. London: Routledge. ISBN 9781138692664 Available from: http://eprints.uwe.ac.uk/31394

Firat, M., Dikbas, F., Koç, A.C. and Gungor, M., 2010. Missing data analysis and homogeneity test for Turkish precipitation series. *Sadhana*, *35*(6), p.707.

Fischer E.M, (2013), Robust spatially aggregated projections of climate extremes

Fischer E.M., (2014), Detection of spatially aggregated changes in temperature and precipitation

Fischer, E. M., Beyerle, U. and Knutti, R. (2013) ‘Robust spatially aggregated projections of climate extremes’, *Nature Climate Change*. Nature Publishing Group, 3(12), pp. 1033–1038. doi: 10.1038/nclimate2051.

Foggin J.M., 2016 Conservation Issues: Mountain Ecosystems ã 2016 Elsevier Inc. All rights reserved

Food and Agriculture Organization (FAO), (2014) *The State of Food Insecurity in the World*.

Food and Agriculture Organization (FAO). (2015). *The State of Food and Agriculture 2015 (SOFA): Social Protection and Agriculture: Breaking the Cycle of Rural Poverty,* Food and Agriculture Organization (FAO) of the United Nations, Rome, 2015.

Geist, H.J., Lambin, E.F., 2009. Proximate causes and underlying driving forces of tropical deforestation. BioScience 52 (2), 143–150.

Githui, F., Gitau, W., Bauwens, W., 2009. Climate change impact on SWAT simulated streamflow in western Kenya. J. Clim. 29,1823–1834,

Glade, T., Crozier, G.M., 2004. The nature of landslide hazard impact. In: Glade, T., Anderson, M.G., Crozier, G.M. (Eds.), Landslide Hazard and Risk. Wiley, Chichester, pp. 43–74.

Gray D.E., (2009), Doing Research in the Real World. 2nd ed. Thousand Oaks, California: Sage Publications; 2009.

Hagg, W., Braun, L.N., Kuhn, M., Nesgaard, T.I., 2007. Modelling of hydrological response to climate change in glacierized CentralAsian catchments. J. Hydrol. 332, 40–53, Hamududu, Byman & Killingtveit, Ånund. (2012). Assessing Climate Change Impacts on Global Hydropower. Energies. 5. 305-322. 10.3390/en5020305.

Harper, D. T., Zeebe, R., Hönisch, B., Schrader, C. D., Lourens, L. J., & Zachos, J. C. (2017). Subtropical sea-surface warming and increased salinity during Eocene Thermal Maximum 2. *Geology*, *46*(2), 187–190. https://doi.org/10.1130/G39658.1

Helsel, D.R. and R.M. Hirsch. 1992. *Statistical methods in water resources*. Studies in Environmental Science 49. New York: Elsevier. (available on-line as a pdf file

Helsel D.R. and Hirsch R.M. (2002, Techniques of Water-Resources Investigations of the United States Geological Survey Book 4, Hydrologic Analysis and Interpretation ,Chapter A3 Statistical Methods in Water Resources

Hitimana, J., Legilisho Kiyiapi, J., Thairu Njunge, J., 2004. Forest structure characteristics in disturbed and undisturbed sites of Mt. Elgon Moist Lower Montane Forest, western Kenya. Forest Ecology and Management 194 (1–3), 269–291.

Hjerpe, M., & Nasiritousi, N. (2015). Views on alternative forums for effectively tackling climate change. *Nature Climate Change*, *5*(9), 864–867. https://doi.org/10.1038/nclimate2684

Hussein, M. A. (2011). Climate change impacts on East Africa. In *The economic, social and political elements of climate change* (pp. 589-601). Springer, Berlin, Heidelberg.

IFRC (2006) *How to conduct a food security A step-by-step guide for, 2nd Edition*.

IIED. (2009). *Water ecosystem services and poverty under climate change Key issues and research priorities, Mayers, .J. B., Charles .B., Ivan .H., Rob. Iied*. Retrieved from http://pubs.iied.org/13549IIED.html

IPCC (2001) Climate Change 2001. *Synthesis report*. Cambridge University Press. Cambridge.

IPCC (2007) 'Climate change 2007 : impacts, adaptation and vulnerability : Working Group II contribution to the Fourth Assessment Report of the IPCC Intergovernmental Panel on Climate Change', *Working Group II Contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report*, 1(July), p. 976. doi: 10.2134/jeq2008.0015br.

IPCC., (2007). Summary for policymakers. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Ignor, M.T.,Miller, H.L. (Eds.), Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel onClimate Change, 2007. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC 2008, Climate Change and Water . Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., 2008: Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp.
https://doi.org/10.1093/nq/s10-IX.235.507-c

IPCC (2014) *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*. doi: 10.1017/CBO9781107415324.004.

IPCC, 2014: 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.)]. IPCC, Geneva, Switzerland, 151 pp.

ITFC (2012).Institute of Tropical Forest Conservation, Mbarara University of Science and Technology webpage. Accessible on: http://www.itfc.org/mt_elgon_national_park.htm (accessed March 2017).

IUCN. (2000). Guidelines for the Prevention of biodiversity loss caused by alien invasive species. Gland, Switzerland: IUCN Species Survival Commission,. *Iucn*, (February), 25

Jamshed, Shazia. (2014). Qualitative research method-interviewing and observation. Journal of basic and clinical pharmacy. 5. 87-8. 10.4103/0976-0105.141942.
https://www.researchgate.net/publication/266946266_Qualitative_research_method_interviewing_and_observation

Johnson, R. & Onwuegbuzie, Anthony & Turner, Lisa. (2007). Toward a Definition of Mixed Methods Research. *Journal of Mixed Methods Research*, *1*(2), 112-133.
https://doi.org/10.1177/1558689806298224.

Kendall, 1975

Kingston, D. G. and Taylor, R. G. (2010) 'Sources of uncertainty in climate change impacts on river discharge and groundwater in a headwater catchment of the Upper Nile Basin, Uganda',*Hydrology and Earth System Sciences*, 14(7), pp. 1297–1308. doi: 10.5194/hess-14-1297-2010.

Kizza M, Rodhe A, Xu CY, Ntale HK, Halldin S. 2009. Temporal rainfall variability in the Lake Victoria Basin in East Africa during the twentieth century. Theoretical and applied climatology, 98(1-2), 119-135. Researchgate

Kosygin L., Ujjal D., Pratima S., Basudhara R.C., 2019. Glyptothorax gopii, a new species of catfish (Teleostei: Sisoridae) from Mizoram, north-eastern India
https://biotaxa.org (viewed August 30, 2019)

Kumar, R. (2005). *RESEARCH METHODOLOGY a step-by-step guide for beginners, second edition*. SAGE Publications Inc. 2455Teller Road, Thousand Oaks, California 91320

Kummu, M., Guillaume, J., de Moel, H., Eisner, S., Florke, M., Porkka, M., Siebert, S., Veldakamp, T.I.E., Ward, P.J., (2016). The world's road to water scarcity: shortage and stress in the 20th century and pathways towards sustainability. *Sci Rep* **6,** 38495 (2016) doi:10.1038/srep38495

Laman, M., Khamati, B., and Milimo, P. 2001. Mount Elgon Integrated Conservation And Development Project (MEICDP). External Evaluation, Final Report.

Lee .H. and Kang K (2015), "Interpolation of Missing Precipitation Data Using Kernel Estimations for Hydrologic Modelling," Advances in Meteorology, vol. 2015, pp.1-12, Art. No.935868

Liu, Junguo & Yang, Hong & Gosling, Simon & Kummu, Matti & Flörke, Martina & Pfister, Stephan & Hanasaki, Naota & Wada, Yoshihide & Zhang, Xinxin & Zheng, Chunmiao & Alcamo, Joseph & Oki, Taikan. (2017). Water scarcity assessments in the past, present and future. Earth's Future. 5. 10.1002/2016EF000518.

MA (Millennium Ecosystem Assessment), 2005. Ecosystems and Human Wellbeing: Synthesis. Island Press, Washington, D.C.

Mancosu N., 2015 , Water Scarcity and Future Challenges for Food Production- MDP

Meals D, Spooner J., Harcum.S.D, B. and et al. (2011) 'Statistical Analysis for Monotonic Trends Introduction', pp. 1–23.

Mann, 1945

Masese, F. O. *et al.* (2012) 'Effects of deforestation on water resource:integrating science and community perspectives in the Sondu-Miriu river basin, Kenya'.

Matondo, J.I., Peter, G., Msibi, K.M., 2004. Evaluation of the impact of climate change on hydrology and water resources inSwaziland: Part II. Phys. Chem. Earth 29, 1193–1202,

Mayers, J. *et al.* (2009) *Water ecosystem services and poverty under climate change Key issues and research priorities, Iied*.

Mccright, A.M., and Dunlap R.E., 2011. The politicization of climate change and polarization in the Americanpublic's views of global warming, 2001-2010. The Sociological Quarterly, 52, 155-194

Minichiello V., (1990), In-depth Interviewing: Researching People, Reprint, Longman Cheshire, 1990, 0582712726, 9780582712720, 0582712726, 357 pg

Minichiello V., Aroni R., Hays T.N., (2014), Review of In-depth Interviewing: Researching People, Reprint, Longman Cheshire, 1990, 0582712726, 9780582712720, 0582712726

Minichiello V., Aroni R., Timewell E., & Alexander L., (2008), In-depth Interviewing: Researching People, Reprint, Longman Cheshire, 1990, 0582712726, 9780582712720, 0582712726, 357 pg

Mugagga .F and Buyinza .M., (2013). Land tenure and soil conservation practices on the slopes of Mt Elgon National Park, Eastern Uganda, 1Department of Geography, Geo Informatics and Climatic Sciences, Makerere University, P.O Box 7062 Kampala, Uganda. 2Directorate of Research and Graduate Training, Makerere University, P.O Box 7062, Kampala, Uganda. Accepted 18 September, 2013

Mugagga, F. and Buyinza, M. (2014) 'Land tenure and soil conservation practices on the slopes of Mt Elgon National Park Eastern Uganda', *Research Journal of Applied Sciences*, 9(7), pp. 402–406. doi: 10.3923/rjasci.2014.402.406.

Mugagga, F., Buyinza, M. and Kakembo, V. (2010) 'Livelihood diversification strategies and soil erosion on Mt. Elgon, Eastern Uganda', *Environmental Research Journal*, pp. 272–280.

Mugagga, F., Kakembo, V., and Buyinza, M. 2011. Land use changes on the slopes of Mount Elgon and the implications for the occurrences of landslides. Science Direct, Catena 90 (2012) pp. 39-46

Mugagga F, Kakembo V, Buyinza M. 2012. Land use changes on the slopes of Mount Elgon and the implications for the occurrence of landslides. Catena, 90, 39-46.

Muhweezi, A. B., Sikoyo, G. M. and Chemonges, M. (2007) 'Introducing a Transboundary Ecosystem Management Approach in the Mount Elgon Region', *Mountain Research and Development*, 27(3), pp. 215–219. doi: 10.1659/0276-4741(2007)27[215:IATEMA]2.0.CO;2.

Muhweezi, at al., (2013)

Mulligan Mark, (2013), WaterWorld: a self-parameterising, physically based model for application in data- poor but problem-rich environments globally. Water International 36, 17–41.

Mulligan, M. (2018) 'WaterWorld : a self-parameterising , physically based model for application in data-poor but problem-rich environments globally', (November), pp. 748–769.

Mulligan, M., Saenz Cruz, L. L., Pena-Arancibia, J., Pandey, B.,Mahé, G. & Fisher, M. (2011c) Water availability and use across the Challenge Program on Water and Food (CPWF) basins.

Water International 36, 17-41.

Mulligan. M., and Arnout Van Soesbergan , (2016) Mapping ecosystem services in the Volta basin basin using Co$ting Nature ES assessment model

Musau, J. *et al.* (2015) 'Hydrological responses to climate change in Mt. Elgon watersheds', *Journal of Hydrology: Regional Studies*. Elsevier B.V., 3, pp. 233–246.

Mwaura Anastasia , (2011), Mt. Elgon Transboundary Ecosystem, Western Conservation Area, Kenya, Biodiversity Department, KWS, amwaura@kws.go.ke. June 2011, Dresden, Germany

MWE (2013) 'Ecosystem Based Adaptation In Mountain Elgon Ecosystem Vulnerability Impact Assessment (VIA) for the Mt Elgon Ecosystem', *Ministry of Water & Environment(MWE)*, Version, P(December).

Nair, K. S. (2016) 'Impact of climate change and anthropogenic pressure on the water resources of India : challenges in management', pp. 63–67. doi: 10.5194/piahs-374-63-2016.

NatureUganda. (2011). Important Bird Areas Status and Trends 2010. *NatureUganda (2011)*, (6), 1–24.

NEMA (2010). Landslides in Bududa District, their Causes and Consequences.National Environment Management Authority Kampala.

Nsubuga FN, Namutebi EN, Nsubuga-Ssenfuma M. 2014. Water Resources of Uganda: An Assessment and Review. Journal of Water Resource and Protection, 6(14), 1297.

Odada EO, Olago DO, Kulindwa K, Ntiba M, Wandiga S. 2004. Mitigation of environmental problems in Lake Victoria, East Africa: causal chain and policy options analyses. Ambio: A journal of the human environment, 33(1), 13-23.

ODI, 2015, The contribution of ecosystem services to human resilience I International Symposium on Groundwater Sustainability (ISGWAS) 177 Groundwater and Ecosystem Services: towards their sustainable use Bergkamp, Ger and Cross, Katharine IUCN – The World Conservation Union, Rue Mauverney 28, 1196 Gland, Switzerland.

Ogallo, L.A.,Mwangi, K., Omondi, P., Ouma, G. and Wayumba, G. (2018) Land Cover Changes in Lower Jubba Somalia. American Journal of Climate Change , 7, 367-387.

Patton. M. Q. (2002). Qualitative research and evaluation methods (3rd ed.). Thousand Oaks, CA: Sage Publications

Petersen, L., Heynen, M. and Pellicciotti, F. (2017). Freshwater Resources: Past, Present, Future. The International Encyclopedia of Geography. 1–11.

Pettitt. A.N., (1979). A Non-Parametric Approach to the Change-Point Problem Published by : Wiley for the Royal Statistical Society Stable URL : http://www.jstor.org/stable/2346729 A Non-parametric Approach to the Change-point Problem. *Jstor*, *28*(2), 126–135. https://doi.org/10.1016/j.epsl.2008.06.016

Petursson, J. G., Vedeld, P. and Sassen, M. (2013) 'An institutional analysis of deforestation processes in protected areas: The case of the transboundary Mt. Elgon, Uganda and Kenya', *Forest Policy and Economics*. Elsevier B.V., 26, pp. 22–33. doi: 10.1016/j.forpol.2012.09.012.

Poff, N. L., Allan, J. D., Palmer, M. A., Hart, D. D., Richter, B. D., Arthington, A. H., Rogers, K. H., Meyer, J.L. & Stanford, J. A. (2003). River flows and water wars: emerging science for environmental decision-making. Frontiers in Ecology and the Environment 1, 298–306.

Pohlert, T. (2018) 'Non-Parametric Trend Tests and Change-Point Detection', pp. 1–18

Punch, K.F. (1998) Introduction to Social Research: Quantitative and Qualitative Approaches. Sage, London.

Rannveig K. F. and Bernardas P. (2012) Feasibility Study Report, Mt. Elgon Information Needs.

Rath S., Shangninam B., Kosygin L.,(2019). Garra simbalbaraensis, a new species of cyprinid fish (Teleostei: Cyprinidae) from Himachal Pradesh, India
https://biotaxa.org (viewed August 30, 2019)

Revenga C., Campbell I., Abell R., De Villiers P. & Bryer M. (2005) Prospects for monitoring freshwater ecosystems towards the 2010 targets. Philosophical transactions of the Royal Society of London. Series B, Biological sciences, 360, 397–413.

Revenga et al., (2009)

Rockström, J., Folke, C., Gordon, L., Hatibu, N., Jewitt, G., Penning de Vries, F., … Schulze, R. (2004). A watershed approach to upgrade rainfed agriculture in water scarce regions through Water System Innovations: An integrated research initiative on water for food and rural livelihoods in balance with ecosystem functions. *Physics and Chemistry of the Earth*, *29*(15-18 SPEC.ISS.), 1109–1118. https://doi.org/10.1016/j.pce.2004.09.016

RoU (2012) Republic of Uganda: Ministry of Local Government. List of Local Government Districts. Can be accessed online at: http://molg.go.ug/local-governments.

Rwigi, S. K. *et al.* (2012) 'Comparative Case Study of Rainfall - Runoff Models over the Nyando River Basin River Basin ', (July 2016).

Rwigi, S. K., N. J. Muthama, A. O. Opere and F. J. Opijah, 2016. Assessment of Potential Changes in Hydrologically Relevant Rainfall Statistics over the Sondu River Basin in Kenya

Under a Changing Climate. *J. Meteorol. Relat. Sci. vol 9 pg 2-12.*
http://dx.doi.org/10.20987/jmrs.1.05.2016

Rwigi et. al., (2015)

Sakinatu Issaka & Muhammad Aqeel Ashraf (2017) Impact of soil erosion and degradation on water quality: a review, Geology, Ecology, and Landscapes, 1:1, 1-11 To link to this article:

Sassen, M. *et al.* (2013) 'Complex contexts and dynamic drivers: Understanding four decades of forest loss and recovery in an East African protected area', *Biological Conservation*, 159, pp. 257–268.

Schmidhuber, J. and Tubiello, F. (2007) 'Global food security under climate change', *Proceedings of the National Academy of Sciences of the United States of America*, 104(50), pp. 19703–19708.

Shadananan K Nair Proc. IAHS, 374, 63–67, 2016, Impact of climate change and anthropogenic pressure on the water resources of India: challenges in management

Soini, E. (2007). Land tenure and land management in the districts around Mount Elgon*: An assessment presented to Mount Elgon Regional Ecosystem Conservation Programme* (MERECP). ICRAF Working Paper no. 49. Nairobi, Kenya: World Agroforestry Centre.

Taylor, P., Tyler, S. and Moench, M. (2012) 'A framework for urban climate resilience', *Climate and Development*, 4:4(March 2013), pp. 311–326. doi: 10.1080/17565529.2012.745389.

Trochim, W. M. K. (2006). The Qualitative Debate. Research Methods Knowledge Base. http://www.socialresearchmethods.net/kb/qualmeth.php

Tue *et al*,2003

Uganda Bureau of Statistics, Kampala. Uganda Bureau of Statistics (2006). 2002 Uganda Population and Housing Census. Analytical Report. Population Size and Distribution. October 2006

United Nations. (2017). The sustainable development goals report 2017. *The Sustainable Development Goals Report 2017*.
https://doi.org/10.29171/azu_acku_pamphlet_k3240_s878_2016

UNDP. (2012). *Human Development Report 2012 Africa Human Development Report 2012*. *Towards a Food Secure Future*. United Nations Publications 300 East 42nd Street, IN-927A, New York, NY 10017, USA.
https://unp.un.org, www.undp.org/africa and www.afhdr.org

UNEP. (2009). *"Kenya: Atlas of Our Changing Environment."*

UNFCCC (2015). Adoption of the Paris Agreement. FCCC/CP/2015/L.9/Rev.1, 32 pp. Retrieved https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english_.pdf

Van Heist, M., 1994. Land Unit Map of Mt. Elgon National Park: Accompanying Report. Mbale, Mt. Elgon Conservation and Development Project. IUCN.

van Vliet, M. T., Franssen, W. H., Yearsley, J. R., Ludwig, F., Haddeland, I., Lettenmaier, D. P., & Kabat, P. (2013). Global river discharge and water temperature under climate change. *Global Environmental Change*, *23*(2), 450-464.

van Vuuren, D.P., Edmonds, J., Kainuma, M. et al. Climatic Change (2011) 109: 5. Springer Netherlands https://doi.org/10.1007/s10584-011-0148-z

Venkatarman, V., A.D. Sagar, G. Habib, N. Lam, and K.R Smith,*"The Indian National Institute for Advanced Biomass Cookstovves: the benefits of clean, combustion,"* Energy for Sustainability Development, 14, 63-72 (2010)

Viviroli D. et al (2007).Importance of mountains as "Water Towers" of the world pp 12

Viviroli, D. *et al.* (2007) 'Mountains of the world, water towers for humanity: Typology, mapping, and global significance', *Water Resources Research*, 43(7).

Wayne Fife (2005), Doing Fieldwork: Ethnographic Methods for Research in Developing Countries and Beyond : 1-188 pages; Publisher: Palgrave Macmillan; 2005 edition USA

WWF (2006). *Living planet report, 2006*. WWF, Gland.

Xu, Y. P. *et al.* (2013) 'Impact of climate change on hydrology of upper reaches of Qiantang River Basin, East China', *Journal of Hydrology*, 483, pp. 51–60.

Yue, S., Pilon, P. and Cavadias, G. (2002) 'Power of the Mann ± Kendall and Spearman ' s rho tests for detecting monotonic trends in hydrological series', 259, pp. 254–271.

Zhang, Y. and Wildemuth, B. M. (2016) 'Unstructured interviews. Applications of Social Research Methods to Questions in Information and Library Science', p. pp.000-060.

Zhou, G., N. Minakawa, A.K. Githeko, and G. Yan. 2004. Association between climate variability and malaria epidemics in the East African highlands. Proceedings of the National Academy of Sciences of the United States of America. 101: 2375-2380.

APPENDICES

APPENDIX 1: An illustration of Unstructured Interview Guide

S/N	**Introduction:** My names are Khaitsa Susan Wasubire a Master of Science student with the University of Nairobi School of Physical of Physical Sciences in the Department of Meteorology. I am carrying out a research study investigating the anthropogenic causes impacting sustainable mountain freshwater ecosystem services in Mt. Elgon watershed under changing climate in Uganda and Kenya.
1	I can see you are carrying out a activity along this river do you mind if I ask you a few questions regarding your work in relation to this river?
2	Can you a give brief history of this river especially its significance here?
3	How does this river benefit you and your community as a whole?
4	Do you have other rivers in the area?
5	Is this a common activity carried out along this river?
6	Is it your only means of livelihood?
7	Are the water levels constant and how many rain seasons you have in a year?
8	Do you experience drought and flooding in this area?
9	Are there any other sources of water within this area within reach from your activity?
10	Do you experience challenges in relation to the water availability and levels in this river?
11	How does this affect your activity?
12	What efforts are being done to ensure its sustainability at a personal level and at a government level?
13	Are there any forests around or significant woodlots within this area?
14	Are there any sensitization meetings in the community regarding the use of the river banks for livelihood activities?
15	If any how has it impacted the river levels as well as your livelihoods?
16	Other than this livelihood activity do you have plans for alternative means of livelihood in the near future?
17	Do you have any questions that you would like to ask regarding the questions I have been asking you?
Thank you very much for listening to me and all the information you have shared it will be very useful in my study. God Bless You	

APPENDIX 2: An illustration of Observation form

S/N	Observation
1	Identify freshwater resources in the area of study
2	Identify Freshwater ecosystem services in the area
3	Observe land use activities taking place in area
4	Observe land cover types
5	Observe land use activities along the rivers
6	Observe land cover along the river banks
7	Identify livelihood activites within and along the river areas
8	Identify physical features affected by freshwater ecosystem services
9	Observe and visible Climate change impacts
10	Livelihood activity impacts on freshwater ecosystems and services
11	Observe Water levels in river
12	Observe Water quality in terms of clear appearances
13	Observe livelihoods impacted due to human activity
14	Identify sustainable conservation practices
15	Freshwater ecosystem services sustainability.