THE EFFECTS OF MOUNT KENYA GLACIER RECESSION ON WATER SUPPLY AND COMMUNITY LIVELIHOODS – A CASE STUDY OF NYERI AND LAIKIPIA COUNTIES, KENYA

BY

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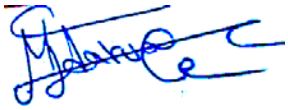
DECLARATION

I, Moses Ndarua Njoki, declare that this is my original work and has not been submitted for examination to any other learning institution.



6th November 2022

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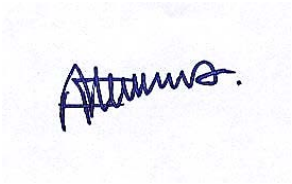
This project report has been submitted for examination with our approval as university supervisors



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DEDICATION

This project report is dedicated to my mother Ms. Safira Njoki Ndarua and Uncle Chege who remains a great inspiration in my life. It is also dedicated to my dear wife Jane and younger sister's Mwihaki and Nyambura for their prayers and support.

This is ours.

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LIST OF ABBREVIATIONS

A.S.L	Above sea level
ASALs	Arid and semi-arid lands
CBD	Convention on Biodiversity
CBNRM	Community Based Natural Resource Management
CETRAD	Center for training and Integrated Research in ASAL Development
CIDPs	County Integrated Development Plans
ES	Ecosystem services
FAO	Food and Agriculture Organisation
GOK	Government of Kenya
IUCN	World Conservation Union.
IWRM	Integrated Water Resources Management
KENWEB	Kenya Wetland and Biodiversity Research Group
KNBS	Kenya National Bureau of Statistics
KNWDR	Kenya National Water Development Report
LWF	Laikipia Wildlife Forum
NOROWASCO	Naromoru water and sanitation company
NAWASCO	Nanyuki Water and Sewerage Company
NEMA	National Environment Management Authority
PwC	PricewaterhouseCoopers.
SPSS	Statistical Program for Social Sciences
SDG s	Sustainable Development Goals
UNDP	United Nations Development Programme
UNESCO	United Nations Educational Scientific and Cultural Organization
WCSLC	Wildlife conservation strategy for Laikipia County
WRMA	Water Resources Management Authority
WRA	Water Resources Authority
WRUAs	Water Resources User Associations
WSRS	Water Sector Reform Secretariat
WSTF	Water Services Trust Fund
WWAP	World Water Assessment Program

ABSTRACT

The case study was aimed at determining whether the watershed ecosystem beneficiaries are aware of deglaciation trends affecting Mount Kenya and it's implication on their livelihood systems. The survey was guided by following specific objectives: a) To determine Mount Kenya glacier trends from the 1970's to 2000's, b) To investigate the perceived implications of glacier recession on river water supply and livelihoods with an emphasis on small scale irrigation, urban water use and pastoralism and c) To determine whether age, gender and level of education significantly influenced perception on availability of clear Adaptation and coping strategies for Glacier recession effects. Glacier cover change for the last four decades (1976- 2016 period) was determined through the analysis of Landsat satellite imagery using Arc GIS and the findings compared with local communities perception specifically on the leeward side of the mountain of which is an ASAL. The local perception survey on effects of glacier changes on river flow and livelihoods took place on August 2017 using a Self-Administered Likert Scale Standard Questionnaires; face-to-face interviewing 87 riparian residents along the Naromoru and Likii rivers, which included small scale farmers, low class urban residents and pastoralists. The respondents were selected through systematic random sampling. Kruskal-Wallis H test was used in testing the three Null hypotheses. In addition, a Non-Parametric Mann Whitney U Test was used to compare local perceptions based on gender, age and level of education at α=0.05 significance level. Satellite imagery analysis findings indicated a progressive glacier recession ranging from 1.86km^2 in 1976 to about 0.17 km^2 in 2016 arrived at through Landsat imagery analysis. These results were similar to the public perception survey on glacier change dynamics with a majority of respondents (67%) strongly agreeing that glaciers within Mt Kenya had decreased significantly in the last 40years study period. The study also found out that: - 66% of the irrigation zone respondents (along the Naromoru River), 60% of respondents within the semi-urban study zone (Likii Village) and 32% of respondents on the pastoralism zone agreed that Mt Kenya deglaciation had led to a reduced river discharge downstream. There was no significant difference between the glacier recession trend and in terms of age (P=0.713), gender (p=0.116) or education level (0.077). The study established a varying perception between the young and old, male and females, educated and uneducated respondents. The perception difference based on age was attributed to the contact duration of time with Mt Kenya ecosystem with respondents above 64 years of age easily recalling behavioral glacial change for the study period more than the younger respondents aged 25-34 years. The perception difference between males and females was attributed to the nature of Kenyan males whom are more mobile owing to their household responsibilities unlike females who mostly remains at home thus the male gender had clearer visual perspective of glacier retreat as they moved to different geographical locations within the area. In addition, there is a higher likelihood of the uneducated respondents' to have clearer vision of actual glacier retreat trend due to a possibility that they had remained in the same environment longer without migrating elsewhere for formal education. The perceived effects of glacier recession on reduced river flows were as follows: 66% of the irrigation zone respondents agreed that reduced Naromoru river flow had affected irrigation; 27% of the Low class urban respondents agreed that reduced discharge in Likii River had negatively affected urban water use and finally 32% of the pastoralism study zone respondents agreed that decreased Likii river discharge had negatively affected their livelihood through reduced stocks sizes and type. However, all the respondents raised concern and feared about future water related tensions and conflicts as Mount Kenya glacier retreat progresses. Second and third Null Hypothesis tests results gave test statistics with P-Value being lesser than 0.05 Significance Level, thus they were rejected and their alternative adopted. Finally, these study findings are beneficial to National and

County Governments, water project financiers, NGO's, water users and all Mount Kenya ecosystem stakeholders as they endeavor to sustainably utilize and manage natural resources bearing in mind the hydrological implications of their actions on water supply, tourism, watershed services and livelihoods. These will enable them develop sound long term adaptation and coping strategies for the glacier recession effects.

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CHAPTER ONE: INTRODUCTION

This section outlines the background to the study on effects of glacier recession on water supply and livelihood: a public perception study in Nyeri and Nanyuki Counties; further indicating the problem statement, research questions, study objectives, hypotheses, justification, the research scope and the operational definitions.

1.1 Background to the Study

Globally, many mountainous regions are facing increased glacial meltdown due to climate change thus triggering concerns about the future of water resources available both locally and in the region (Barnett et al 2005; Brandley et al 2006; Kaser et al 2010)

World's mountain glaciers and ice caps are known to contain less than 4% of the world's ice cover, but they give crucial information in regard to climate changes since glaciers act as early indicators of climate change, (Lonnie G. Thompson, 2010). Notably, glaciers are smaller and thinner than the polar ice sheets making them to have a greater surface area to volume ratio, hence they are more sensitive to temperature changes. (Bradley, Keimig, Diaz, & Hardy, 2009)

Increased glacier recession trends are expected to affect negatively water resources both within the mountain regions and their neighboring lowlands. Mountain Glaciers within the tropical region especially in Eastern Africa could be more affected due to the fact that the region is dominated by summer season in bigger part of the year and more so the environmental degradation trend within the mountainous ecosystem and downstream that is on worrying levels.

Mount Kenya ecosystem is the largest mountain ecosystem in Kenya, with Mount Kenya itself being the highest in Kenya (5,199m). This ecosystem is made up of six counties: - Meru, Nyeri, Tharaka Nithi, Kirinyaga, Laikipia and Embu. It's a young volcanic mountain whose current summit is a remnant of a volcanic plug left after the softer rocks were continuously removed through glacial erosion (Tanui 2009). It's an ecosystem well-endowed with a variety of scenery.

The climate of the Mount Kenya ecosystem is primarily controlled by the continental north eastern monsoon winds which brings dry conditions, while the south- eastern monsoon winds

brings moisture from the Indian Ocean and owing to topography the region experiences orographic precipitation throughout the year. There are two wet periods namely the 'long rains' (March to May) and 'short rains' (October to November) separated by relatively drier months (Ogallo *et al.* 1990). Maximum precipitation occurs within the southern and eastern slopes at an altitude of between 2500 and 3000m A.S.L. In addition, its high altitude zone experiences low mean temperatures of 2^0C which encourages evolution of glaciers, (Hastenrath 2005). Mount Kenya glaciers were first observed early 1890's when they stood close to their Little Ice Age moraines which later progressively reduced by the 20th century due to climate change and according to Odada (1999), glaciers are highly sensitive to changes in temperature. In addition, glaciers ensures stability in the mountain ecosystem hydrology by storing water in ice form during wet seasons which is later gradually released on dry season ensuring societies' living downstream are continuously fed with river water (McDowell & Koppes 2017).

Winiger (1990); Mizuno & Fujita (2014), describes Mount Kenya ecosystem as a key biodiversity hub containing a variety of species of endemic plants and animals. This ecosystem which are characterized by unique vegetation zones that ranges from lowland dry forest on low lying areas to dry montane rain forests, bamboo zone and others (Pellikka, Ylhaisi & Clark 2004, Mizuno & Fujita 2014) In addition, a wide range of wildlife species such as: - buffaloes, elephants, bushbucks, waterbuck, black fronted duiker, and others exist within the mountain ecosystem (Nyaligu & Weeks 2013). Moreover, its home to: Grevy's Zebra, Jackson's Hartebeest, the globally endangered African Wild Dog and equally a safe refuge to the four of the world's eight surviving Northern White Rhinos.

According to the local communities, Mount Kenya is seen as being "sacred" by the local due to the white snow cap summit at its' top. It has a wide range of sacred natural sites in form of hills such as: - Karima hill and others.

Finally, this mountain is also of great value economically since it supports sectors such as: tourism, fishing, wildlife conservation, agriculture, hydroelectric power generation, forestry among others. There exists a forest reserve and a 715km^2 national park within this mountain ecosystem both gazette in year 1932 and 1949 respectively. In 1978, Mt. Kenya was listed as one of the UNESCO-MAB Biosphere Reserves and later on in 1997 it became a UNESCO World Heritage Site.

The focus of this project therefore, was to assess the local perception of the Mount Kenya ecosystem beneficiaries regarding deglaciation and how it has impacted onto river water supply and locals' livelihood systems downstream; and their level of preparedness by having adaptation and coping strategies.

1.2 The Research Problem

Global warming related effects of climate change has overtime increased melting of glacier in many mountainous regions of the world, thus raising concerns about water availability locally and beyond in future (Barnett *et al.* 2005; Brandley *et al.* 2006; Kaser *et al.* 2010). 4% of the world's ice cover is in form of mountainous glaciers which gives earlier signs on climate changes (Lonnie G. Thompson 2010). According to recent scientific research, Mount Kenya's summit has suffered massive glacial loss with only 10 out of the initial 18 glaciers remaining a century ago. Lewis Glacier, the largest on Mt. Kenya is an example of which by 2010 it had decreased by 90%. According to scientific evidence, it's believed that the major glacial loss happened in the 1970s' UNEP (2009). Bradley *et al.* (2009), compared glaciers with polar sheets stressing that glaciers are smaller and thinner than polar ice sheets which makes them to have a greater surface area to volume ratio hence can be severely affected by temperature changes.

Mountain ecosystems and their adjacent lowlands have been affected by high environmental stress brought about by deforestation and land degradation which in many cases leads to negative effects on water resources (Viviroli *et al.* 2011). The stream flow is regulated by mountain glaciers through water storage in form of ice during wet seasons, which later is slowly released during the dry periods, (McDowell *et al*. 2017). If todays' climate change trends continues, one quarter of current's mountain glacier could disappear by year 2050 (Fitzharris 1996) Tropical region's glaciers are generally sensitive to a more constant temperature regime brought about by climate change due to (Rabatel *et al*. 2013). Francou *et al.* (2000), energy fluxes within the atmosphere causes deglaciation often leading to a decline in streams and rivers' discharge thus affecting human population and ecosystems dependent on glacier melt water. Arid and semi-arid lands (ASALs) often receive approximately 50 to 90% of freshwater originating from mountain catchments (Messerli *et al*, 2004). Laikipia County and parts of Nyeri County in particular kieni area area fall under ASAL's regions that

are well served by streams and rivers originating from Mount Kenya; with Laikipia being a tourist destination owing to its exciting wilderness safaris' and wildlife.

With a prolonged mountain glacier retreat trend, there is high likelihood of these affecting water resources negatively. The western and northern slopes of Mount Kenya have recently faced chronic water shortages never witnessed before. In addition, water increased demand for irrigation; livestock watering and domestic use is stressing the available water resources with over abstraction having been witnessed in many rivers. For example, Naromoru River has a total of 98 abstraction points that have been documented within a 30 km river section, supplying water to around 30,000 people; with 97% of this abstracted water being used to irrigate 9% of the total catchment area through furrows, gravity pipes, and direct water pumping. This has raised a need for an immediate intervention to save this important water catchment area. If Mount Kenya glacier shrinkage continues, there is a likelihood of total disappearance of this mountain's glacier in near future (Prinz *et al.* 2018) with such impacts likely to be more severe on the drier leeward side of the mountain ecosystem thus creating water shortages within the surrounding counties. It's not clearly understood whether people who are dependent on Mount Kenya for their livelihoods and water supply are aware of the on-going global warming related glacier retreat and its possible effects to the society at large. Moreover, very few studies have been conducted in order to determine the hydrological effects of such glacier recession especially to the downstream societies which motivated this study to be conducted, guided by the following research questions, objectives and hypotheses:

1.3 Research Questions

a) What is the trend in glacier cover change in Mt. Kenya for the last 40 years?
b) What is the public perception on the past and present trends of Mount Kenya glacier?
c) How has Mount Kenya glacier reduction affected water supply and livelihoods; focusing on irrigation, urban water use and pastoralism?
d) How significantly do respondents' age, gender and the level of education influence perception regarding availability of adaptation and coping strategies for Mount Kenya glacier recession effects?

1.4 The Study Objectives

1.4.1 General objective

To determine the effects of Mount Kenya Glacier recession on water and livelihoods

1.4.2 Specific Objectives

a) To determine Mount. Kenya glacier trends from the 1970's to 2000's,
b) To investigate the perceived implications of glacier recession on river water supply and peoples' livelihoods with an emphasis on small scale irrigation, urban water use and pastoralism and
c) To determine whether age, gender and level of education significantly influenced perception on availability of clear Adaptation and coping strategies for Glacier recession effects.

1.5 The Study Hypotheses

1) **H_0**: There is no significant reduction in Mount. Kenya glaciers for the last four decades
   H_1: Alternative
2) **H_0**: There is no significant difference in perception for the effects of Glacier Recession on river water supply and livelihood systems
   H_1: Alternative
3) **H_0**: There are no clear adaptation and coping strategies for Glacier Recession impacts.
   H_1: Alternative

1.6 Justification and Significance of the Study

FAO (2002) emphasizes that economies and livelihoods of countries within the sub-Saharan Africa rely on agriculture; an indication that agriculture plays a critical role in supporting such economies. Moreover, a majority of families' depends on smallholder subsistence farming which enhances food security in African continent, (IFAD 2010)

Africa's arid and semi-arid areas (ASALs) have been a target for agricultural expansion (Kenyan Treasury report 2009; 2010) since they comprise of large tracts of irrigable land which is not exhaustively utilized. In particular, the Eastern Africa rangelands makes up about 80% of the region's land surface area with Kenya having 85% of its total land mass under rangeland (Ruigu *et al.* 1987; Sombroech *et al.* 1982; Macharia2008) Rangelands have historically supported economy of Kenya mainly through meat production

as seen in Laikipia County where both ranching, pastoralism and wildlife conservancy thrives John *et al.* (2011) Rangeland ecosystem supports close to 25% of total human population within East Africa (Malopola 2006) contributing significantly to the economy of this region.

Scientists strongly believe that on-going climate change may lead to ecosystem degradation that would eventually harm rural populations directly in terms of their livelihoods and water supply provisioning (IPCC 201; MEA 2005; ICIMD 2010 and Van de sand 2012), hence the need for the governments both at County and National level to join efforts in resource mobilization and development of this region owing to the vital role it plays in sustaining economic growth. To this regard, the study is significant and justifiable in that it's focuses on ASALs areas of Kenya which have been facing perennial drought now and then with many local communities suffering in terms of livelihood lose, hunger and even deaths. The study targets to bring out a clear picture on the current state of river water supply and livelihoods that are dependent on it downstream, how affected communities were coping and the way forward in terms of mitigating water and livelihoods crises today and in future.

The study will give an insight into what really is ailing Mount Kenya Rivers' of which a majority are drying up despite Glacier retreat up in the mountain and heavy rainfall being experienced within the ecosystem. Scientifically, it's expected such rivers to have an increased discharge owing to melt water and rainfall water surface run off downstream but situation on the ground is different. Rivers' Naromoru and Likii whose source is Mount Kenya, draining into Ewaso Nyiro are ironical drying up and few years back they existed as huge rivers.

In addition, policy makers will also find this study results beneficial by giving them more insights on public concerns that matters hence enabling them come up with sound policies, plans and programmes that will bring sustainable development within the study area, the county and the entire country at large.

The study is also important and justifiable in that it focused on Mount Kenya water shed as a source to rivers that provides water to downstream communities. Water and sanitation is well elaborated in the United Nations Sustainable Development Goals (SDGs); in particular SDG-6 that set to ensure availability and sustainable management of water and sanitation for all by the year 2030. This study aim is to advocate for access to adequate and cleaner water as

stipulated in the Kenyan Constitution as well as fostering local and international cooperation through protection of water towers and rivers; equally encouraging sustainable farming through irrigation in line with United Nations Sustainable Development Goals (SDG-2) on Eradicating Hunger and achieving food security through sustainable agriculture by year 2030. On the other hand, SDGs 15 particularly refer to mountains ecosystems as the water towers of the world and the study seek to promote and equally advocates for sustainable use and protection of Mount Kenya ecosystem by all stakeholders for continued benefits today and in future.

1.7 Scope and Limitation of the Study

1.7.1 Scope

The study focused on Naromoru ward, Nyeri County (small scale farming), Likii village within Nanyuki town (low class urban residents' river water utilization mainly for drinking and cooking, washing, and floriculture) and Segera Ward within Laikipia North on the lower parts away from Nanyuki Town (pastoralism along the River' Likii riparian areas. The selected respondents included household consumer's heads, individual small scale farmers and pastoralists. These study areas were selected because they are classified as water scarce zones that face perennial drought and low annual precipitation. In addition the targeted study rivers, (Rivers' Likii and Naromoru) both originate from Mount Kenya flowing downstream through the target study areas.

The local communities have interacted with these rivers and the mountain ecosystem at large for a longer period and they must have noticed some changes if any. In addition, this is a region of interest given that Government and development partners have in the past been sponsoring water development projects due to persistent water scarcity. Thus it's an area that has t characteristics which the researcher wanted.

1.7.2 Limitation of the Study

The following challenges were experienced during the study:-

a) Inaccessibility challenge within lower Nanyuki region due to rough terrain in some areas and poor road network. However the local guides assisted in identifying suitable access routes to our target study sites.

b) Language barrier in that some respondents couldn't fill in the questionnaires because of being illiterate. This was however countered through research assistants training program

c) Lack of co-operation among selected respondents due to their misinformation state.. For example some of pastoralist within the lower Nanyuki study area thought we had come to take away their land and livestock. Likewise some respondents within Likii village (Nanyuki Town) requested for payment for the needed service since to them we were getting some monetary gains out of the research. However this challenge was handled by teaming up with community leaders as well as making the respondents understand that the research was solely for academic purpose

d) Fatigue. The study was rigorous, in-depth and exhaustive, involving walking for long, critical thinking and interacting with the respondents, with a few of them being problematic at times. However, the training previously gained from the supervisors and previous experience in field research enabled smooth running of activities to the end

1.8 Research Assumptions

The researcher assumed all respondents interviewed had a basic knowledge on glacier or glaciation subject and were willing to freely present their views.

1.9. Operational Definitions

a) **Glacier recession: -** shrinking of a glacier, an ice sheet through melting resulting to exposure of the earth's surface.

b) **Global warming:** An increased air temperature brought about by the greenhouse effect resulting from high levels of carbon dioxide, chlorofluorocarbons, and other pollutants within the atmosphere.

c) **Public perception:** This is a social phenomenon that focuses on differences between a factual absolute truth and virtual truth based on a popular opinion, media coverage and / or reputation.

d) **Climate change: -** long term changes in the earth's climatic conditions brought about by an increased average atmospheric temperatures.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter's focus is effects of climate change on mountain glacier and the resultant effects on river water availability and livelihoods in the world, then narrowing down to Kenya. Also it reviews the previous studies that were conducted and case reports concerning deglaciation impacts on water supply and livelihoods.

Main thematic areas tackled in the literature review were as follows:

a) Global climatic changes and its influence on glaciated Mountains of mid- and high-latitudes.
b) Regional review of fluctuations of tropical glaciers outside Africa
c) Glaciers of Eastern Africa and their recent changes
d) Climate change and deglaciation in Africa public perception studies related to:-
    i. Riverine irrigation
    ii. Low-class urban water supply
    iii. Pastoralist river water utilization for livestock watering

2.2 Global Review of Glacial Change on Glaciated Mountains of Mid and High-latitudes

2.2.1 Climate change in Western Montana glaciated mountains, U.S.A

The Western Montana is one of the world's undisturbed temperate ecosystems still remaining with a considerable amount of native species that historically inhabited the region. It hosts the plant species including the American Bison and animal species such as the Grizzly Bear and Gray Wolf. Besides conservation of the biodiversity value, it also has a hydrological value in that it's the sources of Columbia, Missouri, and Saskatchewan Rivers. This has led to designation of part of it as federal protected lands namely:- The Glacier–Waterston International Peace Park and the Yellowstone National Park both of which have been declared UNESCO and World Heritage sites. However, the western Montana glaciers' biological and natural resources within and around these protected areas are under threat by the global warming (Pederson *et al.* 2004, 2006; Watson *et al.* 2008).

According to Hall & Fagre (2003), the formally Glacier National park in Montana initially it contained over 100 glaciers but by year 2003, only 23 were remaining with a high possibility of them disappearing by 2030 as current climate change effects continues.

2.2.2 Glacial change in Central Asia, Hindu-Himalayas ecosystem

The Himalaya ranges are the highest mountain range of the world found in Central Asia containing approximately 114,800 km^2 total ice cover. Its glaciers are categorised as follows: Pamir (12, 260 km^2), Karakoram (16,600 km^2), Tien Shan (15,417 km^2), and Kunlun Shan (12,260 km^2) ranges (Burga *et al.* 2004; Dyurgerov and Meier 2005).

There has been a rise in temperatures and precipitation within the Hindu-Himalayas ecosystem recently due to climate change which has led to water shortages and food insecurity among the downstream communities (J.D. Miller 2012). Glacier melt water serves as crucial sources of water especially for the westerly basins. It's believed that communities leaving nearer the Himalayan Mountains might face water scarcity in future as a result glacier retreat (Barnett *et al.* 2005). These mountains serve as headwaters to a number of major rivers systems that originate from these mountains including: - the Gangles, Brahmapotre and river systems. A variety of Climates experienced in the Himalayan ecosystem causes differences in glacial mass and river flow from west to east.

Bookhagen *et al.* (2010), informs that central Himalayan catchment area experiences precipitation declines from east to west with more precipitation being received in winter from the westerlies leading to glacier accumulation which later on melts during summer; feeding streams and rivers during dry seasons (Milner.A.M; Khamis. K *et al.* 2017)

Recent remote sensing studies have revealed a reduction in glacier extent and mass (Kaab *et al.* 2012), declining more fast than elsewhere in the world occasioned by climate change and its projected that by 2035 or before there would be total deglaciation (WWF 2005).

2.3 Regional review of fluctuations of Tropical glaciers outside Africa

2.3.1 Tropical Glaciers in South America

Close to 99% of tropical glaciers of world are natively found in South America with a 71% of them being in Peru. Majority high mountains have glaciers that are their integral part providing water to both upstream and downstream environments. The Peruvian Andes glaciers have for years' provided water for drinking and agriculture by slowly releasing melt

water into rivers. Scientists in their research projects total disappearance of the Peruvian Andes, the world's highest tropical glacial field in the next 40 years, with immediate disastrous flooding of nearby towns and water shortages later. Such glacial retreat would threaten livelihoods of close to 2 million residents of the desert coastal cities and valleys below.

Through an interview conducted by a journalist named Krista, from the Australian Broadcasting Corporation (ABC NEWS, 5 November 2015), it came out clearly that farmers within Peru Ecosystem some years back used to water their crops 8 to 10 days per week but today they do 3 to 4 days owing to water shortages and they have to depend on limited rainfall to support spring water which is available only few hours a day.

Recent studies indicates that Peru's one third of its glaciers have already been lost since 1970 and already water scarcity is being felt in that 3.3 million out of the 8.9 million Peru's rural people have no access to drinking water (Stern 2006). It's projected that agriculture is likely to suffer greatly from such water shortage and the poor locals whom depend on small scale subsistence farming would suffer more. The urban poor equally are not safe especially the low class urban dwellers. UNDP based on their research, the low class urban dwellers receive the least water which highly costly hence water supply reduction would worsen the situation.

According to Bradley *et al.* (2006) and Vuille *et al.* (2008), Communities within the Andes have relied on Andean ecosystem for water-related services that includes: domestic water supply, river flow regulation and others. However, effects of global warming on glaciers and degradation of vegetative cover have raised concerns. At the present, most of water in several large cities within the region is from the Páramo streams however, the Andean rivers (both glacier- and páramo-fed) supplies most of water for irrigation, livestock watering amongst other benefits (FAO 2003; Buytaert *et al.* 2006). However, the glacial retreat together with drying up of wetland and páramo areas poses a threat to stream flow patterns, and water supply to the region in near future.

In addition, close to 27% water consumed in the dry season originates from the Cordillera Real glacier through River Rio Santa (Milner.A.M; Khamis.K *et al.* 2017). On-going deglaciation within the upper Rio Santa headwaters could lead to a reduced river flow by 30% negatively affecting irrigation water supply.

2.4 Glacier of Eastern Africa and their recent changes

Today, the only glaciated mountain in three namely: Mt Kilimanjaro (5,895 m), Mt Kenya (5,199 m) and Ruwenzori (5,109 m) (Grove 2004). The last two decades of the 19th century have been characterised by massive deglaciation due to climate change which has affected the environment and human beings by interfering with vegetation pattern, disrupting livelihoods such as agriculture and pastoralism, has caused water scarcity amongst others in the lowlands away from the mountain, (UNEP 2007, 2008). In addition, glaciers forms part of the earths' freshwater stored in ice form and later released seasonally thus recharging rivers and the ground waters which then provides communities and the ecosystems downstream with water.

Glaciers are crucial earth's system component and for the last two decades of the 19th century they resulting from climate change

On the other hand, glaciers' aesthetic or visual value promotes local and international tourism whereby people visits the eastern African glaciated mountains to enjoy the spectacular scenery often paying for that service. However, about 80 per cent this glacier since 1900, has been lost negatively affecting the tourism sector.

2.4.1 Eastern Africa glaciated mountains

Mt Kilimanjaro is the highest of the three Eastern Africa glaciated mountains and one of the worlds' most easily noticed mountains. Its' located to the north of Tanzania. A research conducted between year 1984 and 1998 reviewed that Mount Kilimanjaro's' glacier had declined 300metres vertically on one section. Later on in year 2005, further observation has revealed that very little glacier is still remaining on this mountain (Framming *et al.* 2009). (Cullen *et al.* 2006; Thompson *et al.* 2009**)** using Terrestrial photogrammetric maps, aerial photographs and satellite imagery analysis revealed that there has been close to 85% glacial loss on the ice fields on Kibo, the highest part of Kilimanjaro since 1912.

Finally, Mount Ruwenzori's, third highest of the three Eastern African glaciated mountain ranges is highly dissected into valleys and individual mountains with its glaciers mainly being found on its three peaks : Baker ,Stanley and Speke (Klein and Kincaid 2007). Scientists believe that Mount Ruwenzori's' location nearer Congo forests slows its rate of deglaciation while its slopes which are forested are key sources of rivers supplying water to the lower plains. It's quite a challenge monitoring ice cover through aerial or satellite photography due to the continuous cloud cover over the Ruwenzori's (Vidal 2012).

However, researchers who had visited the glacial field, combined images of the Ruwenzori's glaciers in determine its ice area between year 1987 and 2006 noting that it had shrunk by around (50%) from 2.55 km^2 to 1.31km^2 (Klein and Kincaid 2007). There isn't a conclusive explanations as to the cause of Ruwenzori deglaciation, however many scientists suggests probably it could be due to less snow accumulation and circulation of warm air within the lower atmosphere (UNEP n.d, Barry 2006; Glacier Hub 2014)

Finally, Mt Kenya is the second highest mountain in Africa's having an ice cap comprising of 10 glaciers that occupy its valleys (UNEP 2007). It's valued for its contribution to the country's tourism industry, timber, agriculture, and tourism with its forested slopes serving as important catchment areas (UNEP2009)

Most of Mount Kenya's glaciers are located within its' upper slopes including:- Gregory Glacier ,Ali Caesar Glacier, Darwin Glacier (Kenya), Diamond Glacier, Heim Glacier, Lewis Glacier, Tyndall Glacier and others. Research conducted on the Lewis Glacier revealed that 1990's higher temperatures could be the root cause of its shrinkage compared to the sun exposure (Campbell 2008); (Hastenrath *et al.* 2010). Research has it that Mount Kenya's eight glaciers out of a total 18 disappeared in the 20th century; with ice volume on Lewis Glacier decreasing from about 7.7 km^3 in 1978 to about 0.3 km^3 in 2004 (Hastenrath *et al.* 2005)

UNEP (2008) and Thompson *et al.* (2009), points out that current glacier shrinkage due to climate change trend may eventually translate to total deglaciation of the high mountains in near future thus affecting aquatic ecosystems and human activities that are dependent on them. At the beginning, river discharge would go up due to melt water inputs followed by a sharp decline in river discharge there after (UNEP 2007).

There is minimal contribution of African continent to greenhouse gas emission globally; a key driver of climate change yet it's a continent highly vulnerable to climate change effects. It's believed that on the long run, glacier loss would lead to loss or reduced tourism revenues which support the economies of Kenya and Tanzania.

2.5 Mountain Glaciers, River flow and Livelihoods

Mountain ecosystems are capable of providing crucial goods and services hence the need to be protect and use them sustainably for future continued enjoyment (Singh & Thadani 2015) Mountains are regarded as water catchment areas since they serve as headwaters to the many

rivers and streams (Viviroli *et al.* 2007, 2011). It's believed that deglaciation will negatively impact on ecosystem service provisioning for the glacial fed rivers thus affecting agriculture and pastoralism. Glaciers are a critical source of freshwater to the communities leaving downstream as well as streams and rivers flow regulators (Milner.A.M and Khamis.K *et al.* 2017). Cordillera Real glacier within the Andean region of South America has for many years recharged River Rio Santa that flows down through Atacama dry coast where it provides water for drinking and irrigation within the Atacama dry coast. It's feared that continuous deglaciation would have a negative impact on hydrological systems which would adversely affect ecosystems and human systems (Baraer *et al.* 2012).

100% of water fed to River Rio Santa during the dry season originates from the Yanamarey glacier and Mark *et al.* (2010) projected that this glacier might have disappeared by 2020 if global warming continues. IPPCC AR5 recent report revealed that globally, all glaciers were continuously shrinking in volume, area and mass of which would translate to a declined river and stream discharge , severely affecting communities' and ecosystems downstream that are dependent on glacial melt water. Notably, the Himalaya's mountain range contains more than 54,000 glaciers reserves occupying approximately 6,100km^2; serving as headwaters to major river systems in Asia (Viviroli *et al.* 2003).

Finally, the Western Montana glaciated mountains in U.S.A, feeds the Columbia, Missouri and Saskatchewan Rivers that provides water downstream for domestic, irrigation and industrial purpose.

River basin as a management or planning unit concept has been around many years, re-emerging in 1990s' as Integrated water resources management (IWRM) both at management and watershed levels. Majority of communities living in rural areas of Kenya as well as a section of semi urban residents, abstract water directly from rivers and other surface water sources for various uses, thus their socio-economic development is directly connected to availability of quality and adequate water supply.

2.5.1 Riverine irrigation

Discussions concerning how to develop river basins and irrigation were widely held within the 19th and early 20th century (Molle.F 2006). Since Kenya got independence, its economy has relied mainly on agriculture of which a considerable number of Kenyans depended on as their source of livelihood with approximately 29% of the total National GDP coming from agriculture. Recently, irrigation agriculture has become more popular than the rain fed one

due to climate change effects with 40% of the irrigated land under private farmers who cultivate horticultural and other crops mainly for export and a few consumed locally.

Several previous researches have clearly brought out a strong connection between climate change and food systems, with Ogra and Badola (2015) stating that changes in precipitation patterns due to a declined snow cover had adversely affected subsistence agriculture.
Agriculture for example in Alberta had depended on available melt water from Peyton Glacier and proximal glaciers within the Canadian Rockies as climate change effects continuous to be felt, it is projected that approximately 90% of present glacier will have been lost by 2100 (Milner. A .M & Khamis. K 2017). Tien shan region of China is facing aridity today but initially when it was served by glacial run off water used in irrigation, it was very green and luxuriant earning the name "Green Labyrinth" However 1964-2004 was period of massive glacier loss with close to 20% of its 446 formal glaciers being lost thus creating a water crisis in the region (Milner.A.M &Khamis.K 2017)

Within the Andean region of South America, most of the melt water from glacier is utilized in both irrigation and drinking. Cordillera Real glacier melt water feeds river Rio Santa then flows down to Atacama dry coast where it provides approximately 27% of water that is used for irrigation and drinking. However, in the recent years, glaciers within the Cordillera Blanca, Peru have faced massive deglaciation, half of them having disappeared (Baraer *et al.* 2012) which has culminated to river flow reduction thus affecting crop irrigation. A stakeholders meeting held in year 2012, revealed that agricultural practices were slowly changing from year round irrigation to rain-fed agriculture alone. Notably, between 1972-2008, cultivated area had shrank by 19% owing to increased water demands in water scarce environment (Bury *et al.* 2011). Finally, Peru have already lost one third of its former glaciers since 1970 which has culminated to severe water supplies reduction affecting the rural poor dependent on subsistence agriculture (Stern 2006).

Irrigation agriculture within San Joaquin valley was adversely affected by a declined rivers' flow brought about by a reduced glacier melt water supply (UCD 2015). On the other hand in California, winter snow melt water feeds rivers and streams especially during summer but according to a report by the California's department of water resources (year 2015) absence of snow on the Phillips station due to the warming effect experienced during winter of year

2014-2015, it led to reduced water volume in streams and ground reserves thus affecting agriculture in California (Zommers. Z; Van der Greest.K *et al.* 2016)

Lastly, for 50 years irrigated area in countries of the Indian sub-continent has been increasing however reduced river discharge has caused river water shortages and farmers are shifting to ground water abstraction (Rasul 2010).

2.5.2 Low-class urban water supply

Surface water is a crucial water source in urban areas occurring mainly in form of rivers and streams. Many cities and towns in the world are to be found on river banks but often depend on water abstracted upstream where quality is better. According to the World Bank report (2010), Urbanization trends as seen in developing countries are both opportunities to growth and development as well as a challenge in that it has pushed low class urban dwellers to informal settlements that suffer inadequate water. The Kenyan water politics has created disparities in water provisioning both in urban and rural areas and in most cases rural areas are left without water; with urban settings rarely getting enough thus posing a challenge to the Kenyan government in coming up with lasting water solutions.

During the day, One-third of the time for a majority of Women and school going children within rural and low class urban areas is spent fetching water from the nearby fresh water source owing to lack or inadequate tap water. According to the UN-WWAP (2006), Kenya is among water scarce countries owing to the frequent droughts and floods experienced. The National water master plan of 1992 on ground water resources safe abstractions revealed that they are at a rate of approximately 193million mm^3 per. Policy makers have always studied poor urban dwellers and also relied on their initiatives so as to be able to formulate solutions to problems of social development within the city (Beall.J & Kanji.N 1999). In the beginning, water development in Kenya demand driven but today due to an increased depletion of the available resources and their degradation, the focus has now changed to an integrated management. More serious challenges within urban areas relating to water resources management has been created by climate variability and increasing demand for water due to population pressure and development projects.

According to Stern (2006), melting glaciers would first cause an increased flooding followed by sharp reduction in water supplies in rivers and streams which would pose danger to a sixth of world's population in India, a section of China and the Andes in South America. Notably,

low class- urban dwellers would be more affected since they directly abstract water from rivers and streams for various uses including: - washing, drinking and others.

2.5.3 Pastoralist use of rivers for livestock watering

Pastoralists are considered the most marginalized groups facing limited access to socio-economic services. Governments have abandoned pastoralism for many years arguing that it consumes lots of national wealth with little or no returns. However recent studies have revealed the key contribution of pastoralism to National GDP, food security and livelihoods and various authorities and ministries have been created to promote its wellbeing. Climate change globally have had negative effects on water resources and environment such as:- catchments areas degradation , drying up of rivers, river water quality deterioration and an increased water conflicts brought about by competition on scarce water resources.

Pastoral herd survival relies on dry season availability of pastures often along the river courses and within the floodplains (Schulte *et al.* 2006). For example Turkwel River's floodplain in Turkana County Kenya, supports 30% of the total populations mainly in pasture provision, (Oba *et al.* 2004). On the other hand, the floodplain of the Awash River have provided critical pastures resources during the years of drought years (Betachew 2001).However, river abstraction upstream for irrigation purposes has created a direct competition with the pastoral users as well as modifying the river ecosystem leading to massive ecological implications (Scudder 2006).

River Ewaso Ng'iro North within Laikipia County has for many years been used for nomadic pastoralism especially watering of livestock and grazing along its courses and floodplains. Today its quality and quantity has really reduced as seen by high turbidity state of its water. Analysis test conducted on its water revealed high level of nitrate contamination due to deposition of livestock wastes at watering points, which is a common phenomenon in many rivers that are flowing through ASALs which pose a health crisis due to presence water pathogens which in many times leads to outbreak of disease epidemics such as cholera and parasitic worms (World Bank 2010)

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2.6 Research Gap from the Literature Review

According to the literature review, the previous studies especially the ones relating to Glacier recession effects on water supply and livelihoods, mainly concentrated on regions outside Africa , hence the need for more research within Mount Kenya ecosystem in relation to it water provisioning service to downstream communities. For example previous studies on glacial fluctuations of the Peruvian Andes glacial field in South America indicated drastic river water shortages downstream and negatively affecting livelihoods of communities living down the valley and water provisioning to desert coastal cities. In addition, a case study conducted within the Andean region of South America indicated that for years the cordillera Real glacier melt water recharged River Rio Santa which then flowed downstream through Atacama coast providing water for drinking and irrigation but today that has been negatively affected.

Glaciated mountains of mid and high latitudes are also featured in the literature review with a bias on Montana ranges in U.S.A and the Hindu-Himalayas ecosystem of which both have been affected by glacier recession. For example, melt water from the western Montana glacier feed rivers' Columbia, Missouri and Saskatchewan whose water is utilized in irrigation, in the industries and for domestic use by communities living downstream. This is changing due to low discharge in the said rivers, negatively affecting water supply and livelihoods dependent on melt water.

Prinz *et al.* (2018) as provided for in the Literature review stated that already climate change has been associated with the on-going deglaciation of Mount Kenya and it's projected that by 2030 there might be a total disappearance of glacier if current climate change scenario continues. Despite this, studies on Glacier recession effects on river water supply and livelihood systems for downstream residents are still very scanty in Eastern Africa (Zommers. Z; Van der Greest K *et al.* 2016) in particular Mount Kenya ecosystem, hence the need for more research on glacier recession effects on water supply, ecosystem service provisioning and livelihood for the people living downstream (Chevalier et al. 2011)

In addition, there is still very limited research that has been conducted within Eastern Africa on local perceptions assessment among small scale farmers, pastoralists and low-class urban dwellers on how their river water utilization had changed over time and their level of preparedness to mitigate the effects of glacier recession on their water supply and livelihoods.

Majority of previous perception studies conducted within Eastern Africa concentrated on climate change effects on agriculture and pastoralism in general without connecting climate change with glacier recession and the subsequent effect on river water supply and livelihoods downstream.

Finally, the literature review has also highlighted on how remote sensing and GIS has been used globally and within Eastern Africa for glacial change analysis. However in Kenya in particular many researchers conducted glacier satellite imagery analysis and left at that, never tried to relate the glacier dynamics and river flow downstream. Hence there seem to be a local knowledge gap specifically on Mount Kenya glacier dynamics analysis in relation to river discharge downstream.

2.9 Theoretical and Conceptual framework

2.9.1 Theoretical Framework

T. H. M. van Emmerik *et al.* (2014)), demonstrates a social-hydrological model stating that there existed four main developmental eras within socio-hydrological systems:-Introducing irrigation and creation of irrigation related infrastructure, gradual changes in environments as a result of land fragmentation and environmental modification, creating impact awareness and coming up with strategies to mitigate environmental degradation ; probably a strategic government directed interventionist strategy. Stages of socio-hydrological resilience on global scale are as follows:-

a) **People with water**- Human communities originally depended entirely on hydrological cycle for low agricultural productivity and domestic use before environments were rapidly modified (Gleick 2009). The ecosystem by then never faced many issues due to the fact that the population of that time was small, highly dispersed with few water related ecosystem service's needs. This stage was characterised by low absorptive capacity and naturalness of ecosystems which provided adaptability.

b) **Water for people** –As Population grew and socio-economic development was on the rise, demand for water related ecosystem services also increased. Human beings came up with new water related ecosystem services such as:-Irrigation, Hydro-power, flood regulation and others leading to river canalisation that increased absorptive capacity at the same time more water was transferred downstream especially from wet to drier areas as a way of promoting ASALs productivity.

c) **People and Water** – External drivers resulting from Climate change and changes in land use have created pressure on water sub-systems thus creating water crisis. Humanity is now facing a new challenge of meeting water demands at the present and in future calling for a change in water strategies (Gilson *et al*.2013), and need to transit from a resistant to resilient strategies. Approaches that are focussed on ecosystem restoration could be the solution through: - river de-canalisation, improving river connectivity and flood plain recovery. Public participation is vital especially in decision making and also water governance should be devolved as a way to building socio-hydrological resilience.

This Theoretical framework is significant to the study in that it demonstrates a social-hydrological model indication the state of water sub ways in the past, present and projecting their future state. According to the study on effects of Mount Kenya Glacier recession on river flow, external drivers in form of climate change is causing glacier reduction. At the same time land use changes is causing over abstraction of river water through canalisation into private small scale and large scale farms, hence drastically reducing the amount of river discharge downstream.

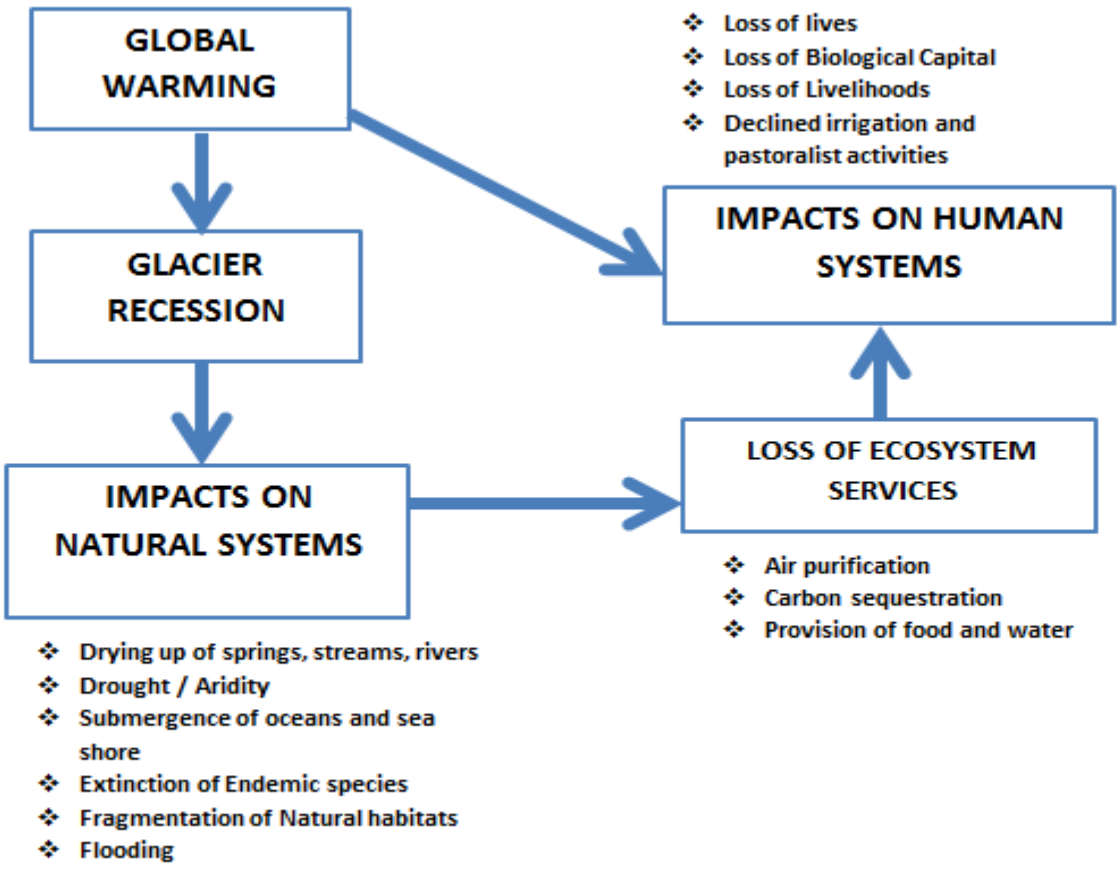
As suggested by this theory, the current problem of Glacier reduction and the subsequent effects on water supply and livelihoods could be partly addressed amicably through ecosystem restoration in form of: River de-canalisation, improving river-stream connectivity and involvement of all stakeholders in decision making and water governance so as to foster a socio-hydrological resilience.

2.9.2 Conceptual Framework

According to this Conceptual framework, there existed a connection between Global warming related Glacial recession, Natural systems, Ecosystem services and Human systems as illustrated in **Figure 2- 1** below, whereby Climate change and glacier recession have an effect on Natural systems, Ecosystem services and Human systems. The conceptual framework further illustrates a close interaction between Human and Natural systems and the way they shape each other. Climate change can directly affect Human systems; for instance through loss of lives and livelihoods or indirectly by causing Glacier recession of which damages Natural systems by causing: drying of streams and rivers, drought and flooding. When Natural systems are damaged, this would hinder their provision of Ecosystem services such as air purification, carbon sequestration, food and water provisioning. These would

impact negatively on Human systems leading to: loss of lives and livelihoods, loss of Biological capital, declined irrigation and pastoralism activities.

Figure 2- 1: Conceptual framework



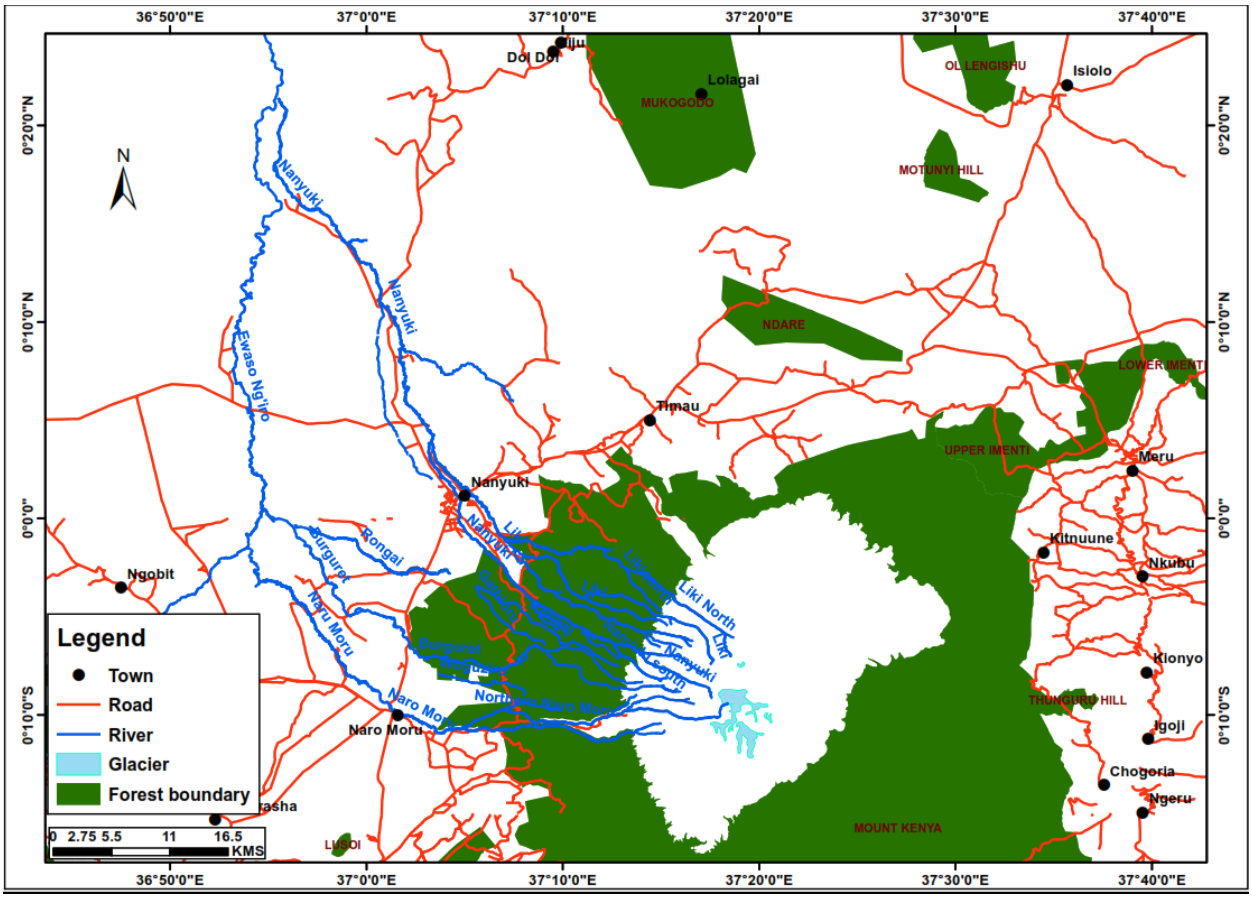
Source: Researcher (2022)

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 STUDY SITES

Glacier extent assessment was undertaken in Mt. Kenya afro-alpine zone while the case study focused on communities living on the western part of Mt Kenya along the Naromoru River (Naromoru Ward, Kieni East Sub-County in Nyeri County), and the northern part of Mount Kenya along the Likii River (Nanyuki and Segera Wards within Laikipia East and Laikipia North Sub-Counties respectively within the larger Laikipia County).

Figure3- 1: Location of the study sites



Source: Researcher 2022

3.1.1 Laikipia County

Laikipia County is bordered by the following counties:-Samburu to the North, Isiolo to the North East, Meru to the East, Nyeri (South East) and Nyandarua to the west. It has an altitude of between 1,500 m at the Ewaso Nyiro basin and 2,611 m around Marmanet forest. Its plateau in nature bordered by the Great Rift Valley to the West, the Aberdares to the South and Mt. Kenya to the South East all of which determines climatic conditions being experienced in the county. The Ewaso Nyiro North basin has its tributaries on the slopes of

the Aberdares and Mt. Kenya flowing from South to North dominating the entire county's drainage system. Some of the Ewaso Nyiro's tributaries include; - Nanyuki, Timau, Rongai, Segera, Naromoru, Ewaso Narok (Likii River) and others. These rivers' system matches the county's topography that is gently sloping from the highlands (in the South) and to lowlands (in the North) influencing to a larger extent people's settlement patterns owing to a fact that they are sources of water much need for:- irrigation, domestic use and for livestock consumption.

Other natural resources within the county including: - rangeland pasture, forest, wildlife, undulating landscapes, rivers and others. The high and medium potential lands comprise 20.5 per cent of the total county's land area while the remaining 79.5 per cent being of low potential.

In addition, this region is characterized by poor weather conditions in form of apparent dry spells and poor rainfall distribution. Climate of this area is mainly influenced by a relief type of rainfall due its high altitude and location, with annual average rainfall ranging between 400mm and 750 mm. An annual rainfall above 1,000mm is mainly experienced in areas nearer Mt. Kenya and the Aberdares.

Lastly, administratively, Laikipia County is made up of five constituencies namely: Laikipia East, Laikipia North, Laikipia Central, Nyahururu and Laikipia West. The case study focussed on Laikipia East sub-county as illustrated in **Figure 3- 1**

3.1.2 Nyeri County

It has an area of approximately 3,337.2Km^2. It's bordered by other counties namely: - Laikipia to the north, Kirinyaga to the east, Murang'a to the south, Nyandarua to the west and Meru to the northeast. Its main physical features are: Mount Kenya which is to the east and the Aberdares ranges to the west. Its western part is relatively flat and further southwards, the topography changes to steeply ridges and valleys, with a few hills.

Ecologically, the county is served by two main forest ecosystems: - the Aberdare and Mt. Kenya forest beside having other isolated forested hills managed by County Government such as Karima, Nyeri and Tumutumu that plays key roles including maintenance of water cycle, wildlife habitat provision and also are repositories for a wide range of biodiversity.

Equatorial rainfall characterizes the climate of this county due to its location within the highland zone of Kenya; long rains being received from March to May while short rains between month of October and December. Annual rainfall ranges between 1,200mm-

1,600mm (for the long rains) and 500mm- 1,000mm (for short rains). Mean monthly temperature ranges between 12.8ºC to 20.8ºC.

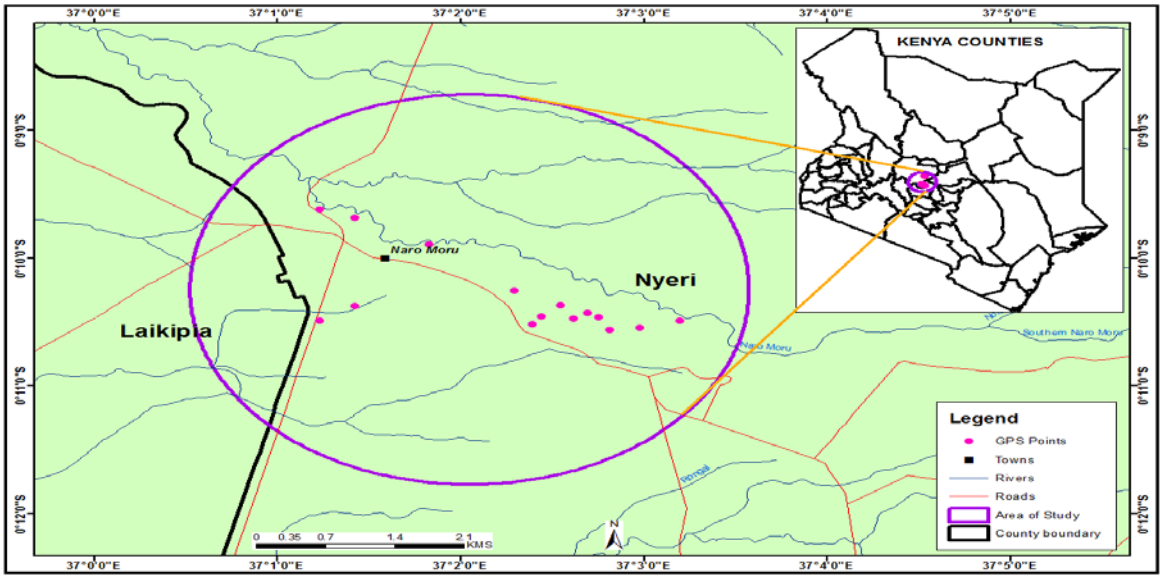
Administratively, Nyeri County has the following constituencies: - Kieni East, Kieni West, Mathira East, Mathira West, Nyeri Central, Mukurweini, Tetu and Nyeri South. The case study focused on Kieni-East Sub County (Naromoru ward).

3.2 STUDY WARDS

3.2.1 Naromoru ward in Kieni East Sub County

Kieni East Sub County is generally semi-arid lowland that receives low rainfall which ultimately has an influence on agricultural activities. Irrigation- agriculture is common here especially growing food crops for domestic consumption. Also horticultural crops are irrigated mainly for sale within and outside the county. Comparing population density in all sub-Counties within Nyeri County, Kieni- East has the least i.e. 122 people per $Km^{2,}$ (KNBS 2013) .The study focused on Naromoru ward (Naromoru sub location) targeting small scale farmers along Naromoru river, aimed at establishing how they have utilized this river's water in the past for irrigation and how that have change over the years.

Figure3- 2: Naromoru ward study area map

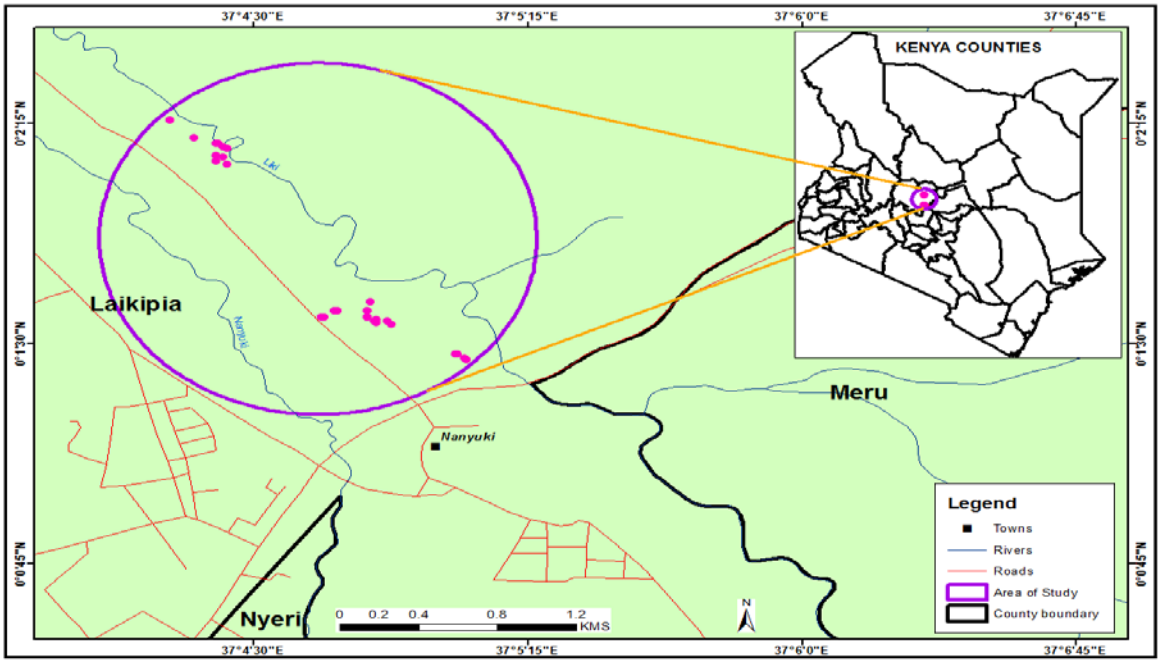


Source: Researcher (2022)

3.2.2 Nanyuki Ward (Nanyuki Town) in Laikipia East Sub County

In Nanyuki Ward, our focus was Nanyuki Town which is located northwest of Mount. Kenya, and also it's the headquarters' of Laikipia County. Within this town, our case study focused on Majengo sub-location (Likii village) aiming at establishing how residents have utilized River Likii's water for various purposes in the past including:-washing or cleaning, cooking and drinking purposes and if that have changed over the years. Figure 3-3 illustrates the key areas along Likii River where the case study was conducted.

Figure3- 3: Likii village (Nanyuki town) study area map



Source: Researcher (2022)

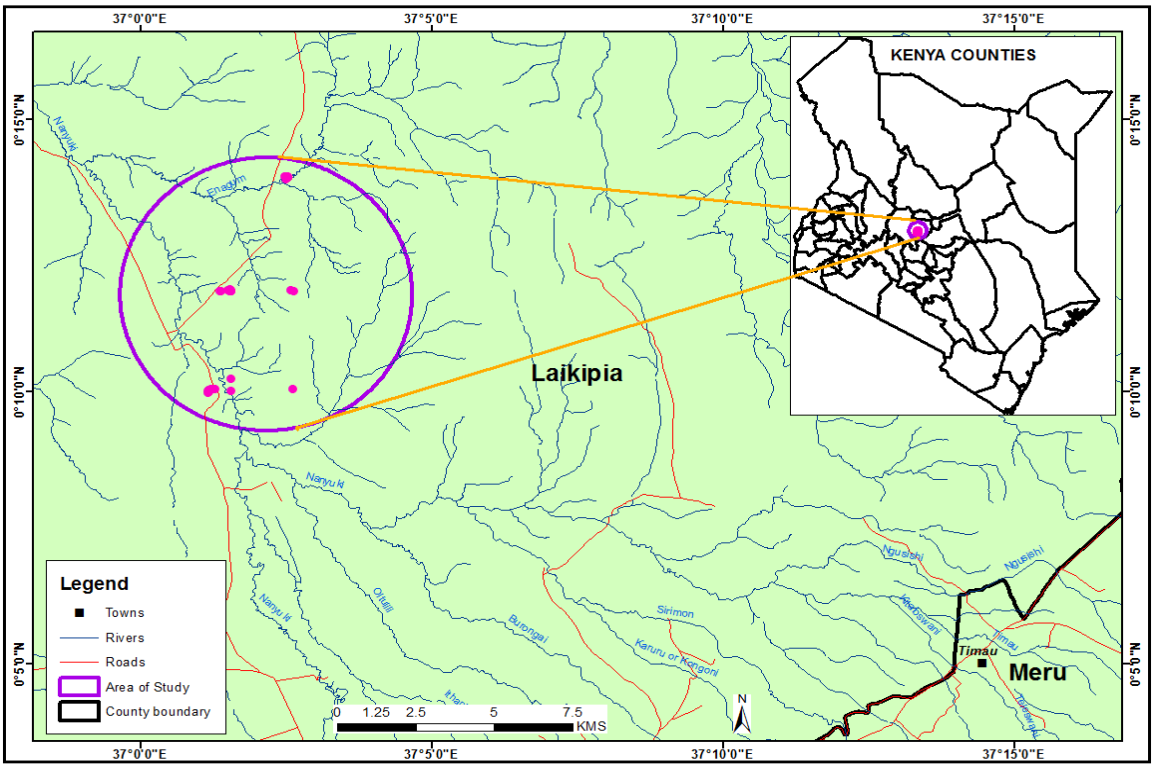
3.2.3 Segera Ward in Laikipia North sub-County

The case study on pastoralists in regard to Mount Kenya glacier recession and its impact on River Likii's flow was conduct in Segera ward, Ngarengiro sub location whereby the aim was establish how the residents utilized River Likii's water particularly for drinking purposes by their livestock and how that had changed or had been affected over the years. Figure 3- 4 illustrates the study area

In general, Laikipia County is classified as ASALs and in particular Laikipia North is quite dry whose main source of livelihood is nomadic pastoralism. Laikipia North is one of the newly created constituencies by IEBC in 2012 after the former Laikipia East Constituency was split into two: - Laikipia East and Laikipia North constituencies. Four wards makes up Laikipia North constituency namely: - Sosian, Segera, Mukogodo East and Mukogodo West

Wards'. The case study was conducted in Segera ward whose population is approximately 15,911 (population Census 2009) and its area is approximately 1,380 Sq. Km.

Figure3- 4: Lower Nanyuki (Segera ward) study area



Source: Researcher (2022)

3.3 Research Design

According to Orodho and Kombo (2002), when conducting a survey on people's attitudes, opinions, habits or any social issues, descriptive design can be used and therefore in this study, the same was used. The study's aim was to collect respondents' views and opinions concerning the effects of Mount Kenya glacier recession on river flow and livelihoods. Primary and secondary data sources were applied during the research; Primary data obtained using a likert scale standard questionnaire while secondary data was sourced from the internet, Journals and books.

3.4 Study Population

In order to conduct the case study on the effects of Mount Kenya glacier reduction on water supply and livelihood systems, the population studied included three clusters: - small scale farmers, low-class urban consumers and pastoralists whereby small scale farmers were

interviewed along the river-based irrigation zone within Naromoru ward, low-class urban water users were interviewed along Likii River (Likii village section within Nanyuki Ward) and lastly ,Pastoralists where interviewed in Segera ward, in particular Ngarengi'ro sub-locations, **Table 3- 1, 3- 2** and **3- 3** illustrates the population distribution of the study sub-counties

Table3- 1: Population distribution in Kieni East Sub-County

Location / Ward	***Male***	***Female***	***Total***	***Households***	***Area in Sq. Km***	***Density***
Naromoru	10,723	10,810	21,533	6,620	133.2	161.7
Kiamathaga	6,130	5,813	11,943	3,356	110.1	108.5
Kabaru	11,263	10,821	22,084	6,205	203.6	108.5
Thegu	7,598	7,021	14,619	4,734	118.7	123.1
Gakawa	13,283	13,038	26,321	8,097	251.5	104.6
Total	48,997	47,503	96,500	29,012	817.1	118.1

Source: Researcher (2022)

Table3- 2: Population distribution in Laikipia North Sub- County, Census of 2009

Location/ ward	***Male***	***Female***	***Total population***
Segera	8,092	7,819	*15,911*
Sosian	*12,695*	*13,153*	*25,848*
Mukogodo West	*6,988*	*6,714*	*13,702*
Mukogodo East	*11,914*	*11,448*	*23,362*

Table3- 3: Population distribution in Laikipia East Sub- County, Census of 2009

Ward	***Male***	***Female***	***Total Population***
Nanyuki	12,943	13,324	**26,267**

Source: Researcher (2022)

3.4.1 Sampling Strategy

Black and Champion (1976) described a sample as a portion of elements taken from a population, that is considered representative of that population Cochran (1977), in his quest to address the representation, he stated that "in order to determine the sample size you have to specify margins of error for the most vital items in the survey with an estimation of the sample size required first being done separately for each of those key items. After calculating, researcher will get a range of n's; smaller n's for scaled continuous variables, to large n's for categorical variables. In this case there will be sufficient variation among the n's making researcher not so quick to choose the largest, either due to budgetary considerations or due to the fact that this might give a standard of precision much higher than expected thus the researcher is forced to relax the desired standard of precision for certain items so as to allow the use of a smaller value of n (Cochran, 1977).

In order to come up with a correct sample size for continuous data (unknown population) at 95% confidence level, with value of the selected $\underline{\alpha} = 0.025$ being 1.96 and the margin of error of 0.03, Cochran's sample table for population size more than 10,000 gave a sample size of 90 riparian respondents who comprised 30 small scale farmers on Naromoru River riparian land, 30 low-class urban consumers along Likii River and 30 pastoralists grazing along the riparian land of Likii river downstream.

Systematic random sampling strategy was applied when selecting the respondents by selecting every third small scale farmer in Naromoru study area, every third low-class urban water user along River Likii uptown within Nanyuki town and every third pastoralist along Likii River downstream in the drier rural areas away from the town.

Table3- 4: Sample distribution across the study areas

Region/ Study areas	**Number of Households**
Nanyuki Town	30
Naromoru	30
Below Nanyuki Town	30
TOTAL	**90**

3.5 Data Collection

3.5.1 Use of Self-Administered Likert Scale Standard Questionnaires

There has been a growing research on farmers' beliefs concerning existence of climate change and how it had affected their livelihoods. Many researchers have opted to use qualitative methods as a way of eliciting farmers' beliefs and risks perceptions using Likert scales. Likert scale serves as psychological measurement device for gauging attitudes, values, and opinions whereby respondents are required to complete a questionnaire indicating to what extent they agree or disagree with several statements, choosing one of the ranked option; either five and seven ranked options with neutral as the middle option.

Previously, Mkuna.E *et al.* (2016) had used a likert scale standard questionnaire in assessing farmers' perception concerning effects of climate change in rice farming in Morogoro, Tanzania. In this survey, respondents were to state how much they agreed or disagreed with a specific statements. Besides that, the socio- economic profile of respondents was also examined which included: - age, household size, level of education, gender and household head livelihood. The respondents were then to state their perception regarding climate change threats on rice production.

In addition, Arburkle *et al.* (2013a) used a five point agreement scale to assess the perception of Iowa farmers on effects of climate change on Iowa's agriculture' livelihoods and if the local communities had any adaptation and coping strategies for the climate change impacts. Last but not least, Belachew. O *et al.* (2015),also had used a five point likert scale questionnaire to study a farming community of Maror, Kebele, central Oromia in Ethiopia, whereby the levels of community perceptions were rated, then summarized showing key characteristics of climate variability, how it had affected small-scale farming and pastoralism at local level and the community's adaptation and coping strategies.

In this study, the primary data main collection tool was a standard questionnaire administered in accordance with Orodho (2004) whereby the public perception study on glacier dynamics, river discharge trends and the affected livelihoods was undertaken face to face with a total of 87 respondents. This included 29 small scale farmers in Naromoru, 30 low-class urban water users along Likii River (Nanyuki town) and 28 pastoralists along the Likii River downstream away from the town. The questionnaire's was divided into several sections with the first

touching on respondents profile while the rest of other three sections assessed respondents' views and opinions regarding to:-

a) Mount Kenya glacier trends in the period 1970s' – 2000s'
b) The public perceived implications of glacier recession on river water supply and livelihood systems focussing on small scale irrigation, low-class urban water use and pastoralism.
c) Existence of clear of adaptation and coping strategies for the effects of glacier recession on water supply and livelihood according to age, gender and the level of education.

The questionnaire offered the respondents a choice of five responses; neutral point being neither agrees nor disagrees. Respondents' were then to show how much they agreed or disagreed with various statements concerning the effects of Mount Kenya glacier recession on water supply and livelihood systems.

3.5.2 Application of Remote Sensing and GIs in analysing Mountain glacial change using Satellite Imagery

For many years, Remote sensing technology has efficiently and effectively been used as a tool for gathering information concerning glaciers. Besides that, Geographic Information system (GIS) and Global Positioning System (GPS) use have enabled temporal glacier dynamics mapping and monitoring (J.Gao and Y.Liv 2001). Satellite imagery has often been preferred for glacial mapping especially where it's impossible to conduct aerial surveys or where glaciers were changing more often (Rutt 1988). The following is usually put into consideration during glacier study from remote sensed materials:-Glacier spectral uniqueness, remote sensed data spatial and temporal resolutions and the characteristics of such glacier. Unlike airborne data such as aerial photographs, satellite images can be taken continuously for a longer period of time, thus enabling prolonged glacier monitoring.

The invention of Landsat sensor early 1970's enabled a deeper study of glaciers whereby it was now possible to see very faint dust bands and medial moraines within Bagley Ice field in Southern Alaska which wasn't possible to seen on an aerial photograph (Meir and Krimmel 1973). Many glaciologists prefer Landsat MSS imagery since it allows accurate ,easier and quick comparison of glacier extent and characteristics thus could be used to identify and

even group glaciers (Higuchi 1975).They can clearly show trends in glacier cover especially areas of small glacier cover of 6 Km^2 or smaller.

Landsat MSS sensor was later advanced to Landsat TM sensor whose spatial resolution had been improved to 30m and spectral resolution had seven bands making it even better for snow and cloud cover discrimination (Dozier 1985). Landsat TM bands in the visible portion of the spectrum combined thus allowing clear identification of ice cover from clouds or fog (Ormsby and Hall 1991). GIS technology has proved to be effective in the analysis of today's glacier's extent and in the future (Li *et al.* 1998) besides enabling glacier area calculation.

A simple spatial analysis of Mt. Kenya glacier was conducted using remote sensing and GIs skills whereby medium resolution (30x30m) Landsat Images sourced from RCMRD (the Regional Centre for Mapping of Resources for Development) Nairobi were used. Glacier change analysis for the period 1976 to 2016 was done whereby low cloud cover satellite imageries for year's 1976,1987,1995,2007 and 2016 were used. ArcGIS and ENVI computer software's were used during the analysis. This process is illustrated in **Table 3- 5**

Table3- 5: Summary of the satellite imagery processing techniques

Components	**Description**	**Tools**	**Deliverables**
1.Data identification and acquisition	Different datasets were identified and acquired from the existing database of Regional Centre for Resources Mapping and Development.	Internet for downloading satellite image	Raw data layer
2.Data processing	The acquired data was processed and maps compiled	ArcGIS and ENVI software used	Formatted dataset
3. Data analysis and interpretation	Data was analyzed to generate the information that was presented on the maps.	ArcGIS and ENVI software used	Information layers datasets
4.Map compilation	Generated information was used to prepare different maps	ArcGIS software used	Thematic maps

3.5.3 Direct observation

The researcher applied direct observation as another method of data collection. The key observations were as follows:- Human activities taking place along the riparian areas of the both Naromoru and Likii rivers', river water levels (quantity) and water quality (level of turbidity) as well as presence of any water pumps abstracting water directly from the rivers', types of crops under irrigation in the farms and farm size, types of livestock and herd size where possible, gender based work force especially in the farms , last but not least the respondents level of sincerity and calmness when being interviewed.

3.6 Data Processing

From the field, the collected questionnaires were examined for any missing data. Data coding then followed for specific demographics (Gender, education level and occupation) and the respondents views on Mount glacier dynamics for the last 40years, deglaciation implications on river flow and livelihoods, availability of adaptation and coping strategies based on age, gender and level of education. Here, responses were allotted specific numerical codes, and then exported to SPSS (Statistical software) to ease data cleaning and analysis. Data cleaning was by checking missing information, wrongly entered codes or presence of similar responses.

3.7 Data analysis

3.7.1 Reliability and Validity

Reliability in research refers to an assessment of the ability of a research instrument to yield gives similar results consistently even after repeated trials, (Miles & Hubberman 1994), (Mugenda & Mugenda 2003). The Cronbach's alpha (α) generated from IBM SPSS 23 was used to test scales for River flow, livelihoods together with adaptation and coping strategies for validity and internal consistency (reliability). The Cronbach's alpha for the overall scale was 0.759 with Cronbach's alpha for the following perceptions also measured as follows: River flow (0.750), livelihoods (0.781), Adaptation and coping strategies (0.763). This was a sign of a good internal consistency for the data collection instrument since based on Cronbach (1951), an alpha (α) ranging $0.7 \leq \alpha < 0.9$ shows good internal consistency for the data collection instrument.

Validity in research refers to accurate and meaningful inferences based on the research results (Mugenda & Mugenda, 1999). All validity assessments are subjective opinions according to researchers level of judgment (Wiersma 1995).The content validity of data collection instrument was improved through expert judgment, thus, the researcher sought assistance of the supervisors whose expertise in research, helped in improving content validity of the instrument.

3.7.2 Data Analysis

Descriptive Statistics were used in giving a description of the population under study whereby distribution of various variables was indicated using frequency tables, charts and Maps. Cross tabulation was also done whereby simple data tables were used to present results from the surveyed respondents.

Inferential statistics were used to draw conclusions about the study population on basis of sample analysis and observation by comparing, testing and predicting data. Non- parametric Kruskal-Wallis H test was used in testing the three Null hypotheses since the data was ordinal in nature and the conditions to be measured were more than two. In addition, Non-Parametric Mann Whitney U Test was used to compare local perceptions based on gender, age and level of education at α=0.05 significance level. In the analysis using The Mann-Whitney U test, Small scale farmers, low-class urban consumers and pastoralists' perception differences were analyzed according to Gender i.e. a comparison of "Males" VS "Females" perception differences as well as according to level of education i.e. a comparison based on "High school" VS "Tertiary" or " primary" VS "non-formal" In this case Independent variable was either "Gender" or "Education Level" while dependent variables were Small scale farmers, low-class urban consumers and Pastoralists perceptions.

Finally, thematic analysis of satellite images showing glacial changes over time from year 1976 to year 2016 was carried out whereby the spatial trends were analyzed using ENVI in order to show the spatial dynamics, then maps were produced. Finally, information obtained from the questionnaires survey and observations made in the field were used to support the glacial change data obtained from satellite imagery analysis.

CHAPTER 4: RESULTS AND DISCUSSION

4.0 Introduction

This chapter provides detailed respondents demographic information and their responses, Mount Kenya glacial changes for the period 1976 to 2016 and the perceived linkages between Mount Kenya deglaciation, water supply and livelihoods for the communities living downstream in Nyeri and Laikipia counties.

4.1 Household Characteristics

The respondents interviewed included:-54% male and 46% females ; the majority of whom were aged 40-49 years (27%), 30-39 years(21%), 50-59 years (19%), 60-69 years (11%), Above 70 years (12%), 20-29 years old (9%). Similarly, from the survey, 33 respondents (38%) had primary education, followed closely by 32 respondents (37%) with secondary education, 16 respondents (18%) had no formal education with 6 of them having tertiary education as indicated in **Table 4-1** A bigger percentage of the respondents depended on farming i.e. 32 respondents (38%) as their source of livelihood followed closely by livestock keeping 25% (22 respondents) , business 13%, 10% for casual labor as illustrated in **Table 4-2**. Finally, from the survey it was also noted that the majority of the household had 1-5 members (68%), 6-10 family members (30%) and families with more than 10 members was 2%.

Farm sizes under irrigation in Naromoru were between 1-10 acres but majority had 1-3acres growing mainly vegetables and maize. Majority of the residents of Nanyuki town (Likii village) were urban poor that depend on river water for their domestic utility with some operating small business including as growing and selling ornamental plants and car wash. Pastoralists included livestock herders' natives of rather drier areas of Laikipia North sub- whose livestock included:-cattle, sheep and goats; ranging from 50 to 100 herd size on average. They depended mainly on River Likii for livestock watering and frequently visited the river.

Table4- 1: Respondents gender, age and educational characteristics

Variable	Male		Female	
	Frequency	Percentage	Frequency	Percentage
Gender Ratio / **Age (Years)**	**56**	*64.4*	**31**	*35.6*
25-34	26	*30*	12	*14*
35-44	12	*14*	6	*7*
45-54	5	*6*	6	*7*
55-64	5	*6*	3	*3*
65 or Older	*7*	*8*	5	*6*

Variable	Respondent	
	Frequency	Percentage
Education Level		
Non formal	16	18.4%
Primary	33	*37.9%*
Secondary29	32	*36.8%*
Tertiary	6	*6.9%*

Table4- 2: Occupation of all Respondents and farm size of respondents in Naromoru irrigation zone characteristics

Occupation of all Respondents	Number of Respondents
Farmer	32
Pastoralist	22
Business	11
Casual Laborer	9
Housewife	3
Teacher	2
Pastor	2
Civil Servant	1
Retired	1
Security Guard	1
Technician	1
IT Technician	1
None	1
GRAND TOTAL	**87**

Farm size in Naromoru Study area (Acres)	Number of Respondents
224	1
50	1
10	1
6	1
4	3
3.5	1
3	1
2.5	1
2	4
1.5	1
1	8
0.75	2
0.5	3
0.25	1
GRAND TOTAL	**29**

4.2 Mt Kenya Glacial change from 1970's to 2000's satellite imagery analysis

An analysis of Landsat satellite imagery for the period 1976 to 2016 was done and the results clearly showed that Mount Kenya glacier had decreased sharply from an area of approximately 1.86221Km^2 in 1976 to 0.16944 Km^2 in year 2016 as follows: .

4.2.1 Mount Kenya Glacier in 1976

According to the analysis Landsat MSS 123 (B475) taken on January 24th 1976 it showed that by then Mount Kenya glacier covered a total area of 1.86221Km^2 whereby each ring of the visible glacier was measured in kilometers and the sum of all the rings measurements gave a total of 1.86221Km^2 as illustrated by plate 4-1 and figure 4-1 below:-

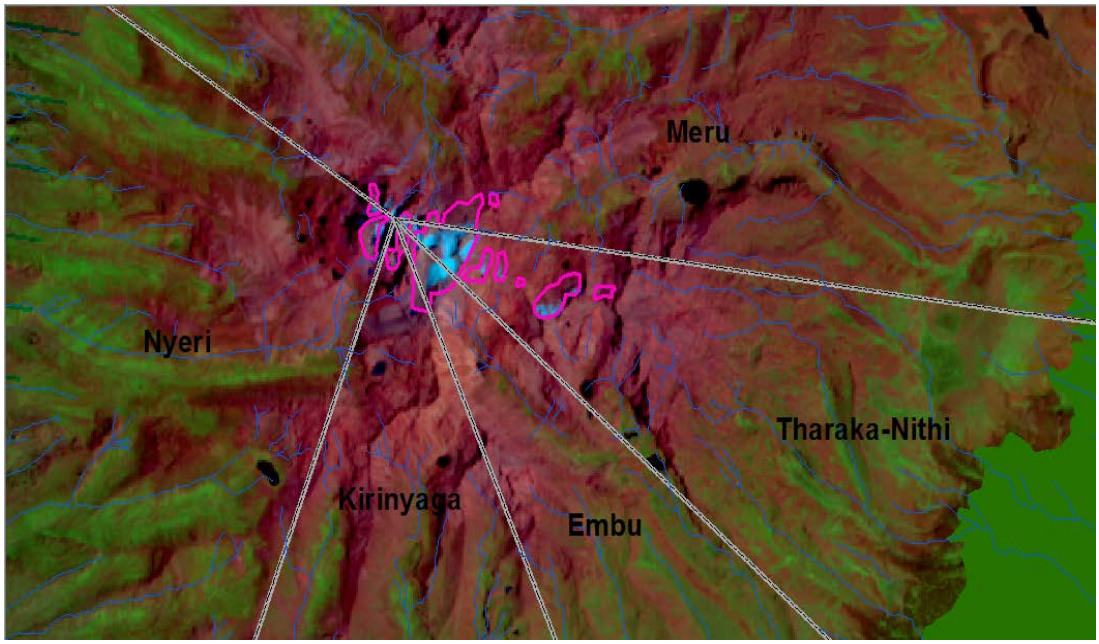


Plate 4- 1: Zoom version of Mt. Kenya glaciers in year 1976

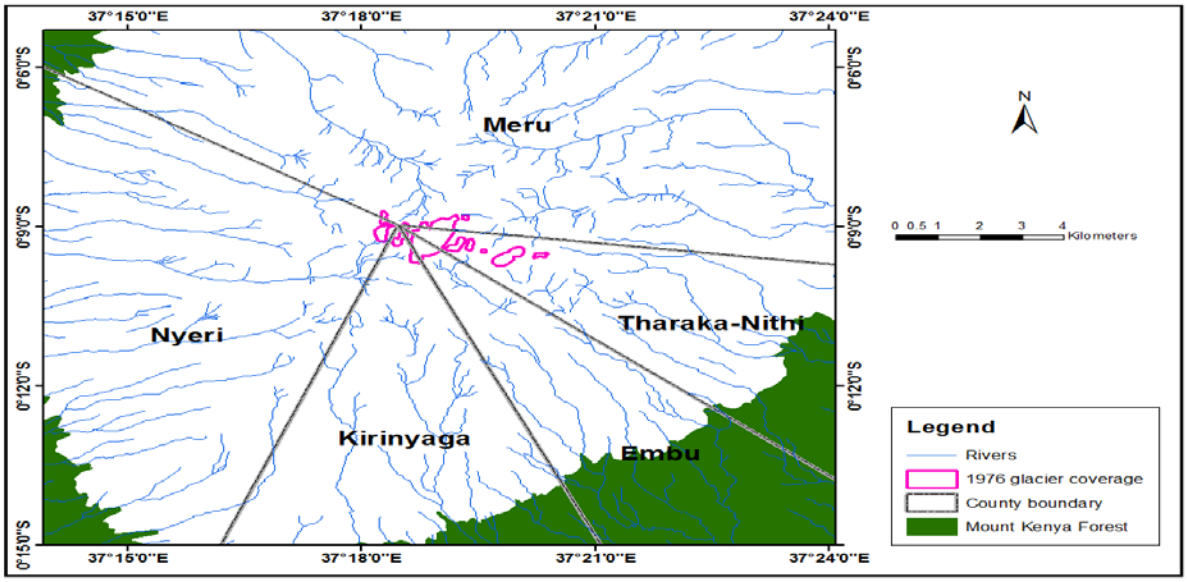


Figure4- 1: Mount. Kenya glacier satellite imagery analysis Year 1976 Map

4.2.2 Mount Kenya Glacier in 1987

The second satellite imagery to be analyzed was Landsat MSS 45(B142) taken on February 25th 1987 whereby it was evident that Mount Kenya glacier had further reduced considerably from 1.86221Km^2 (in 1976) to approximately 1.26892Km^2 as illustrated by plate 4-2 and figure 4-2 below:-

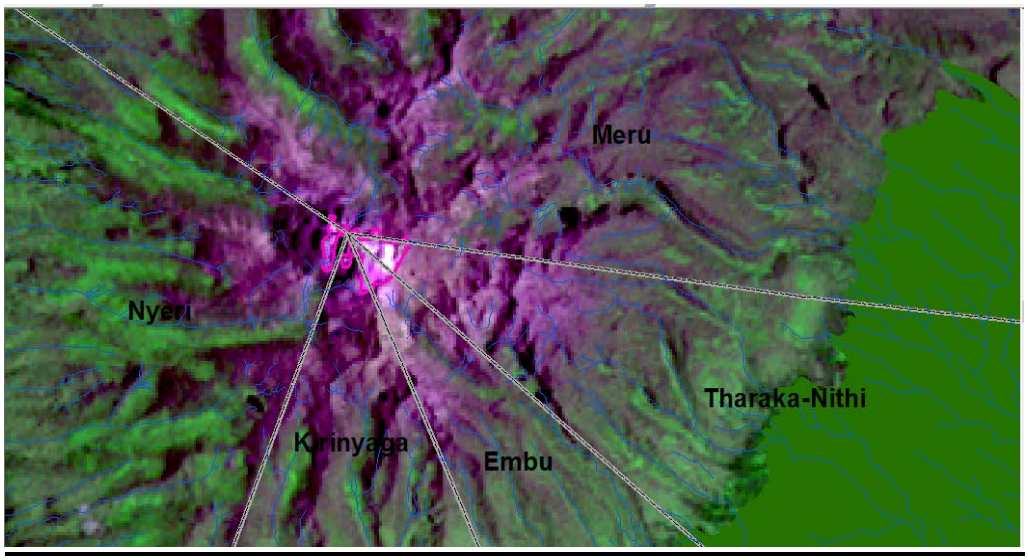


Plate 4- 2: Zoom version of Mt. Kenya glaciers year 1987

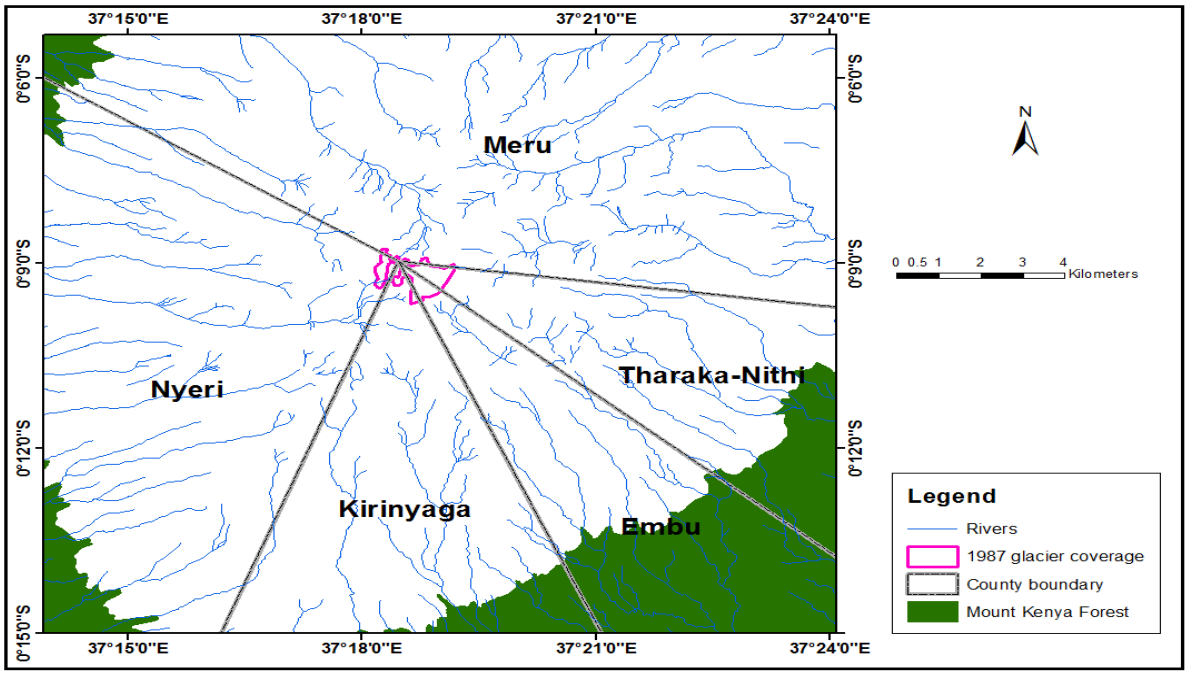


Figure4- 2: Mount. Kenya glacier satellite imagery analysis Year 1987 Map

4.2.3 Mount Kenya Glacier in 1995

Third satellite imagery analyzed was a Landsat TM (B247) taken on January 30th 1995 .The outcome of the analysis should that this time round glacier had increased from 1.26892Km^2 to 1.73256Km$^{2.}$ The reason for this increase can be attributed to high precipitation rate during the time when this image was taken. During wetter season, there are high chances of high mountains receiving precipitation in form of ice especially on their high altitudes making the glacier extent to appear to be more than usual as indicated on figure 4-3 and plate 4-3 below; however this does not last for long since at the onset of dry season most of this ice starts melting down.

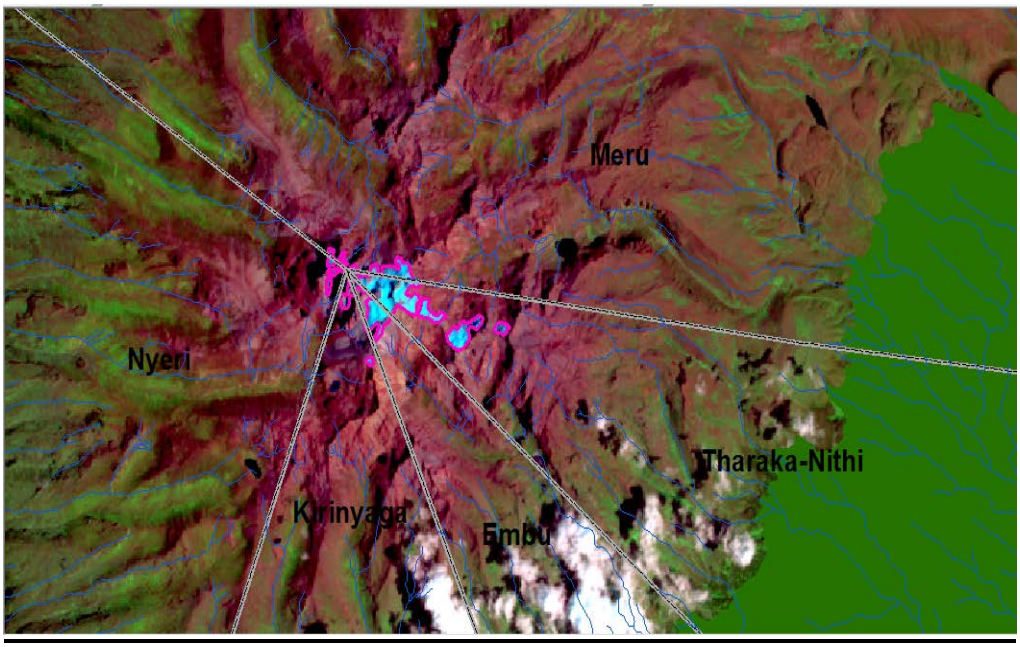


Plate 4- 3: Zoom version of Mt. Kenya glaciers year 1995

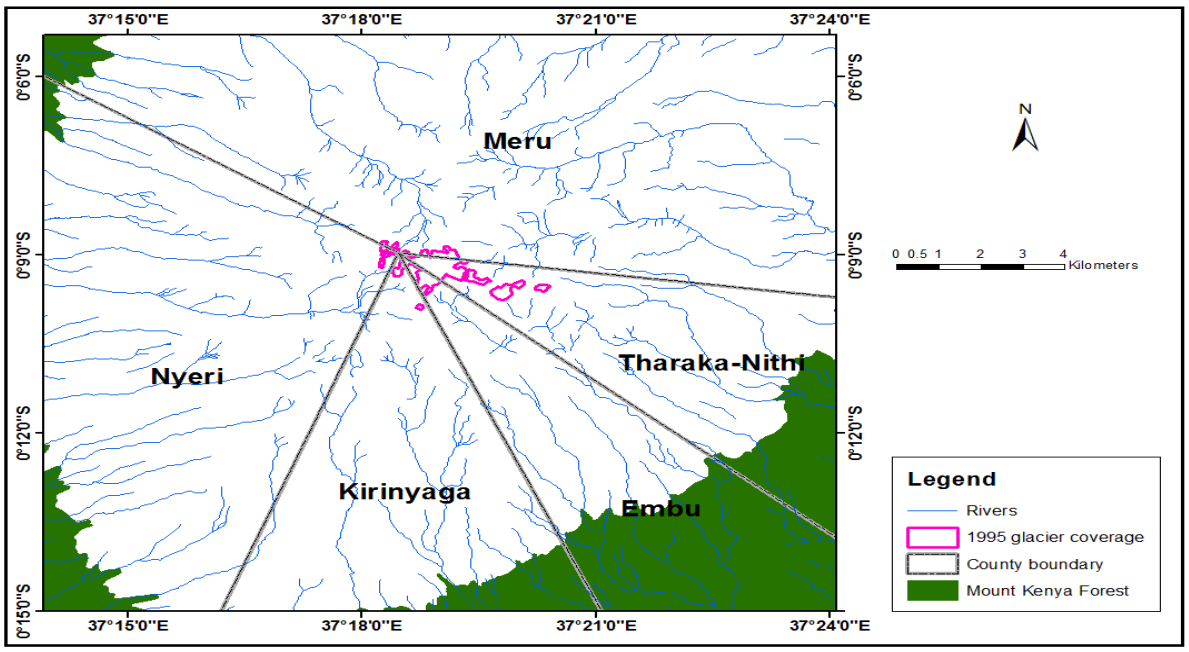


Figure4- 3: Mount. Kenya glacier satellite imagery analysis Year 1995 Map

4.2.4 Mount Kenya Glacier in 2007

The fourth satellite imagery to be analyzed was a Landsat TM (B247) for the year 2007, whose results showed that Mount Kenya glacier had declined by 0.24406 to a total area of 0.89521Km^2 after each ring of the visible glacier was measured in kilometers and the sum of

all the ring measurements gave a total of 0.89521Km^2 as indicated in figure 4-4 and plate 4-4 below.

This can be attributed to climate change effects which resulted to an increased air temperature that forced the mountain glacier to shrink further as thawing process continues.

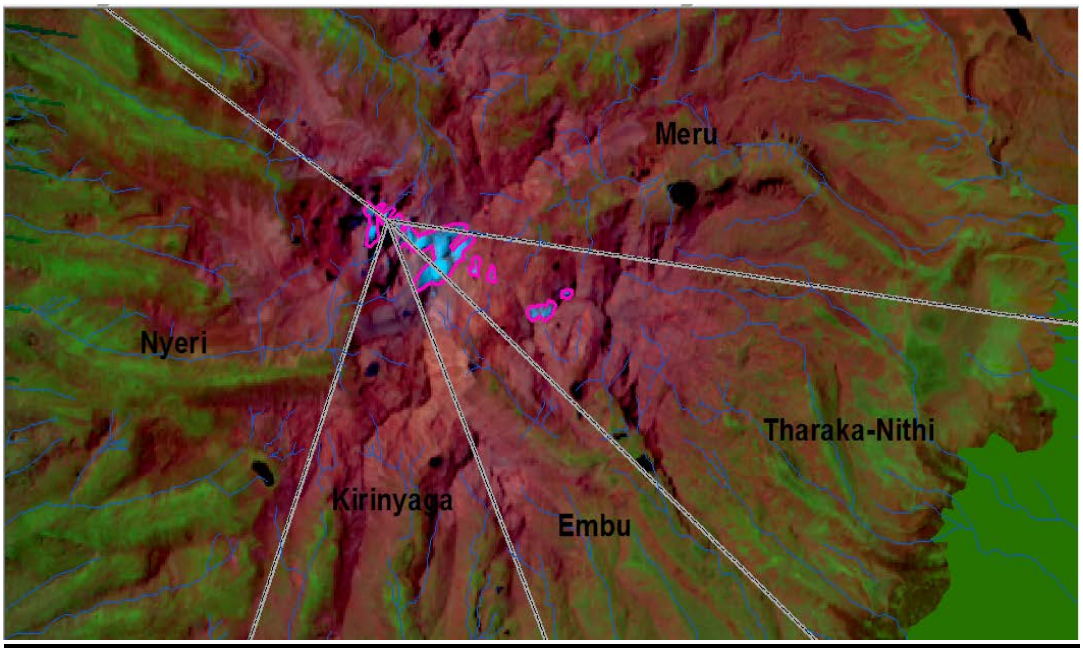


Plate 4- 4 : Zoom version of Mt. Kenya glaciers year 2007

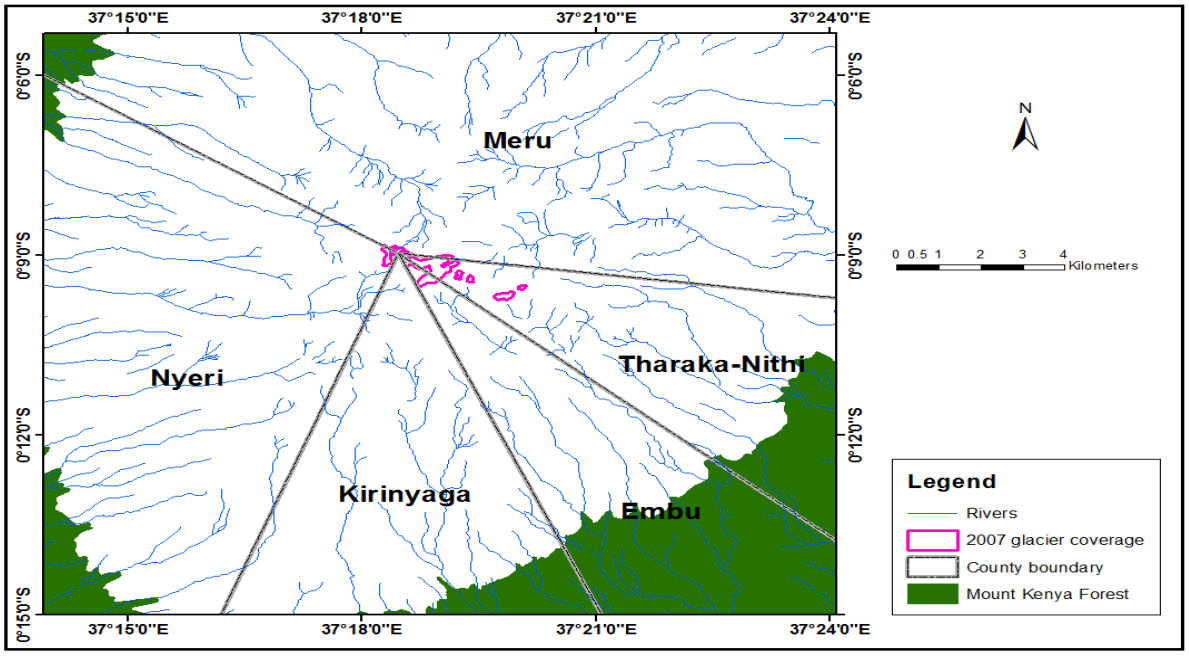


Figure4- 4: Mount. Kenya glacier satellite imagery analysis Year 2007 Map

4.2.5 Mount Kenya Glacier in 2016

Finally, Landsat OLI (B357) satellite image was the last to be analyzed, and the results of the analyses should that Mount Kenya glaciers had declined even further for the last 9 years to 0.16944 Km^2 as illustrated by figure 4-5 and plate 4-5

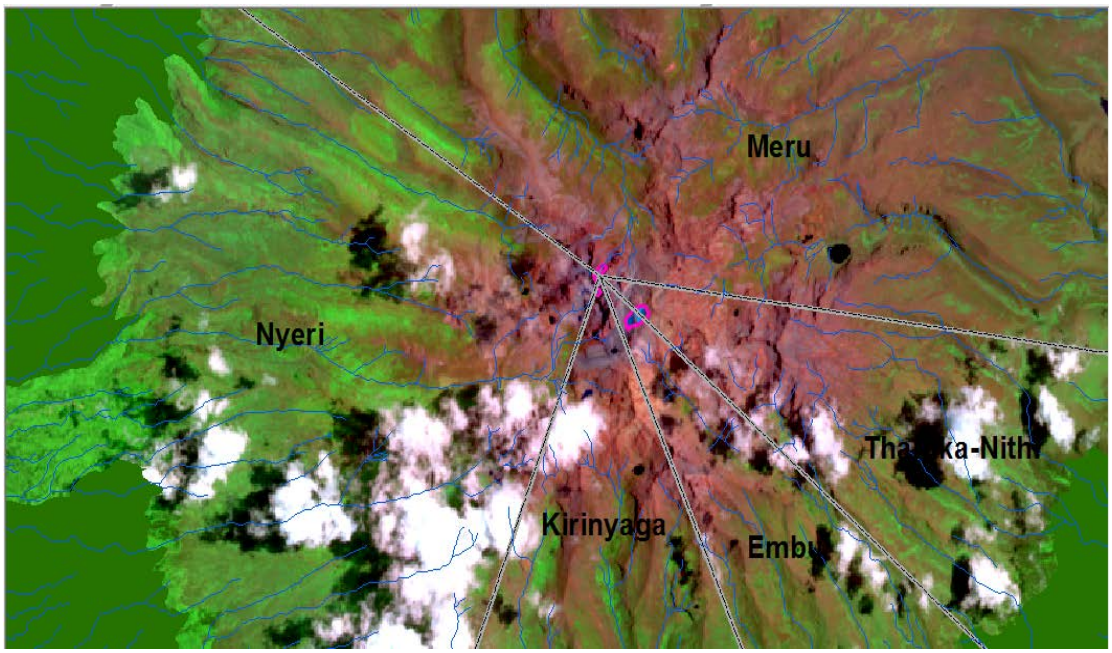


Plate 4- 5: Zoom version of Mt. Kenya glaciers year 2016

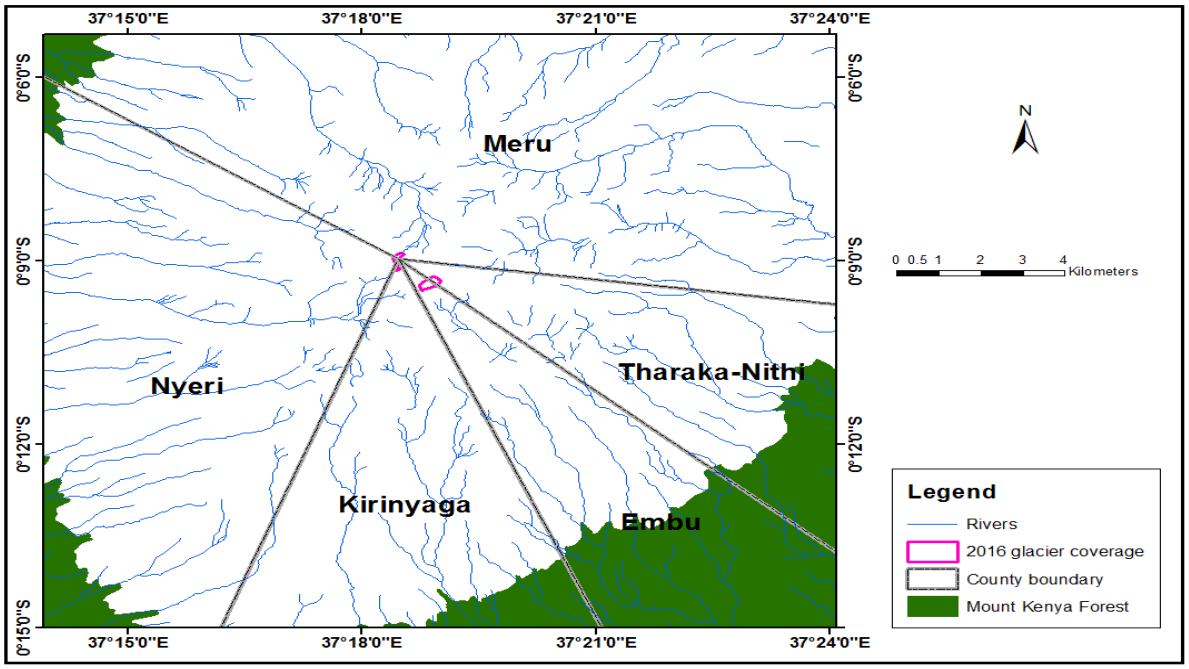


Figure4- 5: Mount. Kenya glacier satellite imagery analysis Year 2016 Map

The satellite imagery analysis indicated a progressive decline in glacial surface area between 1970's and 2000s' whereby almost 50% of total glaciers had been lost from about 1.86km^2 in year 1976 to around 0.17km^2 in 2016 as illustrated in Table 4-3 and Figure 4-6. The analysis of Landsat Imagery also showed that the glacier extent was mainly on the eastern windward side of the mountain, with glacial retreat trend being consistent according to the spatial analysis. From these findings, the main question is whether the local communities living within Mount Kenya ecosystem recognized this glacial retreat trend for the last 40years and if they were aware of how such glacier recession had affected river water supply downstream and their livelihoods.

Table4- 3: Mount Kenya Glacier changes trends in Km^2

Year	**Month & date of the Satellite Image**	**Glacier size**	**Glacier change in Km^2**
1976	January 25th	1.86221	1.86221
1987	February 25th	1.26892	0.59329
1995	January 30th	1.73256	1.13927
2007	February 08	0.89521	0.24406
2016	March 28th	0.16944	0.07462

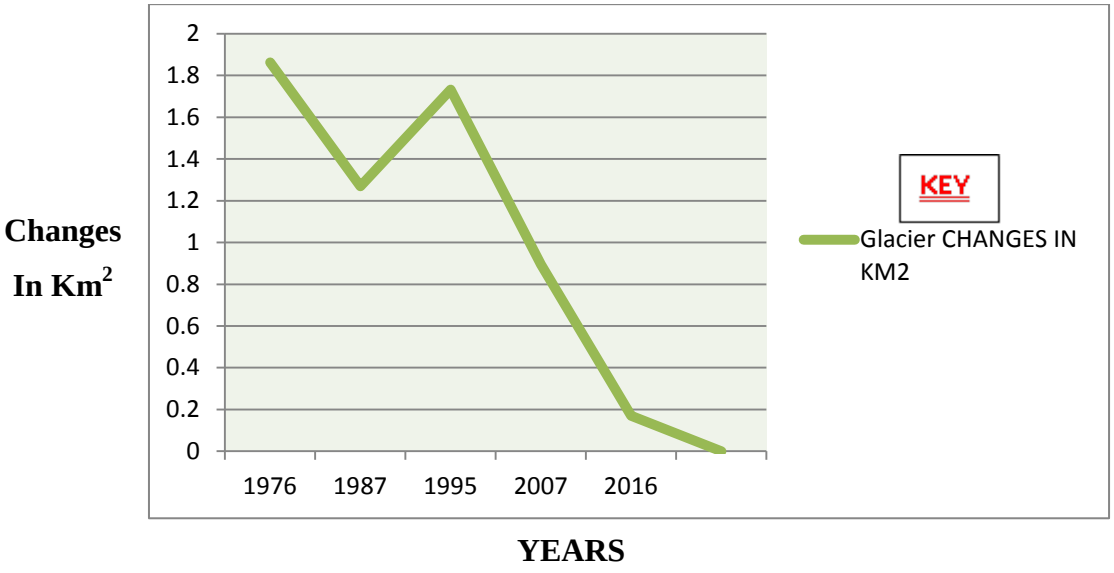


Figure4- 6: Mount Kenya glacier decline for the last 40years

4.3 The effects of Mount Kenya glacier recession on Water supply and Community Livelihoods

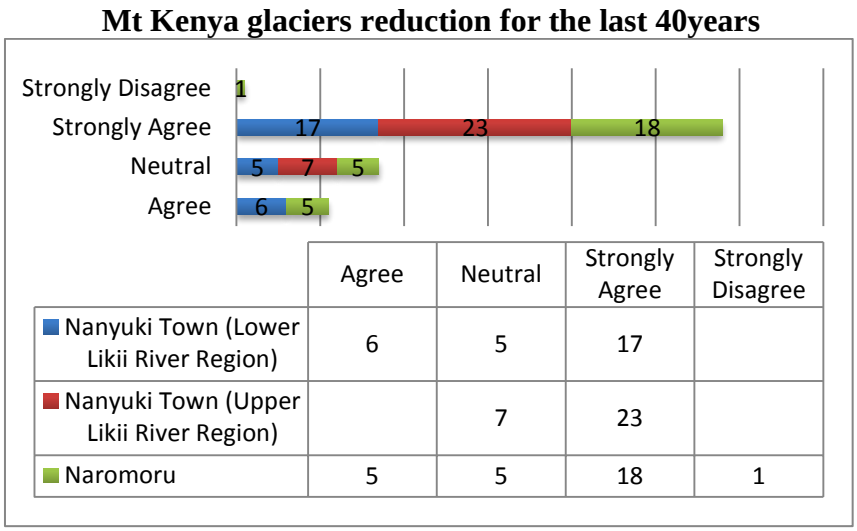
Here we focused on three major areas as follows:-

a) Mount Kenya Glacier dynamics for the last 40 years.
b) Glacial dynamics effects on river water supply and livelihoods of the communities downstream.
c) Local perceptions on availability of clear deglaciation Adaptation and coping strategies based on Age, Gender and Level of education.

4.3.1 Local perceptions on Glacier change for the last 40 years

In addition to Mount Kenya satellite imagery analysis, the assessment of Nanyuki and Nyeri counties residents' perceptions regarding behavior of Mount Kenya glaciers for the last 40 years was also conducted. The respondents interviewed had a good mental understanding of the glacial change trends in Mount Kenya for the 40year duration between 1976 and 2016 based on the researchers' assessment.

The local perception findings indicated that a majority of respondents (58 out of a total of 87) strongly agreed that Mt Kenya glaciers had significantly reduced during the study period. However, some respondents were not sure i.e. 17 respondents (20%) and 1 respondent (1%) strongly disagreed (**Figure 4-7**).Among the respondents who were for the opinion that the glaciers had significantly declined, 36% came from Nanyuki area which is well positioned for a clearer view of the mountain compared to 20% of respondents in Naromoru with same perception. The latter has a poor view of the mountain glaciers since its landscape is more rugged, densely forested and affected by frequent cloudy weather; being located within transitional area between leeward and windward zones.



	Agree	Neutral	Strongly Agree	Strongly Disagree
Nanyuki Town (Lower Likii River Region)	6	5	17	
Nanyuki Town (Upper Likii River Region)		7	23	
Naromoru	5	5	18	1

Figure4- 7: Local perception on Mt Kenya glacial dynamics

The Mann Whitney U test findings revealed absence of significant perception difference in relation to Mt Kenya glacier reduction between 1970s to 2016 either by age(P=0.713),gender (p=0.116) or level of education (0.077). Many respondents strongly agreed that Mt. Kenya glacier had reduced tremendously for the last 40years due to climate change; however a significant perception difference between male and female respondents was noted in relation to Mt Kenya glacier recession trend consistency as illustrated in the Mann Whitney U Test results **(Table 4- 4)**

Table4- 4: Local perception Mann Whitney U test regarding Mt Kenya glacial dynamics for the last 40years

Test variable 1	Test variable 2	N	Mean Rank	Mann-Whitney U	Wilcoxon W	Z	P-value
Significance glacier decline for the last 40 years	25-34	37	24.81	205	283	-1.369	0.712
	=/over64yrs	11	23.58				
	Female	32	40.23	752	1248	-1.577	0.114
	Male	57	46.09				
	Informal education	18	22.53	230	383	-1.866	0.077
	Formal education	34	27.74				
Inconsistent deglaciation trend	Female	31	52.74	597	2193	-2.602	0.004
	Male	56	39.16				

1st Null Hypothesis Test

The first Null Hypothesis test was conducted; “There is no significant reduction in Mount. Kenya glaciers for the last 40years” In this case “Region” was used as the independent variable while Q12 (Mt Kenya glacier has decreased significantly in the last 40 years; 1976 -

2016) served as the dependent variable. A Kruskal-Wallis H test results yielded a test statistic of 0.397 at 2 degrees of freedom. The P-Value was 0.820, which is greater than 0.05 Significance level, thus the Null hypothesis was not rejected due to lack of enough evidence that indicated a statistically significant difference. The test results are as indicated in **Table 4- 5**

Table4- 5: A Kruskal-Wallis test for the hypothesis 1" There is no significant reduction in Mt. Kenya glacier for the last four decades"

Ranks		
Region	**N**	**Mean Rank**
Naromoru	29	45.36
Nanyuki Town (Upper Likii River Region)	30	44.00
Lower Nanyuki Area (Lower Likii River Region)	28	42.59
Total	**87**	

Test Statistics [a,b]	
Chi-Square	.397
df	2
Asymp. Sig.	.820
a. Kruskal Wallis Test	
b. Grouping Variable: Respondents location	

4.3.2 Local perceptions on glacial dynamics effects on water supply and livelihoods

The survey also sought to assess the perception of the locals in regard to how Mount Kenya deglaciation had affected river water supply and their Livelihoods. Many respondents in Naromoru and Nanyuki were of a strong opinion that Mt Kenya glacier recession had resulted to a significant river flow reduction thus causing water shortages and loss of livelihoods by local communities However, few pastoralists in the lower Likii River sections, below Nanyuki town felt that this reduction in river flows could have been caused by upstream abstraction of water especially by the large scale horticultural farmers who irrigated flowers for exports using river water and not Mount Kenya deglaciation. This finding signed an in-depth mistrust and a possibility of water conflicts among Mt Kenya leeward side water users.

Along the Naromoru River, 66% of the respondents strongly felt that Mt Kenya glacier loss and river flow reduction had negatively affected irrigation in future (**Table 4- 6**) However, only a 45% felt that this would increase water users' tension. This view was different from that in Respondents from Nanyuki were of a contrary view due to fact Nanyuki area is

considered a cosmopolitan and the Maasai pastoralists have always felt they are a disadvantaged group having to share “their land and water “while Naromoru is dominated by one ethnic group (the Kikuyu people) majority being farmers.

Table4- 6: local Perception on Mt Kenya deglaciation effects river water supply and livelihood in %

STUDY AREA	**Not sure**	**Agree**	**Strongly Agree**	**Disagree**	**Total**
Naromoru(Irrigation Zone)	13.5	20.9	65.6	-	100
Upper Likii (Urban zone)	-	33.3	60.0	6.7	100
Lower Likii (Pastoralism zone)	3.7	57.1	32.2	7.0	100

Notably, only a 27% of the Nanyuki residents seriously feared that on-going Mt Kenya deglaciation could escalate water user conflicts. A section of the Pastoralists (32%) in the lower Likii area believe deglaciation and reduced river flow had been devastating to pastoralism forcing them to reduce their stocks sizes as illustrated in **Table 4- 7**

Table4- 7: Local perception on deglaciation impacts on livelihoods

	Not Sure	**Disagree**	**Agree**	**Strongly Agree**	**Total**
Glacier reduction and reduced river discharge has affected irrigation negatively along River Naromoru	3.5	-	31.0	65.5	100
Glacier reduction and reduced river discharge has escalated water user conflicts along River Naromoru	24.2	6.9	24.1	44.8	100
Glacier reduction and reduced river discharge has fuelled conflicts among farmers, low class urban and pastoralist water users along Likii River	26.7	33.4	13.3	26.6	100
Glacier reduction and reduced river discharge has influenced pastoralism negatively along River Likii	3.6	7.2	57.1	32.1	100

Table4- 8: local perception Mann Whitney U test based on Age and gender regarding deglaciation impacts on livelihoods

Test variable 1	Test variable 2	N	Mean Rank	Mann-Whitney U	Wilcoxon W	Z	P-Value
Deglaciation has increased irrigation water use tension	25-34yrs	6	11.08	14.5	69.5	-1.828	0.05
	35-44yrs	10	6.95				
Deglaciation has affected downstream irrigation	Females	6	9.83	38	59	-2.010	0.04
	Males	23	16.35				
Deglaciation has escalated irrigation, urban and pastoralism water use tension	Females	5	18.40	38	314	-1.375	0.05
	Males	23	13.65				
Deglaciation has affected the pastoralism sector	Females	5	21.20	24	300	-2.201	0.02
	Males	23	13.04				

The results of the Mann Whitney U test (**Table 4- 8**) indicates a significant difference on local perceptions according to age and gender; perception difference by gender was as a result of sample size configuration; dominant gender being males (64%). Male gender formed the majority respondents for the small scale farming zone in Naromoru and pastoralist zone in the lower Nanyuki sections along River Likii ; a common practice in Kenya. The overall findings from the survey indicated that the formal education was not a necessity for personally appreciating and recognition of Mt Kenya deglaciation and its effects on river discharge and downstream communities' livelihoods.

Plate 4- 6: Reduced discharge in River Naromoru within Naromoru Ward

Plate 4- 7: Reduced discharge in River Likii in Nanyuki Ward

2nd Null Hypothesis Test

The second Null hypothesis "Mount Kenya glacier reduction has neither reduced water supply nor led to livelihoods loss" test was conducted. "Region" was used as the independent variable while questions (*Q19/Q26/Q34)* served as the dependent variables since they were all testing on glacial recession impacts on water supply and livelihoods amongst river users within the three regions. A Kruskal-Wallis H test conducted yielded a test statistic of 11.234 at 2 degrees of freedom; P-Value being 0.004 which is less than 0.05 Significance Level.

The Null hypothesis was thus rejected and its alternative, "Mt Kenya Glacier reduction has significantly reduced water supply leading to livelihood loss.

The test results are as illustrated in **Table 4- 9**

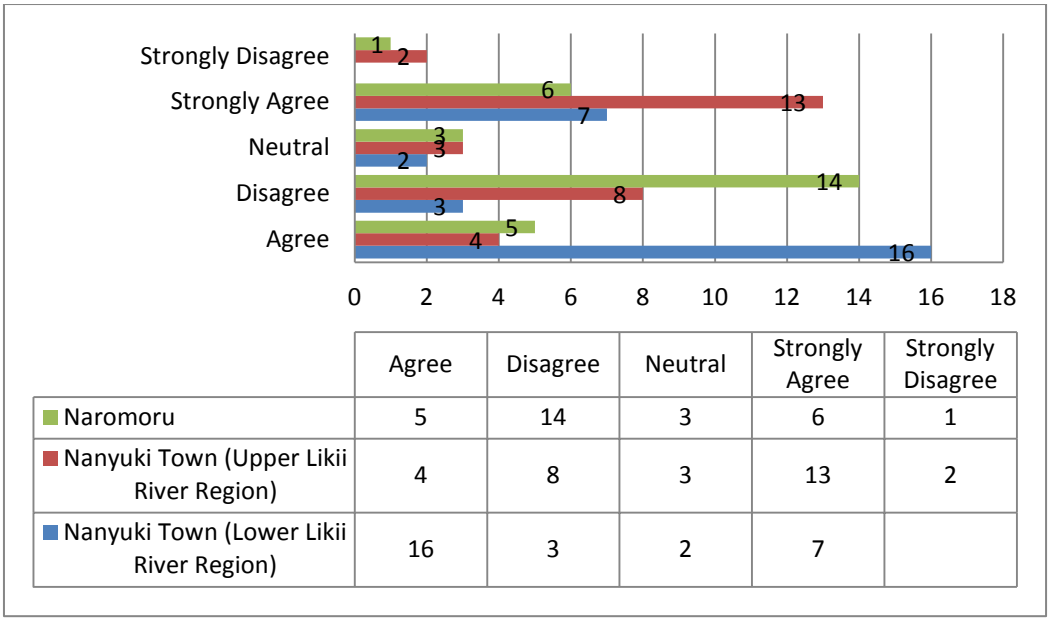
Table4- 9: The second hypothesis, “Mt Kenya glacier has neither reduced water supply nor led to livelihood loss” Test results

Ranks		
Region	**N**	**Mean Rank**
Naromoru	29	56.40
Nanyuki Town (Upper Likii River Region)	30	38.73
Lower Nanyuki Area (Lower Likii River Region)	28	36.80
Total	**87**	

Test Statistics [a,b]	
Chi-Square	11.234
df	2
Asymp. Sig.	.004
a. Kruskal Wallis Test	
b. Grouping Variable: Region	

4.3.3 Local perceptions on availability of clear deglaciation adaptation and coping strategies

Lastly, we sought to assess whether Age, Gender and level of Education influenced public perception on availability of deglaciation adaptation and coping strategies. Respondents gave their views on whether they had any adaptation and coping strategies for Mount Kenya glacier recession. The overall findings were as follows:- 58.6% (51 respondents) agreed while 32.2% (28 respondents) disagreed that adaptation and coping strategies for deglaciation and river water reduction existed as indicated in **Figure 4- 8**



	Agree	Disagree	Neutral	Strongly Agree	Strongly Disagree
Naromoru	5	14	3	6	1
Nanyuki Town (Upper Likii River Region)	4	8	3	13	2
Nanyuki Town (Lower Likii River Region)	16	3	2	7	

Figure4- 8: Public perception on availability of clear adaptation and coping strategies for the impacts of Mt. Kenya deglaciation

3rd Null Hypothesis Test

The third Null hypothesis," There are no clear adaptation and coping strategies for the impacts of Glacier recession" test was conducted, "Region" being the independent variable and questions *Q22/Q29/Q37* which sought to find out if the river users had a clear adaptation and coping mechanism for the impacts of declining glaciers in Mt Kenya served as the dependent variables. A Kruskal-Wallis H test yielded a test statistic of 6.378 at 2degrees of freedom, with a P -Value of 0.041 which is less than 0.05 Significance Level. The Null hypothesis was then rejected and its' alternative adopted. I.e. "Clear adaptation and coping strategies for Mt Kenya Glacier recession effects deglaciation effects on water supply and livelihoods existed"

These results are as illustrated in **Table 4- 10**

Table4- 10: The third hypothesis, 'There are no clear adaptation and coping strategies for the impacts of Glacier recession" test results

Ranks		
Region	**N**	**Mean Rank**
Naromoru	29	35.02
Nanyuki Town (Upper Likii River Region)	30	46.47
Lower Nanyuki Area (Lower Likii River Region)	28	50.66
Total	**87**	

Test Statistics [a,b]	
Chi-Square	6.378
df	2
Asymp. Sig.	.041
a. Kruskal Wallis Test	
b. Grouping Variable: Region	

The results were further analyzed based on the following respondents' characteristics: Age, Gender and Education level as follows:-

4.3.3.1 Adaptation Strategies by Age

The analysis of the respondent's perceptions based on age showed that 30 respondents aged (25-34) agreed that adaptation and coping strategies were available, followed by 7 respondents aged (45-54). 10 respondents aged (35-44) disagreed that adaptation and coping strategies, existed followed by 6 respondents aged (25-34) as indicated in **Fig.4- 9**

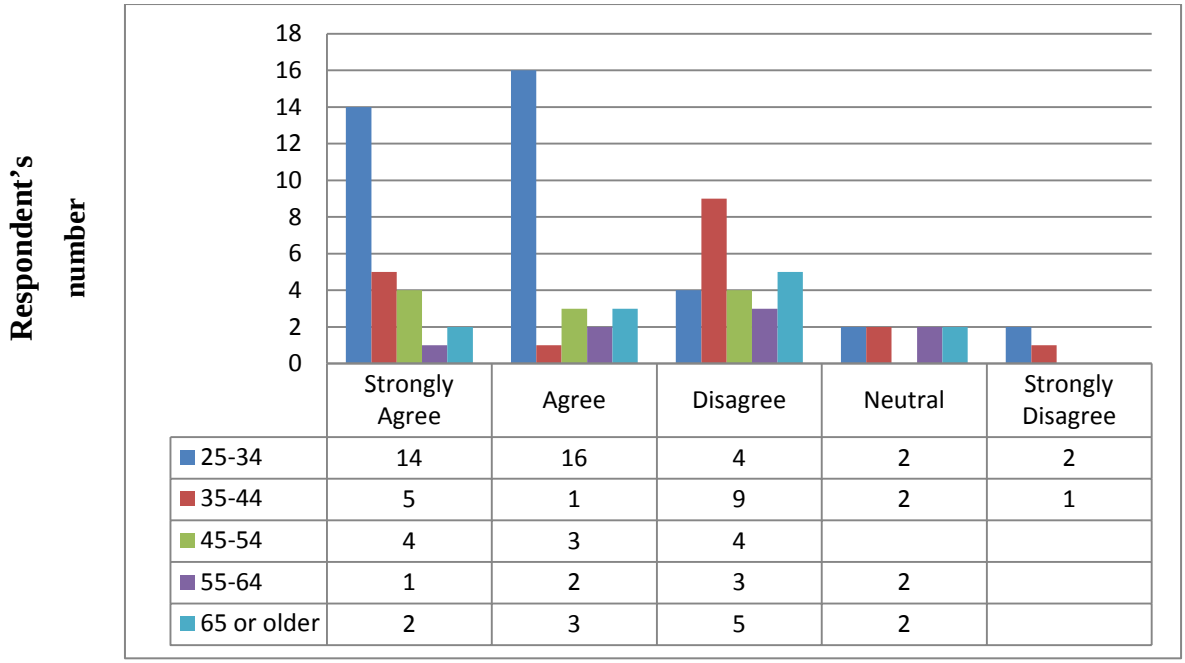


Figure4- 9: Public perception on availability of clear adaptation and coping strategies based on respondents Age group

4.3.3.2 Adaptation and Coping Strategies by Gender

Both male and female respondents were interviewed whereby 34 male respondents (39.1%) and 17 female respondents (19.5%) out of 87 respondents interviewed agreed that there existed adaptation and coping strategies, **Fig 4- 10**

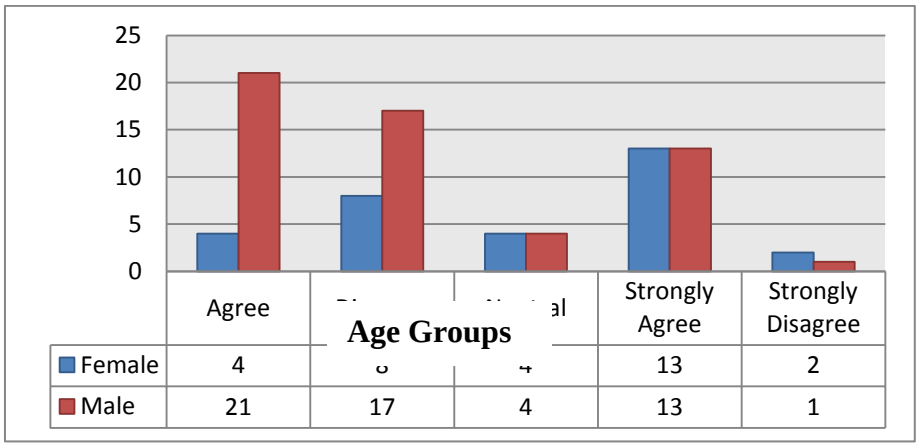


Figure4- 10: Public perception on availability of clear adaptation and coping strategies for the effects of Mt. Kenya deglaciation based on respondents gender

Top ascertain whether gender influenced the public perception, a Mann-Whitney U test was conducted whereby the independent variable Gender had two groups i.e. male and female. The test result gave a P value of 0.565 which is greater than 0.05 Significance Level. This is an indication that the difference between the medians was not statistically significant therefore gender had no significant influence on the public perception on availability of clear Glacier Recession adaptation and coping strategies. This is illustrated in Table 4- 11:-

Table4- 11: A Mann-Whitney U test results on public perception regarding availability of clear adaptation and coping strategies based on respondent's gender

The river users do not have clear adaptation and coping mechanisms for the impacts of declining glaciers in Mt Kenya			
Ranks			
Gender	**N**	**Mean Rank**	**Sum of Ranks**
Male	56	51.58	2401.50
Female	31	35.14	1426.50
Total	87		

	Test Statistics [a]
Mann-Whitney U	805.500
Wilcoxon W	2401.500
Z	-.576
Asymp. Sig. (2-tailed)	
a. Grouping Variable: Gender	

4.3.3.3 Adaptation strategies by education

The perception survey established that 19 respondents (22%) having secondary level of education, followed closely by 18 respondents (21%) having Primary level of education agreed that there existed adaptation and coping strategies as shown in the Fig.4- 11

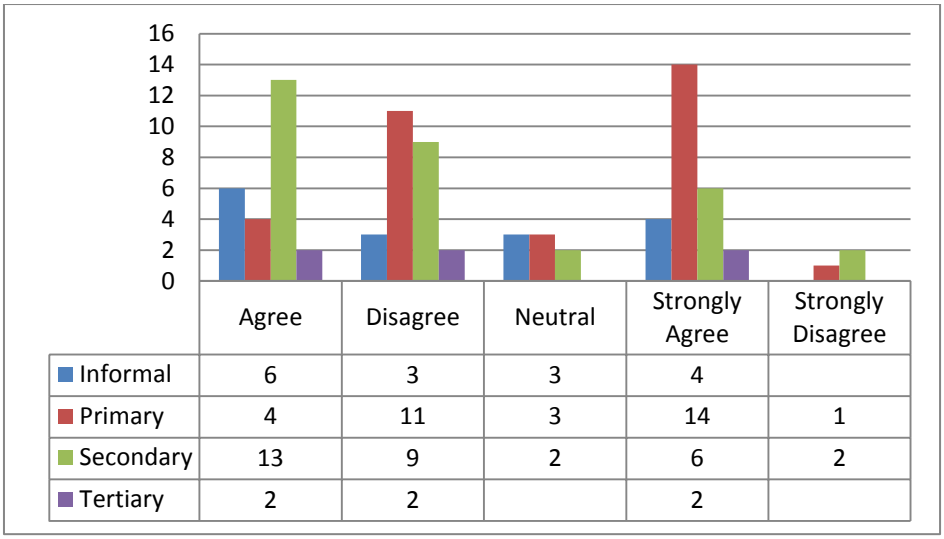


Figure4- 11: Public perception on availability of clear adaptation and coping strategies for the impacts of Mt. Kenya deglaciation based on respondents education level

4.4 Discussions

A Local perceptions finding has been discussed based on the four variables of the research study. Looking at the literature review of previous studies, it's crystal clear that climate change has had serious effects on wellbeing of residents of mountain ecosystem and those living downstream in terms of ecosystem services provision and livelihoods. Below are the discussions of data collected in the field.

4.4.1 Mount Kenya Glacier Reduction Trends

Public perception on Mt. Kenya Glacier Dynamics was a general perception analysis for all the three study areas. We sought to understand people's views on whether Mount Kenya glacier had decreased significantly since 1976-2016 and whether this deglaciation had been consistent within the said period. The findings showed that majority of the respondents had noticed Mount Kenya Glacier recession for the last 40years. This finding was similar to the outcome of Mount Kenya satellite imagery analysis which indicated a continuous reduction in glaciers from 1976 to 2016 indicating that in the year 1976, the glacier was at 1.862Km$^{2.}$, which then reduced to 1.269Km^2 by year 1987 and later rose to 1.735Km^2 by the year 1995 as a result of glacier accumulation due to high precipitation being experienced during the 10 year period. Later on year 2007 it had drastically dropped to 0.895Km^2 and by year 2016, it stood at 0.169Km^2

However, a slight perception difference was note; attributed to the fact that all glaciers were quite a distant away from many respondents' settlements below the mountain and also the

respondents rarely climbed up the mountain. If the assessment had initially focused on regular mountain climbers in the area including tour guides and porters, chances are the findings of the perception survey could have been different owing to their frequent interactions closely with the glacial zone especially when escorting local and international tourists.

This finding is similar to previous studies conducted by: (Hastenrath and Polzin 2004; Hastenrath 2005; Campbell 2008; Hastenrath 2010) on Mount Kenya glaciers which had revealed that high air temperatures (global warming) within Mount Kenya ecosystem had resulted to continuous glacier loss over the years. In addition, research conducted by (UNEP 2009) had revealed massive reduction in Mount Kenya glacier since 1970s, with the highest Ice loss around the turn of the century. (E. *Prinz 2011*)

The Mt Kenya deglaciation perception study also indicated an inconsistent deglaciation trends for the last 40years among the respondents. These findings echoed previous perception studies on deglaciation trends conducted elsewhere in particular the Peruvian Andes of South America as discussed by Mark *et al*. (2010) and Bury *et al*. (2011) whose outcome shows a similarity in both the public perception survey outcome and actual deglaciation trends. In addition, public perception survey conducted on the Andean Cordillera Blanca glacier in South America, yielded results similar to its actual glacier recession trend analysis (Mark *et al.* 2010, Bury *et al.* 2011, and Mark *et al.* 2017)

Elsewhere, glacial extent study by Klein and Kincaid (2007) on the Ruwenzori's mountains using a combination of satellite glacier imagery taken between year 1987 and 2006 confirmed that glacier had decreased almost by 50% (from 2.55 km^2 to 1.31$km^{2)}$. In addition, the analysis of Satellite images taken between 1995 and 2012 also indicated a declined glacier extent on this mountain's peaks .According to Kaser and Osmaston, (2002), These Mountains initially were covered with glaciers nearly 6.5 km^2 but since the late 19th century, they have retreated continuously with total deglaciation being experienced in some of its peaks.

The local perception responses on Mount Kenya deglaciation trends among respondents interviewed on the Nanyuki side were more accurate given that from Nanyuki side visualization of the mountain is clearer compared to the Naromoru side. This local perception difference coincides with the findings from previously done surveys. For instance, Byg and Salick (2009) conducted a perception survey in Eastern Tibet, reporting a public perception

difference among villages in regard to glacial retreat. These perception differences came as a result of nature of the areas landscape together with distance between villages and the mountain glaciers.

4.4.2 Glacier Recession and Climate change

From the findings from this survey, it was established that climate change had considerably affected Mount Kenya glaciers as depicted by the 83% of the interviewed respondents who clearly stated that weather and climate of their native land had changed tremendously as far as they could remember; a majority lamenting that temperatures today are quite higher than they used in 15 to 20 years ago. In addition, they were quick to say that weather had become unpredictable in that you hardly could tell the onset of short rains or long rains. Many respondents in Naromoru study area commented that approximately 15 to 20 years ago, you could hardly see Mount Kenya clearly, early in the morning since its surface was always covered with ice of which even increased during the rainy seasons. Today, Mount Kenya view is clearer in the morning since most of its ice had disappeared due to climate change with a significant section of its natural vegetation having been lost also owing to anthropogenic factors.

This finding also corresponds to previous studies by Campbell (2008) and Hastenrath (2010) on Mount. Kenya glaciers who noted that global warming had adversely affected the Lewis glacier resulting to its' decline from about 7.7 km^2 in 1978 to about 0.3 km^2 in 2004. A similar study within tropical ecosystem was conducted on Mount. Kilimanjaro revealing that the highest part of Kilimanjaro had lost approximately 85% of its glacier since 1912, (Brecher, Mosley-Thompson, 2009) and Ice bodies within this mountain had shrunk continuously from initial 20 km^2 in about 1880 to approximately 2.5 km^2 in 2003 due to global warming effects (Cullen *et al*. 2006).

4.4.3 Mount Kenya Glaciers and River flow

The local perception study findings indicated that majority of the respondents (69%) viewed Mt Kenya deglaciation as the root cause to reduced river flow downstream in their respective areas arguing that such rivers that originates from Mount Kenya close to 20years ago contained huge amount of water that was fast moving and one could hardly cross over neither could you see the river bed; a time in history when Mount Kenya summit contained a significant ice cover. Today such rivers have been reduced to small streams with bare rocks protruding along their channel.

This finding is similar to previously done studies by Viviroli *et al.* (2007) whom earlier had described mountains as world's water towers owing to numerous streams and rivers that they fed. Further, Khamis K *et al.* (2017), described mountain glaciers as reliable sources of fresh water feeding streams and rivers that serve communities far away from the mountain as well as regulating stream flow which is a critical role.

Mt. Kenya has been suffering massive glacier loss occasioned by increased air temperatures. Under normal circumstances, you would expect this to result to an increased river discharge downstream owing to abundance of melt water but on the contrary, according to local perception survey results, the river flow was declining downstream. This finding confirms a hydrological opinion that the rivers and streams source could be from the forested mountain belt and not the glacial belt. This finding could also be pointing out a local communities' misconception brought about by an increasing water demand as downstream population continues to grow whereby people are blinded and fail to notice an increased river discharge owing to the fact that more water is being abstracted from the river daily or at any other given time.

A similar misconception was witnessed in other perception surveys. Mark *et al.* (2010) had noted that although Peruvian Cordillera Blanca glacier recession had resulted to an increased river discharge downstream, communities' maintained an opinion that river flow and water availability was decreasing downstream. This could point out the need to consider actual hydrological studies as a way to differentiate societal opinions and science.

A research conducted and published by the standard newspaper dated 7th August 2018 gave more insight into what was ailing Mount Kenya Rivers. The argument being that despite heavy rainfall that was experienced within the mountain ecosystem, a number of rivers originating there were drying up; notably Rivers' Naromoru and Likii which drains into Ewaso Nyiro (***see Appendix IV***) of which were ironical drying up but few years back they existed as huge rivers. According to the newspaper reporter, deep inside Mount Kenya forest piping systems snake along the river banks diverting millions of litres of water to households and private farms. The water resources Authority (WRA) had issued many licenses allowing abstraction of water from rivers where more users were moving further inside the forest to abstract more. The community forest associations (CFA's) are to blame significantly since

they had been permitted to cultivate in the forest while taking care of the young trees. They excessively abstracted river water for horticultural farming in their private farms pretending to be watering the young trees and they had gone as far as connecting 10 inch pipes into their farms and this could be one of the causes of drying up of streams deep inside the forest.

4.4.4 Glacier Recession effects on Water supply and Livelihoods

Significant number of the respondents indicated that Mount Kenya glacier recession had adversely affected their livelihoods and those of their neighbours. In Naromoru study area, majority of small scale farmers interviewed stated that their income from the sale of horticultural crops had gone down drastically due to less irrigation activities due to a reduction in farm size under irrigation brought about by water scarcity. Many of the farmers abandoned high water consuming crops such as French beans and French peas of much demand in the market.

Significant number of pastoralists within lower Nanyuki study area confirmed loss of livelihoods due to water scarcity and reduced pasture. A good number of respondents failed to establish the direct connection between glacier recession, and loss of livelihoods due to the fact that they had never been to Mount Kenya for them to see the glaciers and more so from their place of residence, they couldn't view the Mountain clearly due to the undulating landscape comprising of many small hills and valleys. However, a majority confirmed that climate change had affected pastoralism (their main source of livelihood) severely, having caused pastures and water scarcity. The study findings also indicated that the communities living on Mt. Kenya's leeward side were aware of the ongoing deglaciation and how it caused river water supply changes downstream. This was similar to other previously done studies. For example, the local perceptions survey on glacier recession within the Bashy Range (4,800 m) of Tien Shan Mountains in Kyrgyzstan, Central Asia that differed among the respondents (Piersall & Halvorson 2014).

This survey finding echoes an earlier survey, conducted by UCD (2015) that reflected on irrigation agriculture in San Joaquin valley of which for many years it was highly extensive, but now it was diminishing due to reduced melt water flowage into the rivers. The cost of production had also gone up since farmers were drilling boreholes so as to get irrigation water. On the other hand in India, reduced river flow forced farmers to rely more on ground

water which was expensive to abstract hence negatively affecting their main source of livelihood which is small scale farming (Rasul 2010).

Within Nanyuki town, several respondents confirmed that their car wash, tree and flower nursery businesses along major roads had been affected negatively due to a reduced Likii river's flow. In addition, five women interviewed, who are residents of Likii village lamented that their income from clothes washing business had gone down since they were now buying water. Some jobless men also lamented that in absence of the tapped water from NAWASCO is not there, they turned to Likii River's water which they could sell to working class residents and hotels within Nanyuki town but due to current reduced water level, they are now counting losses. These findings corresponds to another study by Bangash *et al.* (2013) who stresses that climate change is capable of degrading ecosystems making them to lose their capability and efficiency in provision of ecosystem services.

4.4.5 Adaptation and Coping strategies for the effects of Glacier Recession

Human wellbeing and progress depend on better management of ecosystems thorough sustainable utilization and their conservation. However, as demand for ecosystem services increases, human action at times could hinder capability of such ecosystems to satisfy these demands. When coming up with adaptation and coping strategies, it's important to note that not all climate related stressors could be managed by the already in place mitigation and adaptation efforts (Warner and Van der Greest 2015).At times adaptation and coping strategies may be unsuccessful, insufficient or impossible to implement culminating to further losses and ecosystem damage (Warner and Van der Greest 2013). The success of any adaptation and coping strategy depends on various factors including: - technological, social, economic and political limits (Verheyen 2012).

The research findings established that the beneficiaries of Mt. Kenya do have a significant number of adaptation and coping strategies already in place .However, a few felt that such strategies could be lacking or they existed as just mere statements or policies that are yet to be implemented. A Kruskal Wallis hypothesis test conducted confirmed these. Some of the adaptation and coping strategies already in place are as follows: - the residents of Naibor sub location within Segera ward study area are already working together to control over abstraction of water from Likii River by farmers especially during droughts whereby they invade farmers who are irrigating along river riparian lands putting off water pumps as a way

of conserving water for their livestock. Other respondents confirmed that Indigenous tree planting program along the river banks was taking place although it hadn't been fully embraced by the locals. Priests from the local churches within Mugandura sub-location were working together with Non- governmental Organizations (NGO's) in holding workshops to sensitize the community on importance of embracing rain water harvesting and abstraction of water from a rock. They have gone as far as establishing several water points whose water is sourced from the rocks and also harvested from rain, then stored in plastic tanks for later distribution to the residents especially during droughts. However, high illiteracy levels among majority of the residents is hurting this noble program in that some residents destroyed the water tanks by piercing or cutting them using sharp objects, so as to allow their livestock to drink directly, thus wasting much of the reserved water.

Notably, many pastoralists had opted to change livestock type and reduce their stock size. For instance, majority choose to keep fewer cattle in favour of sheep and goats. In addition, a considerable number of pastoralists had abandoned the indigenous Red Maasai sheep and were now keeping exotic breeds such as dorper (Black headed sheep).

Perception differences based on Age and Education level come out clearly in regard to Mt. Kenya ecosystem beneficiaries having adaptation and coping strategies. A considerable number of respondents who had basic education (primary to secondary) were aware of presence of programs meant for community adaptation and coping with glacier recession effects.

However, respondents who had informal level of education had difficulties in comprehending the questions and equally answering them. The researcher had to translate the question to Swahili or local language for easier understanding.

CHAPTER FIVE: SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATION

5.1 Summary of the Findings

5.1.1 Mount Kenya Glacier dynamics

The study established that for the last 40years, Mt. Kenya glacier had reduced tremendously as confirmed by the public perceptions and Mt Kenya satellite imagery analysis. This is a true indication that indeed the impacts climate change are already manifesting themselves in East Africa and worst is yet to come. This study results mirror studies conducted by other researchers in the neighbouring glaciated mountains; Mt. Kilimanjaro in Tanzania and Mt. Ruwenzori's along Uganda- DRC border whose glaciers had also been diminishing. In addition, the study findings confirmed that the on-going Mt. Kenya glacier recession is as a result of climate change as indicated by 69 respondents (79%) interviewed.

5.1.2 Mt Kenya Glacier Recession trends and River flow

The study findings established that Mt. Kenya deglaciation had negatively affected the river flow in particular the Rivers' Likii and Naromoru of which 20years ago were huge and with plenty of water; at that time equally Mt. Kenya glaciers were more. Today, these rivers are just mere streams with little water trickling downstream. Furthermore, the study was able to establish that Mt. Kenya forests and other small forests such as Kabaru forest under the Mt. Kenya ecosystem had been seriously affected by human encroachment through vegetation clearance for horticultural farming and timber. It also came out clearly that although glacier recession had a critical role to play as far as drying up of rivers and reduced discharge downstream is concerned, uncontrolled abstraction from key streams within the watershed area was a critical concern that needed to be addressed as a matter of urgency since it had a role to play in the reduced Rivers' Naromoru and Likii discharge downstream.

5.1.3 Perceived implications of Glacier Recession on Water supply and livelihoods

The study findings established that key livelihoods had been affected by the on-going Mt. Kenya deglaciation. Small scale farmers in Naromoru had stopped irrigating some highly profitable crops that required plenty of water for their growth, with a number of small scale farmers reducing their irrigation farm size. Tension amongst small scale farmers with their pastoralist neighbours further downstream had increased, the latter claiming that the former were pumping more water into their farms thus creating water shortages further downstream.

The study also established that some livelihoods of residents of Nanyuki town had been tremendously affected. For example, car and carpet wash businesses which initially depended on water from River Likii provided for freely by Mother Nature. They were now forced to buy water from other vendors, thus diminishing their profits.

In Lower Nanyuki study area (Segera ward) the study findings established that pastoralism has been seriously affected as indicated by a significant number of pastoralists whom were contemplating shifting to rearing more sheep and goats, reducing the cattle herd or doing away with them all together, claiming that goats and sheep were easier to manage since they could survive in pasture and water scarce environments. Indeed such a move would bring huge losses to them since cattle generally could fetch good money in the market compared to goats and sheep. These problems of water and pasture scarcity, they were quick to mention could be attributed to climate change and diminishing River Likii, which was their main source of water for their livestock. To them, there is a shared blame between glacier recession and uncontrolled river water abstraction upstream. Kenya Horticultural Exporters (KHE) company name featured in much response; claiming that the said company was diverting large amounts of river water into their private farms

5.1.4 Glacier Recession and River water reduction adaptation and coping strategies

The study findings established that there existed adaptation and coping strategies which included: - Afforestation and Re-afforestation programs, Community control of river water abstraction by switching off farmers water pumps as a way to regulate scarce river water. In addition, pastoralists had reducing herd size, drilling of boreholes, rain water and rock water harvesting amongst other strategies were already in place. However, it came out clearly that Respondent's Age and level of education significantly influenced the public perception about availability of such adaptation and coping strategies.

5.2 Conclusions

The Mt Kenya glacial surface area analysis clearly indicated a progressive glacier loss within the study period (1976- 2016). Public perception analysis on glacier recession effects indicated that the communities within Mt Kenya recognized the ongoing shrinking of glacier but their views slightly differed according to age and education level. Public perception accuracy on glacial recession was affected by respondent's residence proximity and location in relation to the positioning of Mt Kenya's summit. In addition, weather conditions and vegetation obstruction also had an influence. Although the community perception didn't fully connect with actual glacier trend, all respondents had actually noticed Mount Kenya glacier recession.

In all the three study areas, Mount Kenya glaciers were best viewed from the pastoralist study zone (lower River Likii section) due to the nature of terain and its cloudless-ness nature almost throughout the year since its located near the middle of the leeward zone. Naromoru River zone had the most unclear view of the mountain glaciers due to the undulating landscape, cloudliness and thick forest cover. Plates (**4-8**) and (**4-9**) illustrates a scenic view of Mt. Kenya from both Naromoru and Nanyuki respectively.

Plate 4- 8: General view of Mount Kenya from Naromoru study site

Plate 4- 9: General view of Mt.Kenya from Nanyuki Town

Local community's perceptions and experiences within the study area were supported by the Mt Kenya satellite imagery analysis data, revealing that glacier recession brought about by climate change had negatively affected provision of clean water and sustenance of livelihoods, within the study area. Water for domestic use, agricultural use and for livestock had become a scarce resource. As observed, the river discharge in both Likii and Naromoru Rivers had gone down to levels that were disturbing, (as indicated on **plate 4- 6 and plate 4- 7)** and they now existed as small streams with stones and hollows clearly visible on their river bed of which originally were covered by water. This water scarcity had force many locals to look for alternatives as a way to adapt and cope with the situation. For example, small scale farmers were now changing their agricultural practices or abandoning agriculture all together as seen amongst many farmers who had stopped irrigating French beans, tomatoes and cabbages and opted to grow pigeon peas, capsicum and maize that are less water demanding. Pastoralists on the other hand had opted to reduce their herd size with others abandoning cattle rearing for goats and sheep.

Other adaptive and coping mechanisms already in place included rainwater and rock water harvesting and storage, regulating use of the available water, indigenous tree planting programs amongst others. In some areas boreholes and shallow wells had been dug so as to supplement the river water and piped metered water supplied by the County governments of Nyeri and Nanyuki.

What came out clearly was that erratic rainfall, reduced snow fall and ice accumulation together with prolonged drought were major setbacks brought about by climate change and

had negatively affected: small scale horticultural farming within Naromoru, water related small businesses in Nanyuki town and pastoralism within lower Nanyuki region which were major sources of livelihoods to the locals making them even more vulnerable to starvation and poverty due to livelihoods loss.

5.3 Recommendations

5.3.1 Policy Recommendations

a) The study recommends formulation of new environmental conservation policies both at National and county government that will foster sustainable use of Mount Kenya watershed resources especially the ones geared towards control of river and stream water abstraction. Already existing policies and regulations should be effectively enforced for the betterment of the entire ecosystem. In addition, policy on rain and rock water harvesting should be developed by the County Governments of both Nyeri and Laikipia so as ease pressure river water resources.

b) Harmonized policies on land use should be formulated especially in regard to agricultural activities, wildlife conservation and pastoralism as a way of curbing catchment degradation.

5.3.2 Management Recommendations

(a) Local water entities such as WARMA should be strengthened so as to reduce vulnerability and enhance adaptive capacity by the local communities.

(b) Climate change adaptation and coping need to be considered within a wider context both as a technical issue and on a developmental dimension. In addition incorporating climate change adaptations and coping strategies within the local planning process as a way of ensuring the poor households have better adaptive capacity.

(c) County governments in collaboration with the National government should lay down necessary infrastructure needed for increasing adaptive capacities of communities by increasing provision of agricultural services, livestock and crops insurance as a way of cushioning pastoralists and farmers against losses brought about by climate change.

(d) Formulate an integrated water resource management plan so as to enhance socio-economic development and ecological balance in water scarce basins through

effective management of catchment areas, construction of dams and pans in order to increase water storage capacity especially the surface run-off water during rainy season, rational apportionment of water resources so as to avoid water use conflicts and to minimize over abstractions of river water..

(e) There is need to identify water scarce and conflicts hotspots regions so as to set priorities on water development within the basin.

(f) There should be broad-based consensus on water use especially between the consumers downstream and the ecosystem protectors including local communities, KWS, WRA, KFS and NEMA.

5.4 Recommendations for Further Research

The study determined the effects of Mount Kenya glacier on water supply and livelihoods of downstream communities in both Nyeri and Laikipia counties. Thus it proposes further research to be done on effects of Mt Kenya glacier on water supply and livelihoods of upstream communities. Further the study recommends an analysis of Mount Kenya melt water dependency levels for both upstream and downstream communities and the effect on their wellbeing if such glaciers were to disappear completely.

In addition, further research is recommended on the contribution of: - glacial melt water run-off, precipitation run-off and ground water aquifer in recharging streams and rivers in Mount Kenya ecosystem so as to have an in-depth understanding of the main rivers from the source so as to know the right mitigation measures to undertake so as to protect the said rivers for todays and the future generations.

This study focused on effects of glacier recession on water provisioning ecosystem service. Further research is recommended on effects of glacier recession on cultural ecosystem service with a bias on aesthetic and spiritual value of Mount Kenya; guided by (Acar *et al* 2006); (Scirpke *et al* 2013) whom had stated ” Glaciated mountains are highly appreciated for their aesthetic value”

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APPENDICES

Appendix I: Questionnaire

UNIVERSITY OF NAIROBI

COLLEGE OF HUMANITIES AND SOCIAL SCIENCES

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

MASTER OF ARTS IN BIODIVERSITY AND NATURAL RESOURCES MANAGEMENT

INTRODUCTION

Hello, my name is **MOSES NDARUA NJOKI**; I am undertaking research as part of Master in Arts degree in BIODIVERSITY AND NATURAL RESOURCES MANAGEMENT.

The purpose of this questionnaire is to generate information for my study entitled:-

"THE EFFECTS OF MOUNT KENYA GLACIER RECESSION ON WATER SUPPLY AND LIVELIHOODS- A CASE STUDY IN NYERI AND LAIKIPIA COUNTIES, KENYA"

The information you will disclose in this questionnaire will be strictly confidential and shall be used only for the purpose of this research.

PART I

Respondents Profile (Tick Consumer/Producer)

A. Naromoru ……. ☐

B. Nanyuki Town

(Upper Likii river region)…… ☐

C. Nanyuki Area

(Lower Likii river region)…… ☐

1. **RESPONDENT NO:-……**

2. **GPS READING: - ……..**

3. **Age of the respondent**
   - 25- 34 ☐
   - 35- 44 ☐
   - 45 – 54 ☐
   - 55 – 64 ☐
   - 64 or older ☐

4. **Level of education**
   - Informal ☐
   - Primary ☐
   - Secondary ☐
   - Tertiary ☐

5. **Gender** : Male ☐ Female ☐

6. Occupation……

7. Irrigation farm size (River based Irrigation Zone) Naromoru. ……

8. House hold size ……

9. Types of irrigation crops……

10. Herd size……..

11. Type of livestock…….

PART II

On a scale of 1-5 where 1 mean strongly disagree and 5 means strongly agree, please indicate the level to which you agree with the following statements. [CIRCLE THE NUMBERS]

GENERAL PERCEPTION OF MOUNT KENYA GLACIER REDUCTION – FOR ALL RESPONDENTS

Questions		**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
12	**Mount Kenya glacier has decreased significantly in the last 40 years (1977-2017)**	1	2	3	4	5
13	**The glacier reduction has not been consistent in the 40 years**	1	2	3	4	5
14	**The reduction in Mount Kenya glacier is due to climate change**	1	2	3	4	5

PART III

Naromoru Study area

Public perception on Mount Kenya glacier reduction and riverine irrigation

Questions		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
15	**Mount Kenya glacier has led to the declining flow in Naromoru River**	1	2	3	4	5
16	**Mount Kenya glacier reduction and declining river flow has led to a reduction in household irrigation area over the years**	1	2	3	4	5
17	**Mount Kenya glacier reduction and declining river flow has led to a reduction in the variety of irrigation crops over the years**	1	2	3	4	5
18	**Mount Kenya glacier reduction and declining river flow has led to a reduction in level of profit from irrigation activities over the years**	1	2	3	4	5

19	**Mount Kenya glacier reduction and declining river flow has led to loss of livelihoods for people over the years and resulted to increased crime**	1	2	3	4	5
20	**Mount Kenya glacier reduction and declining river flow has led to increased tension among the river water users over the years**	1	2	3	4	5
21	**Mount Kenya glacier reduction and declining river flow has led to increased human-wildlife conflicts over the years**	1	2	3	4	5
22	**The river users do not have clear adaptation and coping mechanisms for the impacts of declining glaciers in Mount Kenya**	1	2	3	4	5

PART IV – Nanyuki Town Study area

Public perception on Mount Kenya glacier reduction and Domestic water use

Questions		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
23	**Mount Kenya glacier reduction has led to the declining flow in Likii River thus affecting urban water use**	1	2	3	4	5
24	**Mount Kenya glacier reduction and declining river flow has led to a reduction in available river water over the years**	1	2	3	4	5
25	**Mount Kenya glacier reduction and declining river flow has led to increased public health problems over the years**	1	2	3	4	5
26	**Mount Kenya glacier reduction and declining river flow has led to loss of livelihoods for people over the years and resulted to increased crime**	1	2	3	4	5

27	**Mount Kenya glacier reduction and declining river flow has led to increased tension among the river water users over the years**	1	2	3	4	5
28	**Mount Kenya glacier reduction and declining river flow has led to increased human-wildlife conflicts over the years**	1	2	3	4	5
29	**The river users do not have clear adaptation and coping mechanisms for the impacts of declining glaciers in Mount Kenya**	1	2	3	4	5

PART V – <u>Below Nanyuki Town</u> (LOWER LIKII RIVER STUDY AREA**)**

<u>Public perception on Mount Kenya glacier reduction and livestock water use</u>

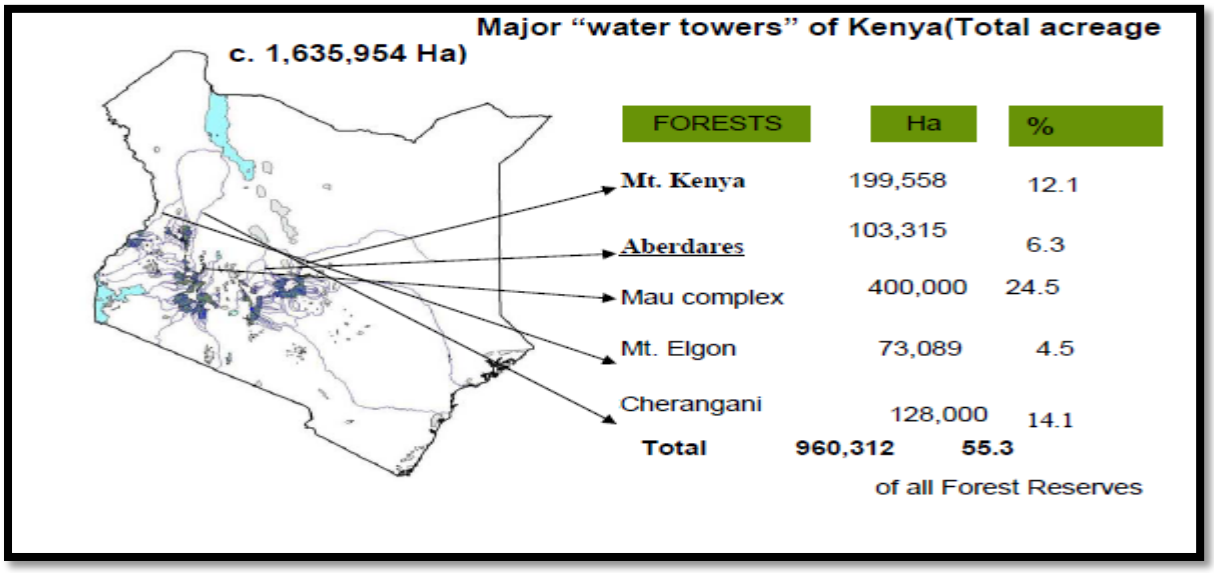
Questions		**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
30	**Mount Kenya glacier has led to the declining flow in Likii River**	1	2	3	4	5

31	**Mount Kenya glacier reduction and declining river flow has led to a reduction in livestock herd size over the years**	1	2	3	4	5
32	**Mount Kenya glacier reduction and declining river flow has led to a reduction in the variety of livestock over the years**	1	2	3	4	5
33	**Mount Kenya glacier reduction and declining river flow has led to a reduction in level of profit from livestock keeping over the years**	1	2	3	4	5
34	**Mount Kenya glacier reduction and declining river flow has led to loss of livelihoods for people over the years and resulted to increased crime**	1	2	3	4	5
35	**Mount Kenya glacier reduction and declining river flow**	1	2	3	4	5

	has led to increased tension among the river water users over the years					
36	**Mount Kenya glacier reduction and declining river flow has led to increased human-wildlife conflicts over the years**	1	2	3	4	5
37	**The river users do not have clear adaptation and coping mechanisms for the impacts of declining glaciers in Mount Kenya**	1	2	3	4	5

THANK YOU

Appendix II: Kenya's major Water Towers



Source: Author

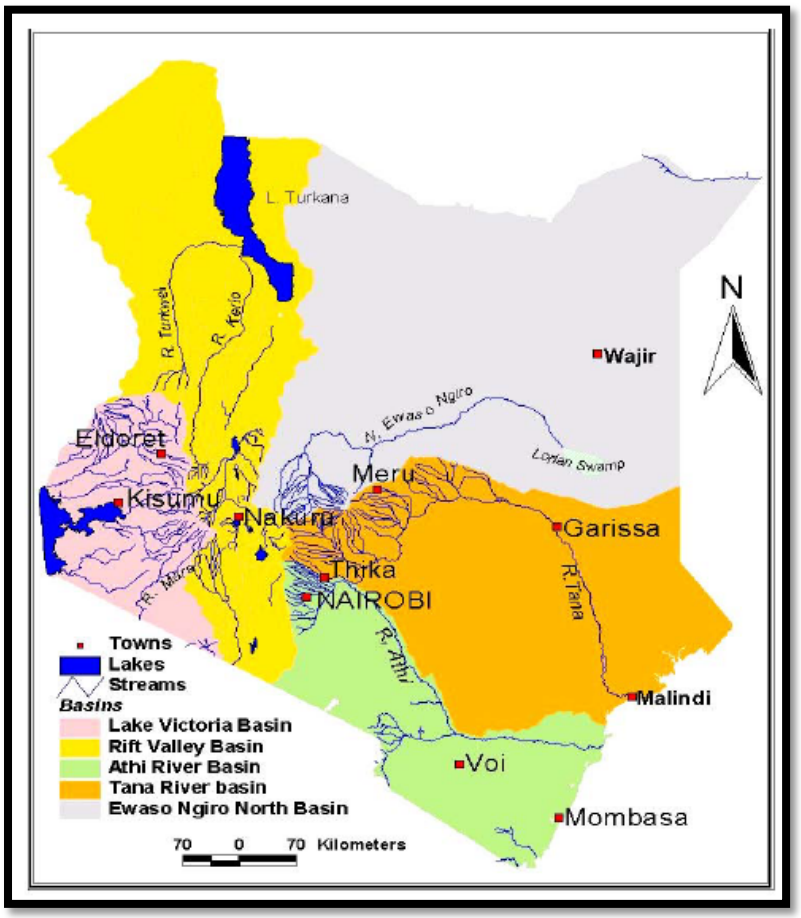
Appendix III: A Timeline for Major Global initiatives and mountain relevant policies from 1981-2015

Policy / Initiative	*Year*	*Details*
Mountain Research and Development	**1981**	Created by the International mountain society, mandated to promote sustainable development in mountains through research, policy and dialogue and strengthening mountain communities.
Rio Earth summit (UN-Conference on Environment and Development	**1992**	Agenda 21 [plan for Action]- How to manage fragile ecosystem Convention on Biological diversity and UN Framework convention on climate change particularly touching on mountain areas.
Mountain forum	**1995**	Meant to promote mutual support, sharing of information and advocacy for mountain people and environment.
World Mountain People Association (WMPA)	**2000**	Started after the world mountain forum. Brought together 900participants from 70 countries Meant for mountain people to air their voices and make their desires known to the rest of world.
Mountain Research Institute (MRI)	**2001**	Promotes and coordinates global changes research within mountain regions. Aimed at detecting changes and their possible impacts on

		ecosystems; advocating for sustainable resource management.
International Year of Mountains (IYM)	**2002**	Passed through resolution in 1998 UN-General assembly as a way of ensuring the wellbeing of mountain and lowland communities through advocating for conservation and sustainable development.
The Bishkek Mountains Summit	**2002**	Followed IYM closely, it provided a framework for stakeholders and other to contribute in sustainable development within the worlds Mountains so as to improve the livelihoods of their residents and to protect the mountain ecosystem. Formed after the 2002 UN-General Assembly resolution.
Mountain partnership	**2002**	UN voluntary alliance of partners, meant to improve the lives of mountain people and to protect the mountain ecosystems around the world.
Global change in Mountain regions (GLOCHAMORE)	**2003**	It was an international project for research and exchange of knowledge on mountain changes globally.
Millennium Ecosystem Assessment (MEAs)	**2005**	Chapter 24 of 'Ecosystem and Human wellbeing' current state and trends – considers mountain systems.
Rio +20 Earth Summit	**2012**	Paragraphs 210-212 of the final document, "The future we want" particularly concerns mountains.
2030 Agenda for Sustainable Development	**2015**	Sustainable Development Goals (SDGs) Goal 6 and 15 particularly refer to mountains.

Source: Adopted from Kohler, T. *et al*, (eds) 2015.

Appendix IV: Kenya Drainage systems



Source: Google Scholar

Appendix V: Fieldwork Photography

a) Naromoru study Area

Plate1: River Naromoru which has declined in water level, on the other hand Small scale Irrigation within Naromoru study area has been negatively by ongoing water rationing by WARMA

b) Nanyuki Town (Likii Village) study area

Plate 2: Children drawing water from the Likii River On the other hand a Likii village resident washing clothes on the river banks

c) Lower Nanyuki Region

Plate 3: Severe drought during our time of study which had adversely affected livestock and drastically reducing water in River Likii

Appendix V: NACOSTI Research Permit

THIS IS TO CERTIFY THAT:
MR. MOSES NDARUA NJOKI
of UNIVERSITY OF NAROBI, 1712-902
KIKUYU,has been permitted to conduct
research in *Laikipia , Nyeri Counties*

on the topic: *IMPACTS OF MOUNT KENYA GLACIER REDUCTION TRENDS ON ECOSYSTEM WATERSHED SERVICES AND LIVELIHOOD-AN ASSESSMENT OF PUBLIC PERCEPTION, NYERI AND LAIKIPIA COUNTIES, KENYA*

for the period ending:
3rd August,2018

Permit No : NACOSTI/P/17/74840/18504
Date Of Issue : 3rd August,2017
Fee Recieved :Ksh 1000

.....
Applicant's Signature

.....
Director General
National Commission for Science, Technology & Innovation