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INTEGRATING CLIMATE CHANGE AND ADAPTATION PROCESSES INTO HYDROPOWER DEVELOPMENT IN SONDU MIRIU RIVER BASIN IN KENYA UNDER CHANGING CLIMATE

BY

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Abstract

The hydropower production from the two-existing run-of-river hydropower projects on the Sondu Miriu river are vulnerable to rainfall variability and requires proper understanding of the climate change trends and policies to support sustainable hydropower development and put in place strategies for building resilience for the local communities. The four specific objectives included examining climate change trends and their impacts on hydropower; examining the impacts of both the climate change and the hydropower development projects on the livelihoods of the community living within the basin; identifying appropriate and sustainable strategies for integrating climate change adaptation into hydropower development; and finally reviewing and identifying appropriate policy options for integrating climate change adaptation into hydropower development within the Sondu Miriu river basin. The methodology involved analysis of downscaled climate data from Coordinated Regional Climate Downscaling Experiment (CORDEX) for the period from 1950 to 2100, gridded data from Kenya Meteorological department for a period from 2007 to 2018, river flows data from Water Resources Authority for a period from 2007 to 2018 and hydropower output data from KenGen for a period from 2007 to 2018 to examine the climate change trends within the Sondu Miriu River basin and impacts on hydrology and hydropower. Participatory methodologies involving administration of questionnaires at household level and focus group discussions with the local leaders and actors were applied to determine the impacts of climate change and the hydropower development on the community livelihoods within the Sondu Miriu River basin. Review of existing climate change adaptation strategies and policies were carried out to identify appropriate strategies and policy options for integrating climate change adaptation in hydropower developments within the Sondu Miriu river basin. The results indicated that maximum and minimum annual temperature increased by 0.7ºC and 0.9ºC respectively between 1950 and 2005. Temperatures are projected to increase by 1.89^0C and 1.85^0C for minimum and maximum temperatures respectively based on the Representative Concentration Pathway of $4.5Wm^{-2}$ (RCP4.5) and by 4.67^0C and 4.47^0C for minimum and maximum temperatures, respectively based on Concentration Pathway of $8.5Wm^{-2}$ (RCP8.5) scenarios between 2006 and 2100 within the Sondu Miriu basin. Annual rainfall increased by 74.8 mm between 1950 and 2005. This is projected to increase by 24.7 mm and 117.8 mm based on RCP4.5 and RCP8.5 scenarios, respectively. For the period between 2007 and 2018, the observed maximum increased by 5^0C while the minimum temperatures decreased by 1^0C. The rainfall decreased by 193.14mm while the mean daily river flows decreased by 0.3 m^3/sec annually during the same period. This resulted in the decrease of hydropower production by 8.3 GWh in Sondu Miriu Hydropower project (HPP) between 2007 and 2018 while the production reduced by 14.18 GWh for Sang'oro HPP between 2012 and 2018. The socioeconomic status of the basin indicates that majority of the households (>59%) are poor and earn below 8 US dollars per day. The employment rate is extremely low with only 22% in formal employment. About 49% of the households still use wood fuel and charcoal as energy sources which is a threat to catchment conservation. Various climate change adaptation actions have been outlined in the National and County adaptation plans with no clear strategies for implementation within the basin. A framework for appropriate adaptation strategies is therefore needed for implementing the outlined adaptation actions at local level within the basin. There exist adequate policies at the national level and County Integrated Development Plans for integration of climate change adaptation into hydropower development with Climate Change Act of 2016 creating a linkage with other existing policies for effective policy support within the Sondu Miriu River basin.

Keywords: Climate change, Adaptation strategies, Hydropower development, Sondu Miriu River basin.

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List of Abbreviations and Acronyms

ADB	-	Asian Development Bank
ADBI	-	Asian Development Bank Institute
AMCEN	-	African Ministerial Conference on the Environment
AMIP	-	Atmospheric Model Intercomparison Project.
AKP	-	Adaptation Knowledge Platform
CBOs	-	community based organizations.
CCCAPs	-	County Climate Change Action Plans
CCCMA	-	Canadian Climate Change Modelling and Analysis.
CDM	-	Clean Development Mechanism.
CFCs	-	Chlorofluorocarbons.
CG	-	County Government.
CIDPs	-	County Integrated Development Plans.
CMIP1-3	-	Coupled Model Intercomparison Project Phase 1 to 3.
CMIP5	-	Coupled Model Intercomparison Project Phase 5.
CNRM	-	National Centre for Meteorological Research.
CO_2	-	Carbon dioxide.
CORDEX	-	Coordinated regional climate downscaling experiment.
CSR	-	corporate social responsibility.
DFIs	-	Development Finance Institutions.
EAC	-	East African Community.
EMCA	-	Environmental Management and Coordination Act.
ESMs	-	Earth System Models.
FEWSNET	-	Famine Early Warning Systems Network.
GCM	-	Global Circulation Model.
GESIP	-	Green Economy Strategy and Implementation Plan.
GHG	-	Greenhouse Gas.
GWh	-	Gigawatt hours
HPP	-	Hydropower project.
IEA	-	International Energy Agency.

IFRC	-	International Federation of Red Cross and Red Crescent Societies.
ILRI	-	International Livestock Research Institute.
IPCC	-	Intergovernmental panel on climate change.
ITCZ	-	inter-tropical convergence zone.
JJAS	-	June-July-August-September.
KALRO	-	Kenya Agricultural and Livestock Research Organization.
KCSAS	-	Kenya Climate Smart Agriculture Strategy.
KEFRI	-	Kenya Forestry Research Institute.
KEMRI	-	Kenya Medical Research Institute.
KenGen	-	Kenya Electricity Generating Company.
KFS	-	Kenya Forestry Services.
KMD	-	Kenya Meteorological Department.
KNBS	-	Kenya National Bureau of Statistics.
Ksh	-	Kenya shillings
LBDA	-	Lake Basin Development Authority.
LVB	-	Lake Victoria Basin
LVBC	-	Lake Victoria Basin Commission.
LVEMP	-	Lake Victoria Environmental Management Programme.
MAM	-	March-April-May.
MIROC	-	Model for Interdisciplinary Research on Climate.
MPI	-	Max Planck Institute for Meteorology.
MTPs	-	Medium-Term Plans.
MW	-	megawatt.
NAP	-	National Adaptation Plan.
NAPA	-	National Adaptation Programmes of Action
NCCAP	-	National Climate Change Action Plan.
NCCRS	-	National Climate Change Response Strategy.
NCCS	-	National Climate Change Secretariat.
NDC	-	Nationally Determined Contributions.
NEMA	-	National Environment Management Authority.

NETFUND	-	National Environment Trust Fund.
NGO	-	Non-governmental organization.
NOAA	-	National Oceanic Atmospheric Observations.
NPBM	-	national performance and benefit measurement.
PRECIS	-	Providing Regional Climates for Impacts Studies.
RCD	-	Regional climate downscaling.
RCM	-	Regional Climate Model.
RCPs	-	Representative Concentration Pathways.
RoR	-	Run-of-river.
SDGs	-	sustainable development goals.
OND	-	October-November-December.
UN	-	United Nations.
UNFCCC	-	United Nations Framework Convention on Climate Change.
US	-	United States
USD	-	United States Dollars
WCD	-	World Commission of Dams.
Wm^{-2}	-	Watts per square metre.
WMO	-	World Meteorological Organization
WRA	-	Water Resources Authority.
WRA-LVS	-	Water Resources Authority's Lake Victoria South.

CHAPTER ONE

INTRODUCTION

1.1 Background

Substantial temperature rise in the twenty first century is projected as a result of the projected increase of greenhouse gases (GHGs) concentration levels (Hamududu and Killingtveit, 2012; Kumar *et al.,* 2011; Milly *et al*., 2005). Through scientific consensus, the mean temperature is projected to increase globally by the close of twenty first century by approximately 3^0C attributed to the current population and economic growth rates. This temperature rise is expected to be accompanied by increased precipitation levels globally by approximately 15% increase (Kumar *et al.,* 2011; Milly *et al*., 2005). The future global precipitation will affect run-off characteristics and therefore influencing water resources availability (Hamududu and Killingtveit, 2012; Milly *et al*., 2005). Climate change particularly associated with reduction of rainfall, shortening of rainfall seasons, delayed rainfall onset, increased drought events and rising temperatures are locally perceived to be the main drivers of some changes such as continuous increase in rivers and streams seasonality and progressive reduction in water flows (Kangalewa, 2017).

Kusakabe in 2005 recommended that climate change adaptation integration into hydropower development is very critical and it is always easier to begin with the application of existing policies and practices instead of coming up with new ones. Integration can bring about money saving through efficient use of the available resources, instead of creating separate entities and processes to support climate change adaptation. This can also assist in harmonization of the conflicting policies. The concept of integration is gaining pace to pool all the resources together for the maximization of the benefits. The experiences from the on-going integration of climate change adaptation programmes can present useful lessons that can be learnt for adaptation efforts. Many barriers for climate change adaptation integration have been identified to include among others lacking political commitment and active meaningful participation including institutional persistent practices that continuously ignore climate change impacts (Kusakabe, 2005).

Adaptation Knowledge Platform (AKP) in 2010 noted that climate change could substantially affect hydropower development through the threat to critical resources, such as water, and increased frequency of occurrence and natural disasters severity. The slowing of global warming and reduction of greenhouse gas emissions are very essential given the urgency of the prevailing problem. It has been recognized more recently that some climate change impacts are now unavoidable leading to growing campaigns for adaptation actions for effective response to threats of climate change by minimizing the impacts on both the ecosystem and people as both the people and ecosystems are vitally important (AKP, 2010). Climate change adaptation actions entail adjustments of ecological systems or social systems as a response to minimizing possible climate change damages. Even though adaptation actions are unable to fully eliminate the adverse climate change impacts completely (Füssel, 2007), there is possibility of decreasing the impacts while taking the advantage of opportunities that have been created in achieving positive outcomes. It should also be noted that, not all are equally well prepared for adaptation to the impacts of climate change due to the significant variations in adaptive capacity that depend on several variables including resource availability, prevailing socio and economic conditions, and governance status.

Füssel in 2007 suggested that the efforts for climate change adaptation need to focus more on building adaptive capacities or transformation of these capacities into specific actions for adaptation to climate change. Strengthening of ecological and social systems and nurturing these systems to improve the resilience is among the critical components of climate change adaptation. The other component requires investments in innovative ways with the potential of transforming socio-ecological systems along pathways that are more sustainable. Whereas some of the threats due to climate change might be new, like exceptional climatic situations, most of the climate change adaptation initiatives are built on long-term efforts, such as reducing the risk of disasters (Füssel, 2007). Therefore, it is evident that adaptation can potentially be aligned closely with major development objectives nationally and locally (Klein, *et al.,* 2005; Schipper, 2007; Schipper, *et al.,* 2008). Therefore, there is an urgent need for putting in place appropriate water resources management strategies for ensuring sustainability of the community livelihoods and environment especially in the context of changing climate (Kangalewa, 2017).

Agrawala in 2004, and Srinivasan and Uchida in 2008 concluded that climate change adaptation integration into the development of hydropower is expected to offer several benefits such as minimizing conflicts of policies, reduction of vulnerability and risks, better effectiveness as opposed to climate change adaptation management in isolation separately, and having more influence on the financial cash flows in various sectoral activities being impacted on by climate hazards compared to the finances that might be made available to finance adaptation actions separately (Agrawala, 2004; Srinivasan and Uchida, 2008). Policies on adaptation to climate change are required for the facilitation of the development and implementation of specific and detailed response options to be included in the already existing sectoral policies in place (Dovers, 2009; Klein *et al*., 2005).

There is already consensus that water resources availability is expected to be affected globally, regionally, and locally by climate change (Milly *et al*., 2005). The changes in characteristics of the river flow particularly in timing and quantity usually accompanied by increased reservoirs water losses through evaporation have higher chances to negatively impact on the hydropower generation. The Eastern African countries except Ethiopia are anticipated to have increase in hydropower generation by 2050 (Hamududu and Killingtveit, 2012). There is expectation of a lot of impacts of climate change on hydropower system operations as well as on the local communities neighbouring the hydropower projects (Harrison *et al.,* 1998). Run-of-river hydropower projects are vulnerable and sensitive to the impacts of climate change such as floods and droughts.

Countries all over the world have made hydropower development a priority for implementing of adaptation measures against the climate change impacts since 2008 (Corsi *et al*., 2012). While there have been few plans for adaptation measures against climate change impacts with a regional focus particularly in Africa (Niang *et al*., 2014), there is more potential to plan for already recognized climate change adaptation measures so far (UNFCCC, 2007; Sonwa *et al.,* 2009; Niang, 2012). The interest in identification of the opportunities that are essential for adaptation needs in Africa is increasing including presenting key success factors for adaptation. Klein *et al*. (2014) identified the opportunities such as awareness raising, capacity building, analysis tools, policy, learning and innovation that are suitable in implementation of adaptation measures during hydropower development process that are simple low regrets and relatively low cost in reducing communities' vulnerability to the prevailing climate variability, with several associated benefits from hydropower projects that in the long term are able to reduce vulnerability to climate change (UNFCCC, 2007; Conway and Schipper, 2011; Niang *et al*., 2014).

Hydropower generation is dependent on the water resources availability. Water resources availability is regulated by the prevailing climatic conditions in the location of the hydropower project, especially the drainage basin for the Hydropower project. The first step for integrating climate change adaptation into the development of hydropower is to understand climate change trends in the area for both historical and the projected climate change scenarios.

Hydropower constitutes about 38% of the installed electricity generation capacity in Kenya. with Sondu-Miriu and Sang'oro hydropower schemes being the most recent to be developed (Kenya Power, 2018). The schemes within the Sondu-Miriu River basin, therefore, offers an opportunity as a case study to learn lessons on integrating climate change adaptation into hydropower developments that results in socioeconomic, environmental, and technical sustainability. As there is still existing potential within Sondu Miriu river basin, this can give guidelines on how to develop future hydropower projects with climate change adaptation fully integrated. Opportunity exists in responding to climate change and awareness enhancement that maintains ecosystem functioning for supporting livelihood and development fundamentally (Shackleton and Shackleton, 2012), and able to motivate new development trajectories (Niang *et al*., 2014).

Hydropower offers a unique opportunity as a renewable energy for supporting social and economic developments locally. This is in the form of actions and strategies for climate change adaptation. Therefore, identifying these opportunities and harnessing them is important in forming part of the climate change adaptation integration activities for into hydropower developments. This is expected to have a major contribution towards the enhancement of the climate change resilience locally among local communities where implementation of these projects is taking place (Kumar *et al*., 2011).

1.2 Problem statement

Sondu Miriu River basin has potential for hydropower development for future development estimated at over 300MW (Koei 2013; Theuri 2015). Currently the basin hosts two run-of-river hydropower projects namely Sondu Miriu and Sang'oro hydropower schemes with installed capacity of 60 megawatts and 21 megawatts, respectively (KenGen, 2018). The design life for a hydropower infrastructure is usually long to the range of 100 years or even more and economic design life of 60 years (Kumar *et al*., 2011). For this reason, consideration of climate change and unique impacts associated with such projects both at planning and operational phases is critical.

The Sondu Miriu river basin that hosts the two run-of-river hydropower projects have got higher chances of encountering challenges associated with future climate change and climate variation. Understanding the projected hydrological trends with possible impacts on the hydropower generation sustainability is needed urgently, which should also be considered and planned for in formulating and customizing the current existing policies as well as appropriate adaptation measures that can support the hydropower development (Zhong *et al.,* 2019). Renewable energy projects such as hydropower are always considered environmentally friendly with negligible greenhouse gases production (Li *et al*., 2019). Nevertheless, the use of various structural and non-structural actions is still needed for the management of impacts of climate change on hydropower projects. Appropriate management and operational strategies for hydropower projects, relating to the future hydroclimate, are essential for adapting or addressing the challenges that may be faced in the management of hydropower (Zhou and Guo, 2013). Nevertheless, the non-structural measures to tackle anticipated climate change impacts may not be sufficient. Therefore, structural measures including modification of canals, tunnels, spillways, number of turbines besides construction and reservoir size customization are made essential for environmental safety for the population relying on hydropower projects (Haguma *et al*., 2017). Appropriate policy options are key in supporting the adaptation integration into the development of hydropower projects within the river basin and therefore need to be given priority.

It is therefore critical to study and identify the specific existing climate change trends within the Sondu Miriu river basin and understand the impact of these trends on hydropower development.

In addition, the impact of climate change and hydropower development projects on the communities' livelihoods within the basin also need to be understood in order to come up with strategies and identify supporting policies for appropriate adaptation actions. Currently, the existing implementation frameworks in Kenya do not compel the development agencies in the hydropower sector to integrate adaptation measures into the development plans for hydropower while adaptation has been considered as an essential element in terms of sustainable development (Moomaw *et al*., 2011). Poor integration of local adaptation needs and appropriate actions into hydropower development processes puts the existing and future hydropower projects within Sondu Miriu River basin at risk of failing to meet their set medium and long-term objectives while compromising the resilience of local communities to cope with the impacts of climate change.

1.3 Research questions

The research questions for this study included:

1. Is there evidence that climate is changing within Sondu Miriu river basin?
2. How does the projected scenarios for climate change most likely to affect existing and the future hydropower projects?
3. What impacts do climate change and development of hydropower projects have on the livelihoods of local community in Sondu Miriu basin?
4. What strategies for climate change adaptation integration are in place in Sondu Miriu basin for the development hydropower?
5. What climate change policies exist for hydropower developments and how can they be made to enhance adaptation strategies within Sondu-Miriu River basin?

1.4 Objectives

The main objective of the study was to examine the integration of climate change adaptation processes into hydropower development with a case study of run of rivers (RORs) hydropower projects in Sondu-Miriu River basin.

The specific objectives included to.

1. Examine climate change trends in Sondu Miriu River basin from 1950 to 2100.
2. Evaluate the impacts of climate change trends on the generation of hydropower in the two-existing run-of-river hydropower projects.
3. Determine the impacts climate change and hydropower development have on the livelihoods of the local communities living within the Sondu Miriu River basin.
4. Identify appropriate and sustainable strategies for climate change adaptation during the development hydropower in Sondu Miriu basin.
5. Review and identify appropriate policy options for the integration of adaptation into the development of hydropower in Sondu Miriu basin.

1.5 Justification and significance of study

For many locations globally the volume and timing of runoff are already changing as well as the precipitation amount (Hamududu and Killingtveit, 2012; Milly *et al.*, 2005). Ignoring the best available climate change information in planning of hydropower is most likely in the long term to prove costly to society (Cherry *et al.*, 2017). The hydropower production from the two-existing run-of-river hydropower projects in Sondu Miriu basin are at risk because of rainfall variability and requires good understanding and knowledge of climate change trends and policies to support sustainable hydropower development and put in place strategies for building resilience for the local communities.

1.5.1 Electricity Generation Expansion in Kenya

The current drive to expand electricity generation is largely driven by renewable energy in Kenya (Government of Kenya, 2019). Among the renewable energy technologies, only hydropower can provide both peak load and base load electricity supply for the peak demand which is ever growing. A hydropower project which is well-designed can strongly drive socioeconomic development only if the sharing of benefit is adequately addressed (Kumar *et al.*, 2011). Integrating adaptation into the development of hydropower is, hence, expected to make a major contribution towards reduction of vulnerability of the environmental and local community to climate change impacts. Therefore, electricity generation expansion within Sondu Miriu river basin should be in line with the projected climate change and climate variation for sustainability.

1.5.2 Development Goals

Sustainable Development Goal (SDG) No. 7 of the United Nations advocates for having access to reliable, modern, sustainable, and affordable energy for all. Globally, it targets to substantially increase, in the energy mix, the share of renewable energy by 2030. This also requires the use of clean energy technology (Desa, U.N, 2016). Among the available renewable technologies, hydropower can contribute majorly toward achieving this goal and by integrating climate change adaptation makes it even more resilient. Implementing this in Sondu Miriu river basin which is majorly rural will increase the access to modern, sustainable, reliable, and affordable energy for rural population, a contribution to Kenya Vision 2030, through more energy at a lower level (Government of the Republic of Kenya, 2007).

In the electricity generation mix for Kenya, hydropower plays a major role which is pivotal in delivery on the Big Four Agenda between 2017 and 2022, which targets manufacturing, affordable housing, food security, and affordable healthcare for all. Kenya government, having recognised the importance of carbon emissions reduction, has committed to support expanding the role of renewable energy in the country's total electricity generation installed capacity. Therefore, in terms of development goals, integration of adaptation actions into hydropower projects within the Sondu Miriu River basin will support the achievement of the development goals at the local level.

1.5.3 Hydropower and climate change

Climate change and hydropower are double related. Hydropower being an important renewable energy resource significantly contributes to reduction of GHG emissions as well as mitigation of global warming while climate change is expected to determine hydropower generation by altering river discharge and resulting into affecting water availability and water regularity (Berga, 2016). Hydropower offers to the local communities an opportunity to contribute to their socioeconomic development. It provides climate change mitigation, safe energy supply, clean energy access, and improvement of health and environmental status. Modern energy services access provision supports the Millennium Development Goals achievement (IPCC, 2011). Lack of climate change adaptation integration into the development of hydropower may lead to an increase in susceptibility of the local communities to the impacts of climate change as well as advancing the larger regional environmental and socioeconomic conditions. The renewable energy technologies' demand is currently growing globally. Among the key leading factors behind this growth towards addressing the root causes of greenhouse gas emissions is climate change mitigation. Besides the Greenhouse Gas (GHG) emissions reduction, other benefits offered by renewable energy technologies include good health conditions and air quality because of no/low pollution compared to the fossil fuels usage (Moomaw *et al*., 2011). It is therefore important to embrace the integration of climate change adaptation actions into hydropower development within the Sondu Miriu river basin to enhance community resilience locally.

1.5.4 Building Community resilience for climate change adaptation

Some of the benefits local communities usually associate with hydropower development are infrastructure developed by the project as Corporate Social Responsibility (CSR) with no linkage to any climate change adaptation measures. Climate change adaptation measures are always reactive or anticipatory in climate change response. Renewable energy technologies are very capable of supporting anticipatory adaptation actions or programmes in a sustainable manner (Klein *et al*., 2007). Dams for hydropower generation can be useful in the management of the impacts caused by the meteorological extreme events that manifest themselves in the form of floods and droughts. In future, the frequency of these extreme events is projected to increase on the basis of projected scenarios for climate change (WCD, 2000).

1.5.5 Need for adaptation strategies.

Kenya is already enduring the problem of climate change and climate variability just like other African countries. Therefore, coordinated approach is needed for addressing climate related risks and vulnerabilities (Government of Kenya, 2016d). Kenya's most priority in climate change response remains adaptation and resilience. The fifteenth African Ministerial Conference on the

Environment (AMCEN) affirmed similar position that, in the preparations to the December 2015 Paris Agreement, there was need to have adaptation global goal with considerations for adaptation needs and also the associated costs, which includes supporting developing countries while recognizing the need to increase investments for adaptation in the developing countries. This will also require ambitious long term mitigation actions globally combined with funding for adaptation in large-scale, rapidly increasing, and predictable (African Union, 2015). AMCEN also recommended the continuation of investment in building resilience as a top priority for funding, including being part and parcel of planning process for development nationally.

The recommendations resonated well with Kenya's country approach for mainstreaming adaptation into the national development plans and county integrated development plans. Kenya is among the countries in the forefront advocating for climate change. Kenya went ahead to launch a National Climate Change Response Strategy (NCCRS) in 2010 and a National Climate Change Action Plan (NCCAP 2013-2017) in 2013 to advocate for climate change. In 2018, another National Climate Change Action Plan (2018-2022) was again launched. The launch of these action plans is a clear demonstration that adaptation has been made one of the country's main priorities due to the adverse social and economic impacts that are related to the changing climate being experienced across various sectors and the increasing vulnerabilities of the various sectors including energy sector. The NCCAP clearly communicates that it is important to address the negative environmental, social, and economic impacts caused by the changing climate to achieve sustainable development. This means that the integration of climate change adaptation and development goals is needed for the purpose of complementarity. Climate change adaptation is therefore recommended to be integrated into hydropower development planning, budgeting, and implementation at the local or river basin level.

1.5.6 Policy support for climate change adaptation

The Kenya Climate Change Act enacted in 2016 has provided necessary policy support for adaptation actions across several sectors. Kenya's energy sector is highly dependent on renewable energy, and therefore makes it extremely vulnerable to the impacts associated with changing climate and climate variability. Continuous temperature rises together with rainfall variability that increases extreme weather events intensity and frequency such as droughts and floods which may be the country's threat to sustainable hydropower development. Development of the National Climate Change Framework Policy by the Kenya Government was to guaranteed sustainability of hydropower development for the provision of a concise and clear guidelines on prioritization of the global response to climate change and climate variability. A commitment has been made by the Government of Kenya for the protection of climate system for the benefit of sustainable development through the support to the UNFCCC process, contribution to regional and continental climate change initiatives, and ratification of the Kyoto Protocol in 2005. In the Kenya's constitution of 2010, there is a commitment for attainment of development that is ecologically sustainable with a provision of a firm foundation to address the climate change associated challenges and at the same time striving to attain the Kenya Vision 2030 development goals.

The policies need to focus on creating interlinkages between climate change and sustainable local and national development. The policies therefore need to elaborate the intervention measures to assist in achieving the low carbon climate resilient development goal. Policies need to be put in place for facilitating a coordinated, effective, and coherent response to the opportunities and challenges associated with climate change at global, national, and local levels. There is need for adoptions of an overarching integration approach to ensure there is integration of adaptation aspects into planning, budgeting, and implementation of hydropower development at all levels of government. This is aimed at enhancing adaptive capacity at all levels and building resilience to the impacts of climate change and climate variability, while promoting the low carbon development pathway.

For the provision of a regulatory architecture that contains important climate change governance components, appropriately designed policy, legislative, and institutional frameworks are required. Complying with the constitutional framework is necessary public administration, particularly the devolved system of governance. Two levels of governance have been set up by the Constitution of Kenya. There is interdependency for the two levels of government though distinct and are expected to carry out their functions in a cooperative and consultative manner in discharging their concurrent and respective mandates. Making of policies on climate change is the mandate of the national government while the county governments' functions are to play an integral role fulfilling the required actions in addressing climate change. Overall legislative and institutional arrangements review may be necessary for governing climate change actions for the coexistence of the two levels of governance. The existing various sectoral policies and laws for the provision of the legislative basis for specific climate change adaptation actions may also need reviews to enhance their ability in tackling climate change challenges and exploiting emerging opportunities.

Integration of adaptation into the development of hydropower is necessary for equipping relevant development agencies in the energy sector with the instruments for effective response to the complicated challenges that are associated with climate variability and changing climate. This should provide for the promotion of integrating adaptation actions and policies into the planning, development, and management processes for hydropower development.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter provides literature review on climate change, impacts of climate change on hydropower, impacts of combined development of hydropower and climate change on the local communities' livelihoods, appropriate strategies which are sustainable for the adaptation integration into the development of the hydropower and policy options to support integration of climate change adaptation.

2.2 Climate Change Trends

Various literature has been reviewed in line with the research work already carried out in the field of climate projections and climate change. These include development of climate modelling, representative concentration pathways (RCPs), downscaling of climate change information to regional level and climate change scenarios.

2.2.1 Climate projections and climate change

To generate possible future climate scenarios, simulating climate systems and developing climate change research by use of Global Climate Models (GCMs) is necessary (Biao, 2017). In most hydrological projections' studies, precipitation and temperature downscaled from GCMs are used to drive the hydrological models especially at river basin scale. In these studies, there are clear indications of substantial impacts on water resources potentially caused by climate change (Biao, 2017).

2.2.1.1 Development of climate modelling

Simulation of present climate to predict the future climate change has resulted into the GCMs development. Despite demonstration of significant skill at hemispheric and continental spatial scales with the incorporation of large proportion of global system complexities, GCMs are not able to represent the local dynamics and features inherently (Xu, 1999). Therefore, for the GCMs to be applied at the local or basin level such as Sondu Miriu River Basin, downscaling techniques for downscaling GCMs outputs are necessary (Xu, Widen and Halldin, 2005).

A hierarchy of climate models are applied for the projections of changes in the climate system. These models range from simple to intermediate complexity, comprehensive, and Earth System Models. The simulated changes by these models are done on the basis of a set of anthropogenic (human induced) forcing scenarios. The Representative Concentration Pathways (RCPs) which is a new set of scenarios has been applied for the recent simulations by climate modelling which were carried out under the framework of the Coupled Model Intercomparison Project Phase 5 (CMIP5) by the World Climate Research programme. Many Earth System and comprehensive climate models have taken part in the Coupled Model Intercomparison Project Phase 5, with the results forming the foundation of the climate system projections (IPCC, 2013).

Land use may substantially affect the precipitation and climate regionally (Hunt *et al.* 2020). These impacts can vary to a larger scale. For instance, precipitation patterns can be affected by converting forest land into agricultural farms (Li *et al*. 2009; Adnan and Atkinson 2011; Price 2011; Hunt *et al.* 2020), the regional average temperatures can be affected by deforestation (Bonan 1997; Hunt *et al.* 2020) alongside other impacts (DeAngelis *et al.* 2010; Mueller *et al.* 2016; Chen and Dirmeyer 2017). Besides land use changes, the regional climate can also be affected by water consumption patterns through evapotranspiration (Hunt and Leal Filho 2018; Liu *et al*. 2018; Zou *et al.* 2018; Hunt *et al.* 2020). Therefore, water and land management practices have a major influence on climate patterns regionally (Betts 2001; Tomer and Schilling 2009). The relationship between climate patterns and land and water management are being proposed as one of the effective regional adaptation measures to manage global warming (Hirsch *et al*. 2017; Hunt *et al.* 2020) and to be incorporated into climate models (Li *et al*. 2018).

2.2.1.2 Representative concentration pathways (RCPs)

The RCPs are scenarios comprising of the concentrations and emissions time series of full set of aerosols and greenhouse gases together with gases which are chemically active, including land cover and land use (Moss *et al.*, 2008). Term “representative” implies that every single RCP is only one presentation of the several potential scenarios that can lead to the characteristics of specific radiative forcing. The term "Pathway" puts more emphasis on the trajectory taken during the period to reach the anticipated outcome in addition to the long-term concentration levels (Moss *et al*., 2010).

The RCPs are references to the concentration pathway section extending to the year 2100, for which the corresponding emission scenarios by the Integrated Assessment Models were produced. The four RCPs that were utilized as the basis for the climate projections and predictions in the latest IPCC Assessment to produce the 5th IPCC Assessment Report were produced from Integrated Assessment Models which were selected from the published literature. The four RCPs included a mitigation scenario leading to forcing levels that are extremely (RCP2.6), stabilization scenarios (RCP4.5 and RCP6), and a scenario considering extremely high greenhouse gas emissions (RCP8.5). Their identification is based on the approximate total radiative forcing such as 2.6 Wm^{-2} for RCP2.6, 4.5 Wm^{-2} for RCP4.5, 6.0 Wm^{-2} for RCP6.0, and 8.5 Wm^{-2} for RCP8.5 (IPCC, 2014).

2.2.1.3 Downscaling climate information to regional level

The necessity for climate change information is a fundamental matter within the climate change discussions. This is especially happening at both the regional and local scale. This information is extremely critical for evaluating the impacts of climate change on the natural systems and human livelihood including coming up with suitable adaptation strategies at both the local and national level (Giorgi *et al*., 2009).

Regional climate downscaling (RCD) through the application of both dynamical and statistical tools have been increasingly used in addressing most of the issues relating to climate change. Presently RCD has become a significant methodology for climate change research (Huntingford and Gash, 2005). There has been underutilization of the RCD based products. It is believed that the main reason for this underutilization can be attributed to absence of coordinated framework for evaluating the techniques based on RCD to produce ensemble projections which are of adequate quality that allows for characterization of the underlying uncertainties on climate change projections regionally. These coordinated frameworks exist for global models including the Coupled Model Intercomparison Projects 1-3 (CMIP1-3) or Atmospheric Model Intercomparison Project (AMIP). This has given a lot of benefits to the global climate modelling community immensely from such coordinated activities. The benefits have been in terms of understanding the process, evaluation of the model and generation of the climate change projections. There has been isolation of the studies on RCD which have been continually tied to specific targeted research interests. This has been done to allow for a comprehensive analysis of climate change projections at regional level based on RCD experiments that are not currently available (Giorgi *et al*., 2009)

Coordinated regional climate downscaling experiment (CORDEX) programme was initiated with an aim of providing a framework for benchmarking for evaluation and possibly improvement of models, on one hand while on the other hand having a set of experiments to provide for exploration to the highest-level possible influence of the various sources of uncertainty. CORDEX, therefore, essentially aims at providing a framework for evaluating and benchmarking model performance (model evaluation framework) as well as designing experiments for producing climate projections suitable for utilization in the studies for impact and adaptation within the framework of climate projection (Giorgi *et al*., 2009).

Framework for climate projections is currently based on new global model simulations within the CORDEX which were planned to support the IPCC Fifth Assessment Report referred to as CMIP5. These simulations are inclusive of various experiments that ranges from the 21st century simulations of new GHG scenarios, dekadal prediction experiments and other experiments such as the carbon cycle and the ones aiming at investigations of individual feedback mechanisms (Taylor *et al*., 2009).

The methodology applied and the results of the 5-member ensemble simulation of the African climate for the period 1950-2100 using climate modelling system PRECIS carried out over the CORDEX Africa domain suggest that Regional Climate Model (RCM) simulations improve the fit to precipitation and temperature observations in most of the African sub-regions. It should be noted that that the range of RCM projections usually differ from the ones from the GCMs in these regions (Buontempo *et al*., 2014).

2.2.1.4 Climate scenarios

The course spatial scale of GCM outputs for water resources studies is among the primary factors limiting the direct application of climate projections to hydrologic modelling. The development of future projections is usually based on the GCMs at resolutions of hundreds of kilometres which makes them difficult to relate to models at watershed scale (Kopytkoskiy *et al*., 2015). The climate change projections based on the watershed scale can give indications on the performance of future hydropower generation.

The purpose of climate projection scenarios is to guide researchers in exploring the consequences, which are long term in nature, of the present decisions being made while taking into considerations the inaction within both the socioeconomic and physical systems. The climate projection scenarios provide important reference for emerging research with economic and technological models (Moss *et al*., 2008). Currently, the research community on climate are applying the four new key scenarios of the Representative Concentration Pathways (RCPs) that give descriptions of a wide range of potential future projections scenarios for the main climate change drivers such as greenhouse gases, land use and air pollutant emissions. The RCP scenarios range from high to low emissions projections (Jubb *et al*., 2013).

2.3 Impacts of climate change on hydropower generation

Climate change has impact on hydropower generation. Climate change influences hydropower generation through hydrological fluctuations driven by climate variability. The literature review covered the relationship between climate change and hydrology, hydropower development and impacts of climate change on hydropower generation.

2.3.1 Climate change and hydrology

For the purpose of hydropower development and other sectors such as agriculture, environment, health and socioeconomic in Sondu Miriu river basin, water is a very critical resource. It is, therefore, a critical element for human activities whereby it affects where and how human communities and local economies thrive across the basin (Kumar *et al*., 2011). A wide range of possible climate projections with related variability in future rainfall and runoff projections have been made available (Bates *et al.,* 2008). During the 21st century, the use of multi-model ensembles in the climate projections has shown that rainfall is projected to increase globally (Milly *et al*., 2005). Almost all the models project rainfall increases in parts of the tropics (Kumar *et al*., 2011). The maximum and minimum annual temperatures are also projected to rise by between 0.5^{0}C and 3.5^{0}C under the RCP8.5 with the increase in minimum temperatures being projected to be higher during the cold season of JJAS compared to the MAM and OND rainfall seasons (Olaka *et al.,* 2019).

The observations from general climate change and runoff predictions indicate that there will be hydropower resource potential decline except for East Africa (Hamududu *et al.,* 2010; Hamududu and Killingtveit, 2012). Few studies have examined the possible climate change impacts on hydropower resource potential. Kenya is particularly vulnerable because 38% of installed electricity capacity is based on hydroelectric power.

2.3.2 Hydropower development in the face of climate change

Climate change impacts of on water resources and extreme hydrological events is one of the major challenges for hydropower development (Biao, 2017). An increase of extreme precipitation and dry spells are projected in regions that are already experiencing wet condition and dry conditions respectively under the present climate conditions (Biao, 2017). In assessment of potential climate change impacts on water resources, climate projections that are derived from Global Circulation Models (GCMs) are usually applied by use of hydrologic model.

Based on the various greenhouse gas emission scenarios, there is evidence that climate change has affected various aspects of water resources and this situation is expected to continue throughout the twenty first century (Shahram *et al*, 2012). Hydrologic impacts assessment usually relies on spatial downscaling for the translation of large scale GCM projections to the scales that represent more physical climate change implications (Kopytkoskiy *et al*., 2015). The two major techniques that exist in downscaling are statistical and dynamic. Dynamic downscaling which is computationally too intensive for multi decadal analysis simulates physical processes at finer scales while the statistical downscaling which is used widely, essentially the GCM projections are based on observed quantitative relationships between climates at the two spatial resolutions.

Hydropower generation and water resources availability are highly influenced by global warming because of increasing global temperatures that alters the rainfall patterns (Shu *et al*, 2018). The water resources availability is determined by the rainfall pattern in the catchment and hence the hydropower potential. Rainfall generally leads to runoff that affects the water availability for use in hydropower generation. The energy system globally is moving towards achievement of sustainable and less carbon-intensive future under the Sustainable Development Goals (SDGs), where a critical role will be expected to be played by the development of hydropower (Zhang *et al.*, 2018).

The global warming is generally most likely to be accompanied by extreme weather. This will increase the risks of frequent droughts and floods making it important for the regulation and water management reservoirs to accommodate the decreased or increased inflows. During the periods of extremely warm and dry weather, there will be increased water demand for irrigation. Therefore, total electricity demand will be expected to exert more stress on the water supply availability for hydropower generation (Shu *et al*, 2018).

2.3.3 Global hydropower status

The design life for hydropower infrastructure is usually more than 100 years and economic design life of 60 years (Kumar *et al.*, 2011). The global energy system is moving towards achieving a less carbon-intensive and sustainable future being a response to the Sustainable Development Goals (SDGs), where a major role is expected to be played by development of hydropower (Zhang *et al.*, 2018).

Hydropower and thermal power plants currently account for about 98% of total electricity produced globally. Electricity supply is projected to affected directly by changing climate through influencing water availability for hydropower generation. Improving the understanding on how water resources availability and temperature are most likely to be impacted on by the changing climate is therefore important (Van Vliet *et al.,* 2016). Some areas projected to experience largest increases in potential of hydropower include the northern high latitudes, central Asia, Central Africa, and India, with a world population ranging between 18% and 33% living in these areas by the 2080s. The areas projected to experience the largest reductions include southern parts of South America, eastern Asia, United States, and Europe. High water temperature increases are projected in Australia and Africa, combined with mean annual streamflow reductions (Van Vliet *et al.,* 2016; Zhang *et al.,* 2018).

The general perception that small run-of-river hydropower plants are renewable energy sources associated with little or no environmental impacts has resulted into a global spread of this hydropower technology. However, at different trophic levels such hydropower schemes may end up altering the natural flow regime and even impairing the fluvial ecosystem. Interdisciplinary research progress involving different stakeholders is crucial to harmonize conflicting interests and enable the sustainable development of small run-of-river hydropower plants (Kurigi *et al*., 2021).

2.3.4 Hydropower sustainability

The has been a boom in hydropower development based on the number projects experienced in the last two decades globally. Hydropower development projects could contribute substantially to the poverty eradication and economic growth that is environmentally friendly considering hydropower as a critical component of sustainable development in developing and post-socialist transition countries (Dogmus and Nielsen, 2019). There is importance in applying cross-sectional coordination as well as integrated approaches for improvement of resources use efficiency and achievement of sustainability in the development of hydropower. These factors have the capability to shape the future of hydropower expansion and need consideration for planning and operations purposes (Hoes *et al.,* 2017; Zhang *et al.,* 2018).

Economic, political, and environmental boundary conditions can have impact on hydropower developments. All the other sectors depending on energy have to be flexible to respond appropriately to the continuous changes in the energy sector. There is need for integrated approaches with consideration of demands for both socioeconomic and environmental sustainability to cope with changes in the energy sector. In addition, innovation and research in hydropower technology and management globally are also key (Wagner *et al.,* 2019).

2.3.5 Types of hydropower generation

Electricity in one of the most important commodities for human livelihood and sustainable development. The basis for the social and economic analyses on electricity supply and development is the correlation between electricity indicators and macro-economic indicators. Achievement of new sustainable development goals (SDGs) by 2030 has become a real challenge to the humanity as the greenhouse gas (GHG) emissions caused majorly by human activities have been continuously altering the global energy and climate patterns (Berga, 2016; Okuku *et al*, 2016; Sridharan *et al*, 2019).

Hydropower is simply created from the moving water in the hydrological cycle. Solar radiation drives the hydrologic cycle through heat and energy exchanges. There is huge potential energy in this cycle with limited amount that may be developed technical. The rainfall in the higher regions generates a large flow of water downstream to the lakes and oceans in the form of rivers and groundwater flow. The rivers' flowing water is what can be utilized for generation of hydropower by tapping the energy contained in the moving water from high to low elevations, driven by the gravitational force (Kumar *et al*., 2011; Sridharan *et al*, 2019).

Hydropower plants are broadly categorized into four types depending on their operations and type of flow. These categories are run-of-river hydropower, storage (reservoir) hydropower, pumped-storage hydropower, and in-stream technology hydropower. The hydropower plants vary from exceedingly small scale to large scale which are determined by the basin hydrological characteristics and topography. (Kumar *et al.,*2011: Sridharan *et al,* 2019).

2.3.6 Hydropower generation in Kenya

There are several run-of-river hydropower generation in Kenya that utilize the flowing water in the river which is channelled through a canal and/or penstock to spin a turbine to generate electric power. This type usually has got no/very little water storage facility. Continuous electricity supply is provided with some small flexibility of operations for daily demand fluctuations through regulated water flow (Kumar *et al.,*2011). Some examples in Kenya include Sondu Miriu (60MW), Sang'oro (21MW), Tana (20MW), Wanji (7.5MW), Gogo (2.0MW), Sagana (1.5MW) and Mesco (0.4MW) (KenGen, 2018). The existing hydropower plants in the Sondu Miriu River basin are all run-of-river (RoR) hydropower. This means that they have little or no water storage facility. These are Sondu Miriu and Sang'oro hydropower plants, respectively (KenGen, 2018; Kenya power 2018).

Storage hydropower is a large system typically utilizing a dam for the storage of water in a reservoir for generation of hydropower. The generation of electricity involves the release of water from the reservoir through a turbine. This type can highly be regulated based on the system demand. It offers a large storage capacity to allow independent operation from the hydrological inflow for a longer duration of time (Kumar *et al.,*2011). Examples in Kenya include Masinga (40MW), Kamburu (94MW), Gitaru (225MW), Kindaruma (72MW), Kiambere (168MW) and Turkwel (106MW) (KenGen, 2018; Kenya power, 2018)).

2.3.7 Other types of hydropower generation

The other types of hydropower generation are not yet developed in Kenya. The pumped-storage hydropower type utilizes water that is continuously cycled between an upper and lower reservoir through pumping and generation. It provides peak load supply by using surplus energy from the system during the period when electricity demand is low in pumping water to the upper reservoir from lower reservoir. The water is released back to the lower reservoir from the upper reservoir through the turbines for electricity generation for the period when the demand for electricity is high (the peak demand), (Tarroja *et al.*, 2016). Currently, Kenya does not have any pumped storage hydropower plant in operation, but studies are underway to develop one. Some of the existing pumped storage hydropower in Africa include Afourer Pumped Storage Station (450MW) in Morocco (Bartle, 2002), Palmiet Pumped Storage Scheme (400MW), Angula (1,332MW), Steenbras (180MW) and Drakensberg Pumped Storage Scheme (1000MW) in South Africa (Berta, 2018).

The in-stream technology hydropower is less established. It functions as run-of-river scheme and involves the development of hydrokinetic devices to capture energy from the power of waves or tidal currents for electricity generation from the sea water. The technology may also be implemented in the inland waters such as free flowing rivers or engineered waterways (Kumar *et al.,*2011; Tarroja *et al.*, 2016).

2.3.8 Impacts of climate change on hydropower generation.

Climate change impacts on hydropower generation are heterogeneous over different spatial scales due to differences in local geographic features and hydrological characteristics. Therefore, it is necessary to carry out an evaluation of potential impacts of climate change on hydropower generation at a local scale possibly at river basin level (Shu *et al*, 2018). Increasing number of research mainly on hydrological impacts have suggested that the results from climate change science is now mature for the integration into the scoping, design, and management of hydropower (Cherry *et al.*, 2017).

Changes in water resource availability resulting from variations in rainfall, temperature increase, and evaporation rate rise facilitates the escalation of the extreme hydrological events frequency (Qin *et al*., 2020). Additionally, water resources availability's temporal and spatial distribution is being expected to be changed by climate change (Yang *et al*., 2016), whereby various basins are being expected to receive less rainfall while the others are expected to receive more rainfall (Turner *et al*., 2017).

Any rainfall and temperature changes are expected to cause fluctuations in the river/stream seasonal flows and contributing to the hydropower output variations, attributable to lack of strategic trade-off between conflicting reservoir management objectives (Yang *et al*., 2016). Consequently, it is projected that the fluctuations in streamflow distribution will cause reduction in the net hydropower generation and operation globally under the RCP8.5 scenario near the end of the nineteenth century (Wang *et al*., 2019; van Vliet *et al*., 2016).

Many countries that depend on agricultural production, water supply, and hydropower for electricity are most likely to face challenges resulting from water resources availability decline (Shrestha *et al*., 2021). Therefore, there is need for sustainable and effective water use. In addition, the developing countries have experienced increased impacts of climate change more than the impacts experienced by developed countries that has been attributed to the lack of economic sectors and technological advancement (Berga, 2016; Shrestha *et al*., 2016; Khan *et al*., 2013). Both the run-of-river and the storage hydropower plants types are affected by spatial and temporal variations in rainfall and temperature but the storage type of hydropower is stable due to its flexibility provided by its storage capacity while the run-of-river type of hydropower being the most affected due to its sensitive to any climate change due to its direct dependence on the availability stream flow at any particular time (Hamududu and Killingtveit, 2012; Koch *et al*., 2011).

Though there is expectation that the average global climate change impacts might be relatively small on hydropower resource potential, the regional and local impacts are expected to be significantly potential. The resource potential for hydropower is determine by factors such as topographical features, and the characteristics of the hydrology including the seasonal distribution, volume of the runoff, and variability. These factors are not only determined locally and regionally, but climate variability, even if the average runoff does not change, can also cause change in hydropower production unless reservoir capacities and operations are modified to respond to the change in hydrology because of change climate (Kumar *et al*., 2011).

Many research projects have been conducted on the climate change impacts on generation of hydropower (Markoff and Cullen 2008; Madani and Lund 2010; Hamududu and Killingtveit 2012; Gaudard *et al.* 2013; Viola *et al.* 2015; Arango-Aramburo *et al.* 2019). On the other hand, only a few research papers on the impacts of hydropower reservoirs on climate change have been published (Wu *et al.* 2012; Song *et al.* 2017; Balagizi *et al.* 2018) because the surface area covered by hydropower reservoirs is low globally (Hunt *et al.* 2020). However, the impact of large reservoirs like the Three Gorges Dam and others in Brazil, Canada and Russia on the regional climate pattern can be significant (Hunt *et al.* 2020).

The large reservoirs for hydropower plants have impacts on the overall basin river flow through increase of evaporation rate and reduction of the overall downstream stream flow annually (Beilfuss 2010; López-Moreno *et al*. 2014; Zhang *et al*. 2015; Digna *et al*. 2018). During the wet season at the surface, the mean atmospheric relative humidity is usually very high resulting in the reduction of the reservoir evaporation rates considerably. Increasing the relative humidity of the region through evaporation has a contribution to the precipitation increase regionally. During the dry period, there is substantial reduction in precipitation making any contribution from the hydropower reservoirs to a possible precipitation increment compared to wet period to be considerably smaller (Hunt *et al.* 2020).

Among the greatest challenges of the 21st century is climate change (Hamududu and Killingtveit, 2017). The renewables-based electricity generation was projected by International Energy Agency (IEA) to triple between 2008 and 2035 under the current campaigns globally to increase the renewable energy sources utilization (IEA, 2011). Hydroelectric power generation is currently making a significant impact towards meeting the current rising electricity needs globally. The renewable energy share in the hydroelectric power generation globally increased from 19% to nearly 33% which is almost equal to the share of coal globally. The primary contribution to this increase came from wind and hydropower combined even though over the projection period hydropower remains dominant (IEA, 2011; Hamududu and Killingtveit, 2017). The hydropower generation is projected to grow by 75% globally from 2008 to 2050 in the business as usual case while with aggressive actions aimed at reducing the greenhouse gas (GHG) emissions, it could grow by approximately 85% during the same period (Hamududu and Killingtveit, 2017).

Altering the water cycle because of deforestation and climate change could a lot of impacts on river flows that fuel generation of electricity. There could be a delay in the period of maximum daily electricity generation due to change in future hydrological conditions making mismatch between peak demand and seasonal electricity supply worse (Arias *et al*., 2020). Overall, climate change has a possibility of decreasing dry season hydropower potential, while combined effects of deforestation also have the potential of increasing interannual variability. Therefore, incorporation of future climate change and coordination hydropower reservoir operations should the principle in energy planning for the development of energy portfolios that are more resilient (Arias *et al.,* 2020).

For accurate regional quantitative predictions of impacts, analysis of changes in both the temporal distribution of river flows and average river flows is necessary using hydrological models for conversion of climate scenarios time series to runoff scenarios time series (Kumar *et al*., 2011).

2.4 Impacts of climate change and hydropower development on community livelihoods.

In the global electricity generation mix, the currently largest renewable energy sources is hydropower. Regardless of the goals for climate change mitigation in many countries, hydropower is still projected to remain important in the future renewable energy mix (IEA, 2010). The hydrologic cycle which is driven by topographical features and prevailing climate is the resource base of hydropower. The prevailing climate determines the resource base and therefore makes the generation of hydropower to be highly dependent on future changing climate and related extreme weather events occurrences (Ebinger and Vergara, 2011; Mukheibir, 2013).

Assessment of climate change impacts on the hydroelectric power generation is very complicated globally. Variable temporal and spatial mean seasonal and annual rainfall and temperatures changes, and the resultant evapotranspiration losses, with regional water demand changes necessitated by economic activities and population growth changes are challenging to projects implementation particularly the competition for the available water resources created by agricultural water demand for irrigation (Arent *et al.*, 2014). The current increasing drive to combine generation of hydropower with flood control and environmental flow objectives caused by climate change regimes also further complicates the matter.

In responding to changes in water availability interannual variations, seasonality, and water quantity in addition to other existing demands, a focus is needed on the possible impacts of climate change on hydropower development and adaptation options in the energy sector. Several studies have concluded that by 2050, it is projected that the overall impacts of climate change and extreme weather events on hydropower generation will be slightly positive in most regions and negative in some regions, with differing patterns across various watersheds, catchments, river basins and regions (IPCC, 2011). The climate change adaptation tools for long term responses and planning of hydropower generation need to be enhanced for coping with continuous change in water resources availability. There is need to enhance short term management models for dealing the impacts of extreme weather events. Several infrastructural and non-infrastructural measures are readily available such as adding bypass channels, raising dam walls, adjusting water releasee for protecting related infrastructure like turbines, channels, dams, among others and scheduling generation during high electricity prices for optimizing incomes (Mukheibir, 2013).

Livelihood identification is linked to sustainability. Apart from providing income and food, livelihoods also make a significant contribution to social capital, personal and social fulfilment, and identity (Goldman and Young, 2015). Livelihood sustainability is measured on its ability to recover from and cope with stresses and shocks and still maintaining or enhancing its assets and capabilities both at present and in the future, without not undermining the natural resource base at the same time (Chambers and Conway, 1992). Sometimes, livelihood is to do with assets, entitlements, and activities for people to make a living. These are referred to as natural, social, and physical aspect (Foo *et al*., 2016). Livelihood assessment basically defines individual, household, or a community behaviour under specific framework environments, as well as understanding livelihood system. Those definition and thought conclude livelihood as a process of perception (thinking), believes and action that frame human interaction among themselves and their physical environment (Foo *et al*., 2016).

The past climate changes are responsible for the recently impacts on natural and human systems globally. There is strong evidence of climate change impacts. The evidence is very comprehensive within the natural systems. Various impacts are linked to the climate change and their minor or major contributions are distinguishable from other influences with the human systems (Niang *et al*, 2014). Climate change will severely impact on hydroelectric power generation in future because the nature of rainfall-runoff process is not linear. Observations have shown that any reduction in rainfall be 10% can easily reduce the generation from hydropower by between 25% and 50%.

Similarly, a rise in temperature by few degrees is capable of increasing evapotranspiration rates substantially and result in severe impact on hydroelectric power generation in addition. Increase in year-to-year climate variability may also cause generally lower security in energy supply (Droogers *et al*, 2009).

The observed historical rainfall trends have indicated that there is a general decrease in the rainfall amount received during the March to May major rainfall season also referred to as "Long Rains" and a general increase in the short rainfall season from October to December within the region (Government of Kenya, 2010a; Liebmann *et al*, 2014). Based on the results of the recent studies, the "Short Rains" usually experienced from October to December period now seem to be extending into the January to February period which is normally known to be hot and dry. This has led to the increased frequency of prolonged droughts in the long rainfall Season. Hydropower is being promoted in Africa as one of the sustainable development technologies. Electricity and water have also been identified as some of the essential resources for supporting socioeconomic growth and community livelihood enhancement. The importance of affordable energy has also been emphasized in the developing world as being a critical input to realize the millennium development goals (Kiteresi *et al*, 2015).

Rural economies are being transformed to more service oriented and industrial economies from traditional agriculture. These changes are always associated with economic and social impacts on nearby communities and sometimes lead to rural depopulation and fragmentation. Even though benefits like employment from the local economic development projects have always accrued to the nearby rural communities, some adverse impacts may be experienced on the communities' future livelihoods due to changes in peoples' occupations and in land use. It is recommended to support new types of economic activities that are land-based to be implemented on agricultural lands that are abandoned, reclamation of degraded lands, and introduction of new production methods and products (Chandy *et al*., 2012).

The Lake Victoria Basin (LVB) within which Sondu Miriu river basin is located has been experiencing land use changes caused by both critical natural and anthropogenic drivers concerning the livelihoods and resources sustainability of the local communities within the Sondu Miriu river basin (Makalle *et al*. 2008). The changes in the basin will always influence the local communities' decisions made and resultant land use practices. The communities living nearer to river are more vulnerable to the impacts of climate change due to greater exposure to the risks associated with riverbank erosion and flooding, very low adaptive capacity because of low socioeconomic status and poor livelihood conditions and high sensitivity to inadequate access to basic amenities and. The social and biophysical parameters are the main contributors for the varying vulnerabilities within an area. The variation in vulnerability of the communities depend on their location in respect to river and the approaches applied based on the social status of the communities. The spatial characteristics within the area or river basin can be valuable in making decisions for addressing the communities' livelihood vulnerability within the river basin (Huong *et al.*, 2019: Das *et al.*, 2020).

Sustainability livelihoods framework involves looking at the theoretical understandings derived from analysis of sustainable livelihoods and combining with additional relevant analytical frameworks in assessing the climate change vulnerability of rural livelihoods. The integrated analytical framework aides in analyzing climate change vulnerability, while at the same time helps in the identification and comparison of climate change adaptation options vulnerability reduction. Despite its weaknesses, the sustainable livelihoods framework can offer a structured way in which complementary theories and concepts on community livelihood vulnerability to climate change can be organized and integrated. The climate change adaptation options effectiveness can be measured by evaluating the sensitivity of natural capital and other capital assets to the level of exposure of the climate change a system (Reed *et al*., 2013).

2.5 Adaptation needs and strategies for hydropower development.

Climate change adaptation involves vulnerability and risk reduction, looking for opportunities, and capacity building of individuals, communities, and natural systems to manage climate impacts. It further involves mobilization of that capacity by implementing appropriate actions and decisions (Tompkins *et al*., 2010). For hydropower development, climate change adaptation aims to reduce risk and vulnerability of the hydropower projects and local communities by seeking opportunities and building the capacity of various related sectors to cope with climate impacts at the river basin level while mobilizing the capacity at the same time both internally and externally to implement decisions and recommended actions (Noble *et al*, 2014). Sufficient information on vulnerabilities and risks is needed for the identification of adaptation needs and appropriate adaptation options for building capacity and reducing risks.

Climate change adaptation needs usually fall into a set of several general categories even though they are unique to specific places and groups. For example, vulnerability at the various levels of governments depend on resources availability, institutional and governance organization, geographic position, and biophysical characteristics, such as economic stability and access to technology (Brooks *et al.*, 2005). There are two broad classes at the local level for determining vulnerability. These include socioeconomic determinants and biophysical determinants (Preston *et al*., 2011). However, climate change adaptation needs are context specific and very diverse. Various stakeholders, both individuals and groups, have different climate change adaptation vulnerabilities and needs. Climate change adaptation needs change from time to time, and the climate change mitigation pathway taken is expected to highly determine the future adaptation needs. Climate change adaptation limitations and constraints may portray that all the adaptation needs will not be satisfied, justifying the need to put more emphasis on monitoring to prevent going beyond critical thresholds (Noble *et al*., 2014).

Natural systems can strengthen community welfare, prosperity, health, livelihoods, and food security. Provisional services including food, fiber, and portable water; regulatory services including flood control, climate regulation, disease control and pollination; and supportive services including nutrients cycling and primary production are vital ecosystem services that need maintenance (Noble *et al*., 2014). Forest is the source of much of the domestic water consumption and other water users while the quality of this water heavily depends on the ecosystem's conditions through which the water flows (Hoegh-Guldberg, 2011). Maintaining green spaces and wetlands can also control flooding and runoff that are associated with rainfall increases (Jentsch and Beierkuhnlein, 2008; Mooney *et al*., 2009).

Socially, vulnerability varies because of the groups or individuals' capacity to reduce and manage the climate change impacts. Ethnicity, gender, health, age, class, and social status are among the key factors that determine vulnerability (Smit *et al.*, 2001; Adger *et al.*, 2009). Among all the conditions that influence vulnerability related to climate change, persistent inequality and poverty are the most significant (Noble *et al.*, 2014). Relatively greater climate change impacts are expected to be experienced by the poor because of several factors. These factors include poor conditions of shelter, limited financial resources, exposure to the climatic elements, unreliable local ecosystem services, and unreliable basic services provision and their lack of resources in supporting recovery from an increased frequency of losses caused by extreme climate events (Tol *et al*., 2004; Huq *et al*., 2007; Kovats and Akhtar, 2008; Patz *et al*., 2008; Revi, 2008; Allison *et al.,* 2009; Shikanga *et al*., 2009; Gething *et al.*, 2010; Moser and Satterthwaite, 2010; Rosenzweig *et al*., 2010; Skoufias *et al*., 2012). Because of the usually compromised health status and limited financial resources, the vulnerable groups including the elderly, the sick and the poor are usually at increased risk caused by climate change impacts (Kasperson and Kasperson, 2001; Haines *et al*., 2006; Costello *et al*., 2009, 2011; O'Neill and Ebi, 2009; Tonnang *et al*., 2010; Ebi, 2011; Harlan and Ruddell, 2011; Huang *et al*., 2011; McMichael and Lindgren, 2011; Semenza *et al.*, 2012).

Under the changing climate, social needs consist of understanding both the psychological and emotional needs within the society. The conclusion is that the extreme climate events such as bushfire, drought, and floods can cause mental suffering resulting in the requirement for counselling and psychological support (Noble *et al*., 2014).

Adaptation to climate change for hydropower development requires adequate information on risks and vulnerabilities on hydropower operations for identification of appropriate adaptation needs and options that can lead to risk reduction and building capacity. Outlining an approach to climate change adaptation requires engagement of people with varying experience, backgrounds, and knowledge in addressing and achieving a shared approach for managing the challenges (Preston and Stafford-Smith, 2009; Tompkins *et al*., 2010; Fünfgeld and McEnvoy, 2011; Eakin *et al*., 2012). In the past, adaptation needs identification was often based on the assessments of the impacts, but the use of resilience assessments or social vulnerability are on the increase (Fünfgeld and McEnvoy, 2011; Preston *et al*., 2011). The approach emphasises on the biological and physical aspects of the climate change adaptation and impacts (Burton *et al*., 2002). The framework for social vulnerability focuses on how the individuals, groups, and communities within the Sondu Miriu river basin are vulnerable to the impacts of climate change. It focuses on how different factors influence the economic and social conditions that may place communities at risk (Adger and Kelly, 1999; Preston *et al*., 2011). These frameworks allow for overlaps and complementarities. Therefore, acquisition of adequate information risks and vulnerabilities on hydropower within the Sondu Miriu river basin is critical for the determination of the adaptation needs for hydropower development.

There is need to adopt an integrated and transformative system approach in responding to the challenges presented by complex and cross cutting climate change problems for sustainable hydropower development and resilient livelihoods (Mpendeli *et al*, 2018) within the Sondu Miriu river basin. The current approaches being applied by various sectors to the initiatives for adaptation usually have the tendency of creating imbalances and hindering sustainable development (Mpendeli *et al*, 2018). There are two main approaches for responding to climate change, adaptation and mitigation. The IPCC defines mitigation as "an anthropogenic intervention to reduce the anthropogenic forcing of the climate system, which includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks" while defining Adaptation as "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC, 2007).

Issues with high possibilities of causing the climate to change can be tackled by mitigation measures. Mitigation actions are mainly targeting to reduce the Greenhouse gas emissions. The mitigation actions are implementable at any spatial scale globally or even locally. Adaptation actions are aimed at addressing the consequences of climate change mainly at regional and local scales as the associated adaptation actions benefits are usually felt regionally of locally (Lebel *et al*., 2012). Climate change adaptation is component of the climate-resilient pathways. Therefore, it has been proposed to integrate adaptation actions in the form of ambitious goal. The proposal was made within the broader sustainable development framework (Wilbanks *et al*., 2007; Bizikova *et al*., 2010) especially with the prevailing financial commitments and considering policy towards responding to the changing climate focusing on following up adaptation actions. Adaptation actions practically tend to involve responsibilities for making decisions, schedules, and various community interests (IPCC, 2007a; Wilbanks *et al*., 2007).

Long term investments decisions need to consider climate change. This requires future infrastructure to be more robust to incorporate projected future changes in climate conditions (Hellegatte, 2009). This requires the climate information users to change their practices and decision-making frameworks such uncertainty management methods as currently applied in forex exchange rate and research and development outcomes (Hellegatte, 2009). Development of strategies to minimize the negative socioeconomic impacts of hydropower projects are needed to enable them to be implemented in a fair and cautious manner that benefits all the stakeholders (Kiteresi *et al*, 2015). There are several strategies for climate change adaptation. These include decision-making time horizons strategies, no regret strategies, soft adaptation strategies, safety margins strategies, and reversible and flexible strategies (Hellegatte, 2009; Guerra, Tejada and Reklaitis, 2019).

The decision-making time horizons strategies reduces the lifetime of investments to reduce uncertainty and corresponding costs as the uncertainty associated with future climate change increases with time. No regret strategies are capable of coping with climate uncertainty and yielding benefits even in conditions when the climate is not changing. Reversible and flexible strategies aim at minimizing the costs in case the future climate change does not happen as projected. Safety margins strategies aims at reducing vulnerability at no or low cost. Soft adaptation strategies such as institutional and financial tools can also be applied. (Hellegatte, 2009).

2.6 Policies for hydropower development and climate change adaptation

The Kenya Government has enacted several policies, legislation, and strategies as a response to various national and international challenges to address these challenges and to meet her international obligations. Due to major challenges brought by climate change, Government of Kenya has made a lot of effort to address these challenges through enactment of Climate Change Act in 2016. The government of Kenya has given prominence to climate change whereby policies and strategies have been developed in such a way that the challenges associated with climate change are addressed (Ongugo *et al.*, 2014). The legal environment for Kenya's climate change is considered progressive and being one of the first countries in the African continent to enact climate law and policies that are very robust for the guidance of local and national action. The existence of comprehensive legal framework is meant to provide the country with an opportunity to coordinate issues related to climate change in a more structured way (Naeku, 2020).

Investments and policy are the main drivers for the development of hydropower and determination of the geographical difference in the level of development. Gross potential of hydropower is affected by climate change through variation of streamflow regime. There has been more focus on hydrologic changes or policy projections in the previous studies discussing hydropower's future (Yüksel, 2010, Ziv *et al*., 2012; Grumbine and Xu, 2011; Huang and Yan, 2009; Bahadori *et al*., 2013; Darmawi *et al*., 2013; Sternberg, 2010; van Vliet *et al*., 2016).

The interactions between adaptation and mitigation actions call for integrated design and assessment of adaptation and mitigation policies (Hellegatte, 2009; Corbera *et al*., 2019). Effective adaptation must integrate both policy and investment issues into the process of planning and decision-making. There is limited economic resources availability currently for combating climate change. As a result, there has been a major policy challenge. The challenge is the determination of the aspects that constitute a balanced mix of adaptation and development policy environmentally, economically and socially (Klein, *et al.,* 2005; Zhang *et al*, 2018).

Integrating climate change impacts responses into the hydropower development process is also a further aspirational goal. Within the wider sustainability and resilience framework, it is proposed in the recent research outcomes that adaptation actions have the potential to be highly effective provided these actions are planned and integrated into the other development interventions and programmes frameworks (Wilbanks and Kates, 2010; ADB and ADBI, 2012). Within each country and its location, depending on the prevailing circumstances, there will always be variations in the available choices for integrating climate change adaptation (Wilbanks, 2003; De Boer *et al*., 2010). For countries with high vulnerability, adaptation may be given high priority depending on the benefits that may be immediately obtainable due to the reduction of vulnerabilities as a result of the prevailing climate extremes and variability including the projected climate changes in the future.

For hydropower development projects, Government agencies are the key investors (Sternberg, 2010). Many countries have long-term, medium-term, and short-term plans for the development of hydropower. In terms of hydropower development, the least developed region is currently Africa. The hydropower technical potential in Africa is almost the same to that in Europe, but out of this potential, what has been exploited is only 8%. as of 2009 (IPCC, 2011). Adaptation to climate change impacts can both create and limit opportunities that support human livelihoods. While other countries (mostly developed) are maximizing the opportunities offered by adaptation to climate change particularly in renewable energy and green technology, most African countries remain complacent with less commitment and more vulnerable to impacts of climate change. Due to increase of negative climate change impacts and livelihoods degradation, policy options are needed to enable the governments across the African continent to adapt to impacts of climate change as well as addressing the problem of unemployment and creating new patterns of livelihoods (Agba *et al*., 2021). There is need for policy proposals in agriculture and green energy which puts Africa at a comparative advantage compared to other nations with a capacity to employ 90 per cent of their workforce.

A wide range of projects, programmes and policies have emerged with the aims of addressing global impacts of climate change and its drivers. They have become the focus in a broader perspective of ongoing discussions on practices, policies, and development. The Intergovernmental Panel on Climate Change (IPCC), which was supported and launched by both the United Nations (UN) and the World Meteorological Organisation (WMO) in the mid-1990s has initiated several discussions and policies on climate change that reflect scientific evidence with a description of the current and future climate change impacts and the relationship between the development processes in general and the provided evidence (IPCC, 2014; 2018). In the development processes, climate change discussions about resilience, adaptation, and mitigation have obtained a lot of focus leading to more influence on development policies and other policy options globally (World Development Report, 2010). The concern at the convergence of climate change and development policies among critical scientists, civil society organizations, development organizations, and governments globally is growing on the possible impacts of these climate-driven treaties, interventions, and policies (Neocleous, 2013; Ribot, 2011; Swyngedouw, 2010; Taylor, 2014).

Climate change-based projects, programmes, and policies put more effort on either the emissions reduction of greenhouse gas (climate change mitigation) or creation of the suitable environments for social institutions and people to be able to adjust to the prevailing climate risks and variability making communities to be more resilient to the past and future climate change impacts (climate change adaptation). These projects, programmes and policies are normally initiated at different levels of government and administration covering varying spatial scales such as local communities, regions, large cities, and countries while always targeting specific places on the ground where their impacts are felt (Mikulewicz, 2017). This makes different actors to be always involved with support from various channels of funding focusing on a diversity of issues and sectors such as land-use and energy, water management, catchment conservation, and basin planning, among others (Fairhead *et al*., 2012; Ziervogel *et al*., 2017).

The aim of most of these initiatives is to review the use of natural resources such as water, land, and forests including their management and governance while developing built infrastructures and steering the society towards low-carbon technologies that serve climate change adaptation and mitigation purposes (Paterson and Laberge, 2018). The initiatives normally come up with effective frameworks aimed at changing practices for supporting climate change adaptation and mitigation policy objectives. These frameworks, including the associated interventions and policies are not neutral. The frameworks change the boundaries of what is illegal and legal, balance risks, opportunities and responsibility, redefine the advantages and disadvantages and the responsibilities and benefits (Béné *et al.*, 2014; Marino and Ribot, 2012)

The understanding and knowledge of the actual impacts of the interactions between the climate change interventions and policies, and the development processes and policies, related resources challenges on the ground and climate change policies in general is limited. This is more specially to understand the possible relationships between interventions which are related to issues touching on poverty and climate change, inequality and exclusion, between other relevant sector policies such as energy, water, agriculture, forestry among others including the conditions for creating conflicts and climate change policies.

The debates currently going on globally on the relationships between development policies and climate change emphasize on the possibilities of their linkages in several ways (Käkönen *et al.*, 2014; Wright and Nyberg, 2017). How development policies and climate change address the issues related to vulnerability, marginalization, and poverty, is one of the concerns (Ribot, 2014), raising an alarm on the translation and interpretation of climate change policies and initiatives (Cavanagh and Benjaminsen, 2017). Considering typical development programmes or projects, it is possible to implement climate change adaptation or mitigation initiatives without considering the wider ecological, social, and other contexts in which resilience, adaptation, and vulnerability are related to the reality by worsening or creating problems instead of solving them (Routledge *et al.*, 2018).

The relationship between conflict, resource availability, and climate change is not conclusive (Scheffran *et al.*, 2012), particularly due to lack of understanding the relationship between the policy, developmental, and local processes and conflict management are difficult to relate only to climate change (Bavinck *et al.*, 2014; Ratner *et al.,* 2017).

Designing of a "win-win" and a "triple-win" interventions and solutions is one of the currently emerging strategies for the integration of policies for development and climate change. These interventions or solutions need to seek the achievement of a balanced adaptation actions that are within the framework of sustainable development (Pyke *et al*., 2007; Swart and Raes, 2007). There are several factors that have been suggested for considerations during the evaluation of designs for combined adaptation policy (Swart and Raes, 2007). These factors include

1. Identification of collaborations.
2. During the design of adaptation policies, there should be no trade-offs.
3. Enhancing capacity for response.
4. Sustainable development policies for incorporating adaptation issues.
5. Development of linkages for international and national institutions.

There exist several enabling legal and policy for guiding Kenya's response to impacts of climate change:

(a) The national overarching policy that includes the Vision 2030 and the Constitution.

(b) The national climate change policies comprising of the National Adaptation Plan from 2015 to 2030, the Kenya's National Climate Action Plan from 2013 to 2017 and the current 2018 to 2022, the Climate Change Framework Policy of 2017, the Climate Change Act of 2016, and the National Climate Change Response Strategy of 2010.

(c) National Supporting Policies and Regulations such as the National Climate Smart Agriculture Strategy, the Environmental Management and Coordination Act (EMCA), the Climate Risk Management Framework, and the Green Economy Strategy and Implementation Plan (GESIP).

(d) Counties frameworks through the Climate Change Fund regulations.

(e) Regional frameworks including the East Africa Community Climate Change Policy, Strategy and Master plan, and Africa Agenda 2063.

(f) International frameworks such as link to Sustainable Development Goals (SDGs), Nationally Determined Contributions (NDC), UNFCCC, and Paris Agreement.

(g) Institutional and Governance structures have been set out in the Climate Change Act of 2016 to guide the actions. Good examples include NCCAP, role of counties, Climate Change Fund, and putting in place the National Climate Change Directorate as the lead agency, among others.

CHAPTER THREE
DATA AND METHODS

3.1 Introduction

In this chapter, transdisciplinary research methodologies used in this study are presented and discussed. These include (1) downscaling the GCM data using the statistical applications to assess the climate change scenarios in the Sondu Miriu basin, (2) application of the IPCC technical guide for assessing the impacts of climate change and adaptation to determine the impacts of the climate variability and climate change on hydropower development and the local community within the basin, (3) participatory methodologies using questionnaires, key informant interviews and observations for determination of strategies that are most appropriate and sustainable for climate change adaptation in the development of hydropower within the Sondu Miriu River basin, and (4) policy analysis framework for the evaluation of the existing policies to propose policy options for the integration of climate change adaptation into the development of hydropower within the Sondu Miriu river basin.

3.2 Area of study

Sondu Miriu River basin has got two ROR hydropower projects running. The basin supports various socioeconomic activities within the basin and in the neighbouring basins. It is, therefore, of interest to study the interaction between hydropower development and socioeconomic and environmental activities in this area.

3.3 Location and description of the study area

Located in the western Kenya, Sondu Miriu river basin is as one of the basins within the Lake Victoria drainage system (Figure 3-1). There are two run-of-river hydropower projects within the Sondu Miriu basin that draw water from Sondu Miriu river, namely Sang'oro and Sondu Miriu, for generation of hydroelectric power into the Kenya national electricity grid.

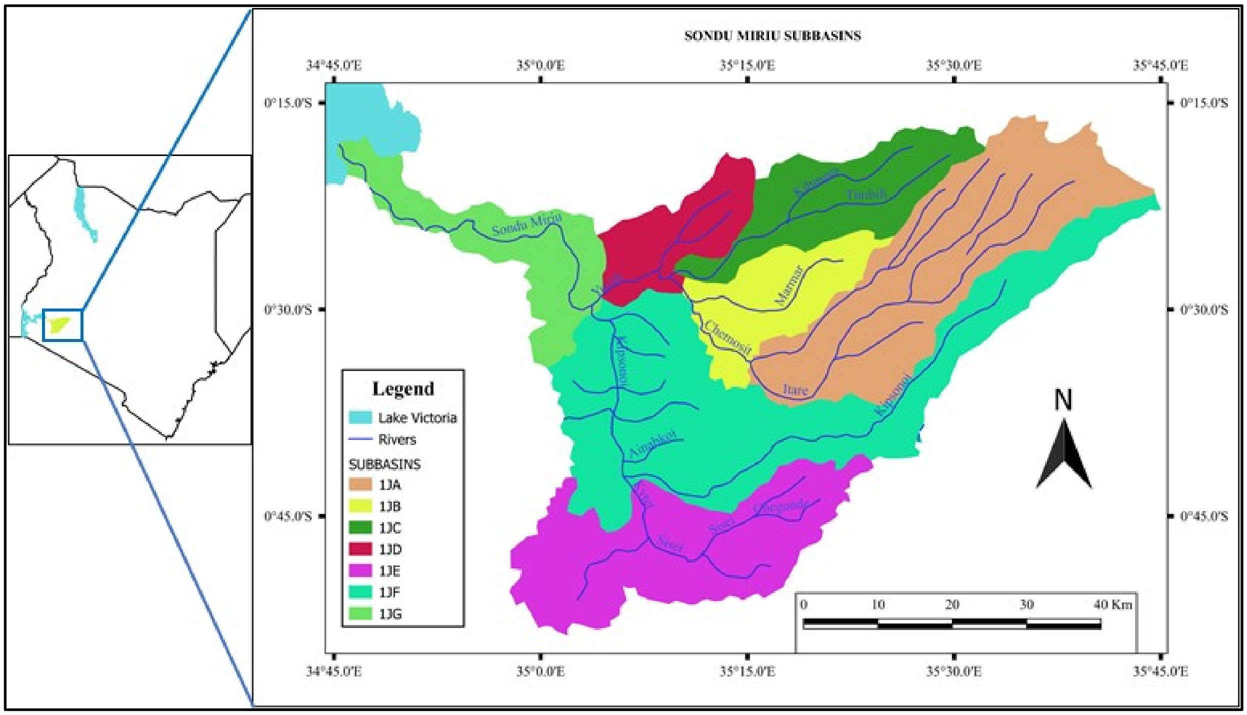

Figure 3-1: Map of Sondu Miriu river basin ***Source: World Resource Institute,2017***

The location of Sondu Miriu River basin is geographically confined within latitude 0º17' S and 0º53'S and longitude 34º45'E and 35º45'E. Among the Kenya's river basins draining into Lake Victoria, Sondu Miriu river basin is the fourth largest covering an approximate area of 3,500 km^2 (Masese *et al*., 2012). The main tributaries of the Sondu Miriu river are Yunith and Kapsonoi rivers. Sondu Miriu River originates from the Mau Complex which is an expansive water catchment within Kenya. Diverse development activities and land use types characterize the Sondu Miriu River basin. The development activities and land use include industries, energy, settlements, agriculture, and forestry, among others. The various current existing human activities that have been occurring at different intensities and scales over the years within Sondu Miriu basin have capability to cause a wide range of reaching consequences to several matters in the basin. A number of these issues included general river ecological status, the river system aquatic biodiversity and the various water uses quality. The sedimentation rates that have been observed to be on the increase within Sondu Miriu River has compromised, over the years, the river water quality in the basin (Masese *et al*., 2012).

3.4 Biophysical setting of Sondu Miriu river basin

Human activities within Sondu Miriu River basin are being influenced by the biophysical status within its boundaries. The scope of human behaviour is defined by the biodiversity status to be capable of fitting within the prevailing environment. The local communities' vulnerability to cope with climate change is determined by the prevailing conditions (Opere and Ogallo, 2006).

3.4.1 Climate of Sondu Miriu river basin

Several factors such as topography, distance from relatively large water bodies, prevailing winds characteristics, latitude, and altitude control the Sondu Miriu river basin climate (Masese *et al*., 2012). A more significant role is played by topography especially in locations having diverse relief and may form barriers in some cases to the prevailing winds. During the months of March and September when the sun is directly overhead, the insolation is always experienced at its highest. This normally results into the creation of a low-pressure region also recognized as the inter-tropical convergence zone (ITCZ). This ITCZ is a zone where air masses converge (Masese *et al*., 2012). There is inducement and transportation of the characteristics of climate associated with the air mass movement all over the whole region or entire area over which the air mass traverses through. Over the low-pressure belt, the air masses usually converge to cause cooling, condensation and precipitation due to the air mass upward movement (Government of the Republic of Kenya, 2010a).

Sondu-Miriu river catchment experiences bimodal rainfall pattern (Opere and Ogallo, 2006). The long rainfall season usually occur between March and May while short rainfall season usually occur between October and November. These seasonal variations are however widely experienced in the low-lying regions than the upland regions. Annually, the amount of rainfall received the basin varies from 1,800mm in the upland region to 1,500mm towards the low-lying regions (Masese *et al*., 2012). The amount of rainfall received in the area is influence by features such as relief and altitude. There is generally higher rainfall amount received in upland regions of the basin than the rainfall amounts received in mid and lower regions. The south-easterly winds cause the rainfall received in the highland areas. These winds are responsible for transporting warmer air masses towards the highlands from the Indian Ocean to cause orographic rainfall. In the lowlands close to Lake Victoria, most of the rainfall is as a result of the convective currents that occur in the lake. An annual average temperature of about 26ºC is experience in the lowlands. The mean annual maximum and minimum temperatures are about 30ºC and 18ºC respectively. For most of the year, the Sondu Miriu river basin experiences relative humidity of approximately 62% (Masese *et al*., 2012).

3.4.2 Population distribution within Sondu Miriu river basin

Within the Sondu Miriu river basin, the average population density is approximately 350 persons per kilometre square based on the Kenya national population census conducted in 2019 (Kenya National Bureau of Statistics, 2019). There is low population density in upland regions that are forest dominated than the middle and lower reaches within the basin. The lower reaches comprising the counties of Kisii, Nyamira, Kisumu and Homabay have got the highest population density within the Basin (Kenya National Bureau of Statistics, 2019).

3.4.3 Community livelihoods in the Sondu Miriu river basin

Within the Sondu Miriu basin, the local community livelihoods depend on trade, fishing and agriculture. In the upper part of the basin, Tea growing is the major practice while subsistence agricultural farming is common in the lower zones. Fishing along the Sondu-Miriu river is also common, particularly in the lower reaches. Small-scale business enterprises are also common in addition to fishing and agriculture within the area (Ayieko, 2007).

3.4.4 Biodiversity within Sondu Miriu river basin

Mau Forest Complex is the origin of Sondu Miriu river. The complex is a vast water catchment area in Kenya. Mau Forest Complex is also the origin of a number of rivers draining into Lakes Bogoria, Natron, Nakuru and Victoria. Nevertheless, the Mau Complex Forest cover has reduced because of subsequent transformation of forest land to agricultural use and deforestation (Kinjanjui *et al*., 2013; Masese *et al*., 2012). The diverse developments and land use types characterize Sondu-Miriu River basin including hydroelectric power generation, agro-based industries, sub-urban and urban settlements, large-scale and small-scale agriculture, and forestry. Due to the combined impacts of the existing human activities, and their increased intensity and scale throughout the years present multiple threats to the rivers' general ecology, aquatic biodiversity, and water quality. Evidently over time, increased sedimentation rates have been recorded in the status of water quality of Sondu-Miriu River (Masese *et al*., 2012).

3.4.5 Land uses and resources.

Arable land constitutes greater parts of the land within Sondu Miriu basin. The most land utilization in this basin include agricultural production purposes and forest cover also occupies a large percentage particularly in the upland regions (Figure 3-2). Agricultural land use includes crop production and pasture. Non-agricultural land uses include settlements, roads, and forest reserves.

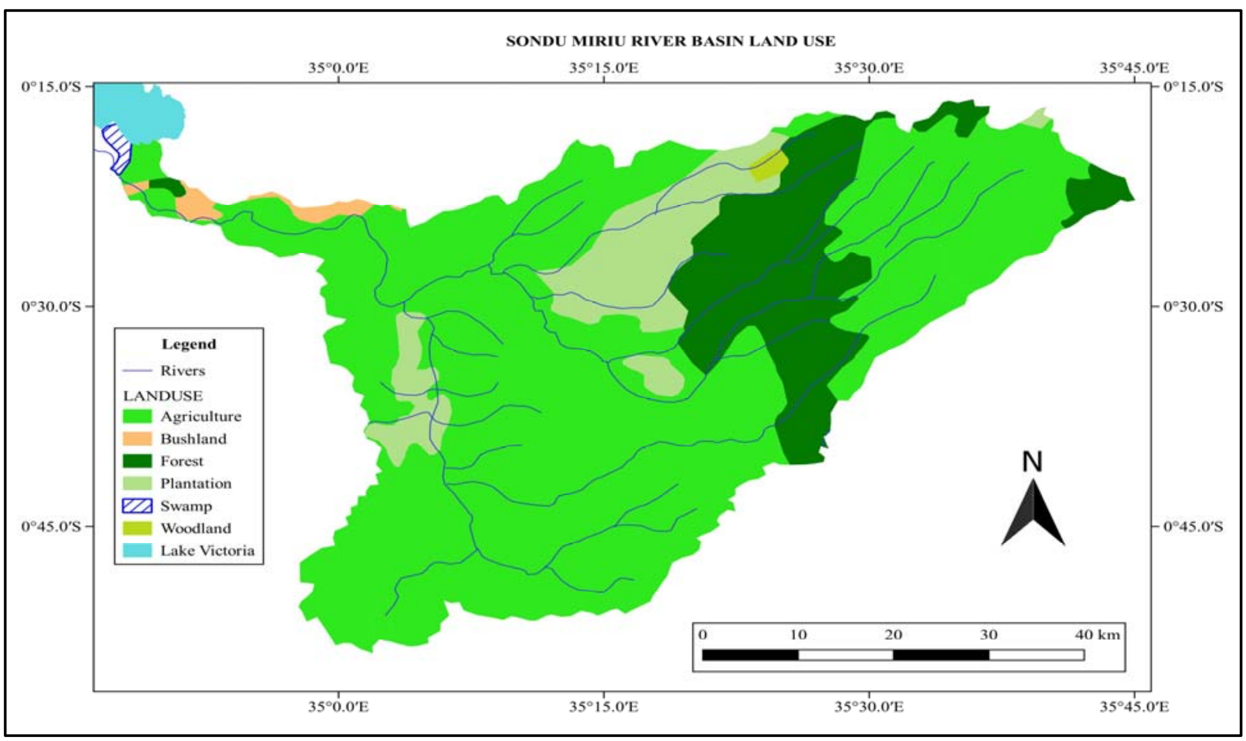

Figure 3-2: Land use cover Sondu Miriu ***Source: World Resource Institute, 2017***

3.4.6 Sondu Miriu drainage system

The main water sources for various uses in the basin is Sondu Miriu River and its tributaries. There is still minimal abstraction from ground water within the basin. The basin consists of permanent rivers with sufficient water flows throughout the year. To identify the watersheds, Water Resources Authority (WRA) has demarcated all the watersheds and with specific codes. Basins within Lake Victoria drainage area begin with “1”. The basins are marked with alphabets and in this case Sondu Miriu river basin is marked with “1J”. The subbasins are also marked with alphabets. Based on the WRA classification, the Basin is divided into seven (7) sub-basins (A to G) (Figure 3-1).

3.5 Socio-economic settings

Several factors with the basin influence economic activities and contribute a lot in shaping of the social behaviour. How a particular socioeconomic class or group behave is influenced by the local factors within the society including their actions.

3.5.1 Political and administrative context

The Sondu river basin traverses eight (8) counties namely HomaBay, Kisumu, Nyamira, Kisii, Kericho, Bomet, Nakuru and Narok. Bomet County has the largest share while Kisii County has got the least (Figure 3-4). This means that administration of the basin climate change adaptation actions needs to be harmonised among all the eight counties.

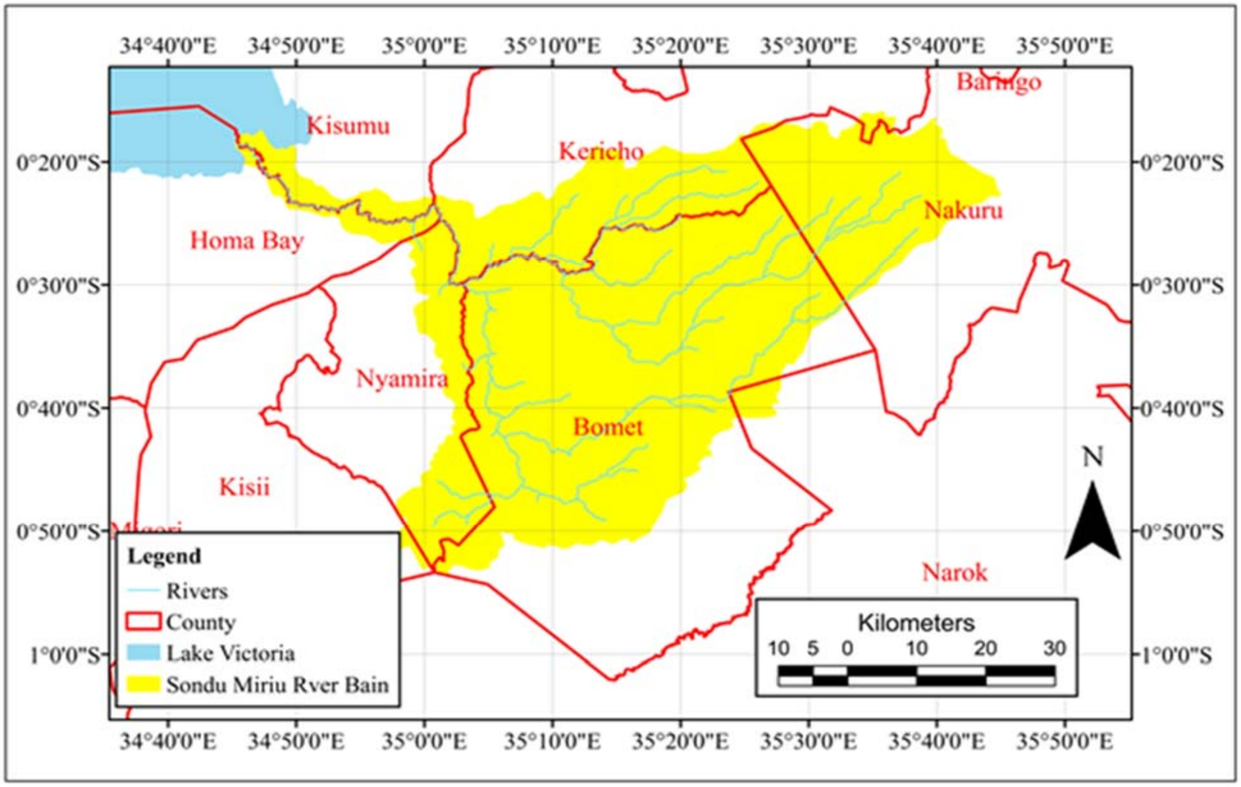

Figure 3-3: Counties covered by Sondu Miriu river basin. ***Source: World Resource Institute, 2017***

3.5.2 Socioeconomic status

The poverty levels are high among the local communities living in this area (Mwangi, 2013). The main source of income within the basin is either from self-employment or their farm produce. Only the privileged few have access to the existing formal employment with steady income within the area. The income disparities within the basin are wide which presents a symptomatic indication of imbalance among the communities locally (Olago *et al*, 2007). Bomet county has the largest household sizes with the highest percentage having more than 6 members while Nakuru county has the smallest household sizes with the highest percentage having less than 3 members. Bomet, Kisii and Nyamira counties have the highest percentage below poverty line at 51% while Nakuru county has the lowest percentage below poverty line. Nakuru county leads in formal employment rate at 30% while Narok leads in informal employment rate at 83.3% with the highest unemployment rate recorded in Kisumu and Nakuru counties at 8.2% (Tables 3-1).

Table 3-1: Socioeconomic status Sondu Miriu River basin counties

		County							
		Bomet	**Homabay**	**Kericho**	**Kisii**	**Kisumu**	**Nakuru**	**Narok**	**Nyamira**
Percentage of household sizes	0 - 3	30	35	34	32	42	49	30	33
	4 - 6	42	43	42	46	40	37	43	48
	> 6	28	22	24	22	18	14	27	19
	Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Percentage below poverty line		51	48	39	51	40	34	41	51
Poverty gap as percentage of poverty line		10	10	8	12	9	6	7	11
Percentage in formal employment		18	14	24	14	25	30	13	15
Percentage in informal employment		79	79.4	72.2	82.5	66.8	61.8	83.3	82.4
Percentage unemployed		3	6.6	3.8	3.5	8.2	8.2	3.7	2.6
Total		**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

(Source: Mwangi, 2013)

3.5.3 Regulatory framework

There are several laws and institutions that regulate the activities with the river basin in Kenya. These includes Environmental Management and Coordination Act (EMCA) 1999, Agricultural Act 2012, Water Act 2016, Land Act 2012 and Climate Change Act 2016. Water Resources Authority (WRA) manages the water resource allocation and use within the basin as stipulated in the water Act 2016 while the National Environment Management Authority (NEMA) enforces environmental protection and conservation as stipulated in the EMCA Act 1999.

3.6 Conceptual framework

The conceptual framework adopted a transdisciplinary approach which looked at climate change characteristics in the Sondu Miriu basin including how it affected water resource availability for hydropower development process and operations. It also looked at how a combination of the development of hydropower and climate change affected community livelihood in Sondu Miriu basin. This incorporated climate change issues at all the stages of hydropower development and consultation with appropriate stakeholders to address the climate change challenges associated with hydropower development (Figure 3-4). For hydropower sustainability and enhanced community resilience, appropriate strategies need to be put in place for climate change adaptation together with necessary policies to support the strategies.

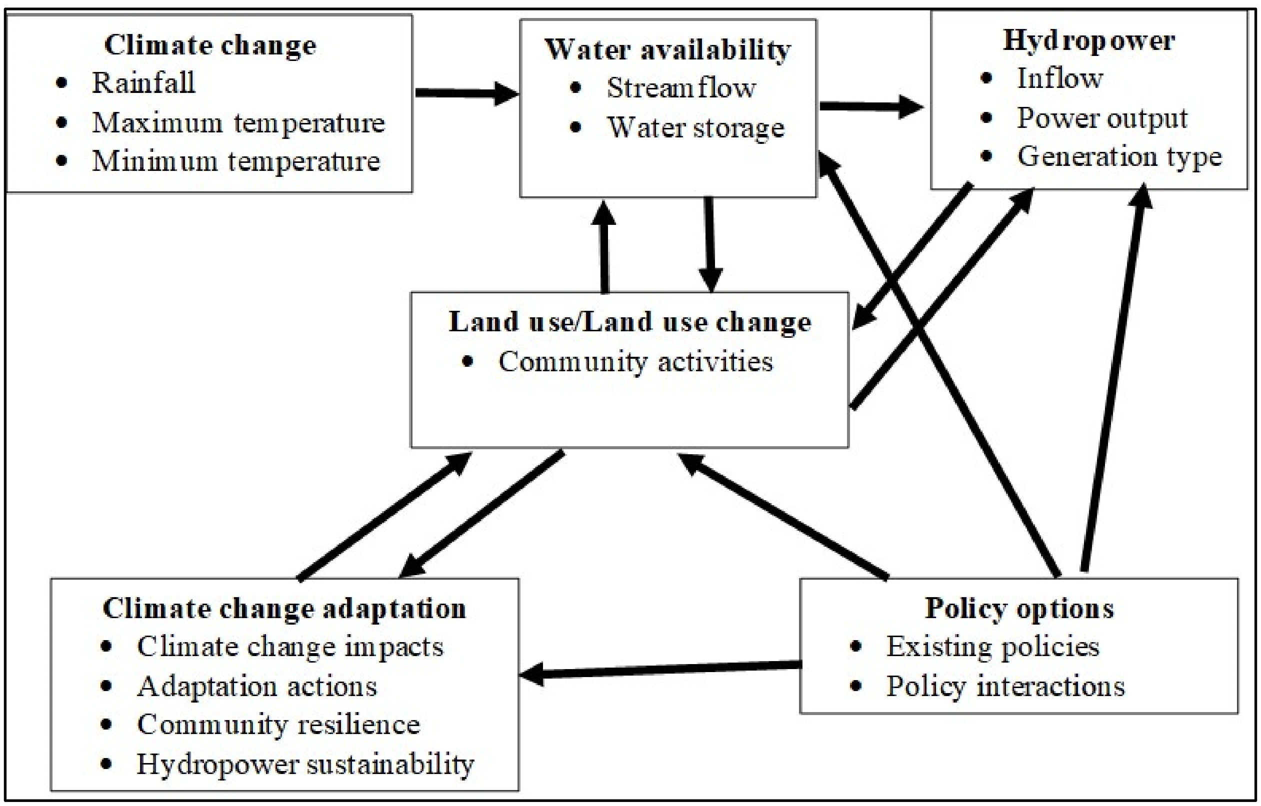

Figure 3-4: Conceptual framework

The first step is to study the past climate change characteristics and the future projected climate change scenarios. This will determine the climate change impacts on the availability of water resources and by extension the hydropower generation. The second step is to assess the impacts that are caused by both the development of hydropower and climate change on the local community livelihood. The climate change impacts will determine how the community will reacts through land use and this will result into land use changes. The third step will involve determining climate change adaptation measures to address the impacts of climate change through enhancement of community resilience and ensuring hydropower sustainability. This will require putting in place strategies for climate change adaptation to give guidance for the appropriate adaptation actions. The fourth step is to assess the policy options for supporting the strategies for climate change adaptation for enhancement of the community resilience and hydropower development and sustainability.

The results obtained over the transdisciplinary research period are integrated into the societal and scientific practice. At this stage, the most appropriate and sustainable strategies for climate change adaptation for the development of hydropower within Sondu-Miriu river basin that are supported by scientific theories will be described in detail including the processes and the roles of various actors. This should also be backed up with the policy issues to be addressed to support the proposed strategies.

3.7 Methodology for specific objective one

Specific objective one was to assess the trends of climate change within the Sondu Miriu River basin.

3.7.1 Data for specific objective one

Downscaled climate data is from 1950 to 2100, consisting of daily rainfall, minimum temperatures, and maximum temperatures from CORDEX were downloaded from https://cordex.org/data-access/ for the purpose of extracting historical and future climate scenarios for the Sondu Miriu River basin.

CORDEX historical and projected climate scenarios were used to compare with the present trends from 1981 to 2018 to facilitate the determination climate change status of over Sondu Miriu River basin. The scenarios were based on the downscaled global circulation models. Scenarios from five models were considered namely Canadian Climate Change Modelling and Analysis (CCCMA), National Centre for Meteorological Research (CNRM), Max Planck Institute for Meteorology (MPI), Model for Interdisciplinary Research on Climate (MIROC), and National Oceanic Atmospheric Observations (NOAA). Ensembles for the five models were used for the analysis of the historical and projected scenarios. The historical scenarios were for the period from 1951 to 2005 while projected scenarios were from 2006 to 2100. The CORDEX projections were used due to their improved fit to observations of precipitation and temperature in most of the African sub regions. CORDEX downscaled projections were based on the Representative Concentration Pathway (RCP) methodology as was adopted by the IPCC for the preparation of the fifth assessment report (IPCC, 2014). For this study RCP8.5 and RCP4.5 have been adopted as the most likely scenarios. The RCP4.5 represent stabilization scenario while RCP8.5 represent high emission scenario.

3.7.2 Data analysis for specific objective one

The annual and seasonal trends of climate scenarios (RCP4.5 and RCP8.5), grided rainfall and temperature data, river flows and electricity output data were determined through trend analysis using Microsoft Excel. The data was grouped into annual and seasonal data sets. the data was subjected to curve fitting to capture the trends in climate change and their magnitudes within the Sondu Miriu River basin. Linear curve fitting was adopted to determine the rate of change with time. The curve fitting was performed for all the data sets both annually and seasonally.

3.8 Methodology for specific objective two

Specific objective two was to assess the impacts of climate change trends on the production of hydropower. A correlation analysis was performed on the rainfall and stream flows within the Sondu Miriu river basin.

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$ ……………………… Equation 1

Where $\bar{x}$ is the mean of variable x values, and $\bar{y}$ is the mean of variable y values.

3.8.1 Data for specific objective two

The gridded daily minimum temperatures, maximum temperatures, and rainfall data for the Sondu Miriu River basin from 2007 to 2018 were obtained from Kenya Meteorological Department (KMD). The daily river flow from and monthly energy generation data from 2007 to 2018 were collected from Water Resources Authority (WRA) and Kenya Electricity Generating Company (KenGen) respectively. The hydropower projects within the Sondu Miriu river basin have been in operation from October 2007.

3.8.2 Data analysis for specific objective two

The data used for the assessment of climate change impacts on the production of hydropower was from 2008 to 2019 and 2013 to 2019 for Sondu Miriu and Sang'oro, respectively to perform correlation analysis between the climate scenarios and hydropower output. This also considered annual and seasonal changes. Correlation analysis between the observed river flow and observed rainfall was performed to determine the level of influence rainfall over the catchment influences river flow for Sondu Miriu river. During the same period (2008 – 2018) the observed and projected rainfall and temperature was also compared through correlation analyses and statistical t-test for confidence level to determine the reliability of the climate projection scenarios. T-test was selected as suitable for comparing two groups (flow and rainfall, observed and projected climatic conditions).

3.9 Methodology for specific objective three

Specific objective three was to determine the impacts of hydropower development and climate change on livelihoods of the local community living in the Sondu Miriu basin. Qualitative social research methods were adopted to explore the community views on the impacts of the hydropower projects. These methods include questionnaires administration at household levels and in-depth interviews due its ability to offer flexibility to understand and explore fully most of the issues from the affected people's perspective. The study selected a sample size of 378 households distributed among the Sondu Miriu river subbasins based on the 2019 population census. The questionnaires were distributed on the basis of population sizes of the sub-basins. The in-depth interviews were conducted at the various existing development actors and local administration offices such as chiefs and assistant chiefs within the Sondu Miriu river basin. The questionnaires were to collect response on the range of socio-economic status of the livelihoods of the local communities within the Sondu-Miriu river basin such as income sources, energy sources, economic activities, sources of water and health.

3.9.1 Data collection for specific objective three

The socioeconomic data were collected from the community within the seven subbasins in the Sondu Miriu river basin through administration of questionnaires at household levels, interviews, key informants, and observation. The sub-basins are based on the Water Resources Authority classification of river basins in Kenya.

Simple random sampling method was adopted for household data collection. In this method, there is an equal chance of every member of the population being selected to respond to the questionnaire. The population total within the basin is approximated at 108,533. Based on an average household size of 5 members per household, the total households in the basin are estimated to be 21,707. The sample size was determined using sample size formula (Equation 1).

Sample size formula

$$n = N \times \frac{\frac{Z^2 \times p \times (1-p)}{e^2}}{\left[N - 1 + \frac{Z^2 \times p \times (1-p)}{e^2}\right]}$$

………………………………………….. Equation 2

Where,

n = Sample size

N = Population size,

Z = Critical value of the normal distribution at the required confidence level,

p = Sample proportion, and e = Margin of error

Sampling frame was based on the Sondu Miriu basin map. This ensured that all the seven (7) sub-basins were covered in the sampling with questionnaires administered in 378 households (Table 3-1). The questionnaires were administered at household levels (Appendix I). In-depth interviews with the local leadership comprising 14 chiefs/assistant chiefs were conducted in every sub-basin (Appendix II) while the in-depth interviews with the local development actors comprising Kenya Electricity Generating Company (KenGen), Water Resources Authority (Lake Victoria South (WRA-LVS) catchment area), Lake Basin Development Authority (LBDA), Kenya Agricultural and Livestock Research Organization (KALRO), and National Environment Management Authority (NEMA) were conducted at their respective offices within the vicinity of the existing hydropower projects (Appendix III).

This provided for continuous field data analysis, using constant comparison and coding methods through the grounded theory guided guidance (Strauss and Corbin 1990; Charmaz 2006). As a means of validating interpretations of the results of the analysis, discussions were held with the interviewees.

Views from the local leaders and development actors were collected and documented as suggestions that need to be considered during stakeholders' consultations.

Table 3-2: Administration of questionnaires per sub-basins

S/N	Sub-basin	2010 population	Estimated No. of households	Sample size
1	1JA	11,641	2,328	41
2	1JB	5,493	1,099	19
3	1JC	23,969	4,794	83
4	1JD	14,933	2,987	52
5	1JE	11,940	2,388	42
6	1JF	31,941	6,388	111
7	1JG	8,616	1,723	30
	Total	**108,533**	**21,707**	**378**

3.9.2 Data analysis for specific objective three

Statistical analysis of the responses was performed to determine and quantify the community baseline in the light of climate variability and climate change together with hydropower generation development in the area on the local community living in the Sondu Miriu river basin. Statistical mean was computed for the socioeconomic parameters based on the responses received through questionnaires. This was used to determine response of the community on various socioeconomic issues such as main source of income, average monthly income, source of energy, primary economic activities, secondary economic activities, domestic water sources, expenditure on health and distance from health facilities.

3.10 Methodology for specific objective four

Specific objective four was to identify appropriate and sustainable climate change adaptation strategies during hydropower development process. To guide the evaluation of strategies for climate change adaptation in Sondu Miriu River Basin, the IPCC technical guidelines was adopted for the assessment of climate change impacts and adaptations (Carter *et al.,* 1994). It provides guidelines on the procedures for assessing potential climate change impacts and evaluation of appropriate adaptation actions. A study framework is outlined that allows for comparison assessments on impacts of changing climate and adaptation actions suitable for various geographical regions, economic sectors, and countries (Carter *et al.,* 1994).

3.10.1 Existing strategy documents

The available strategy documents that address climate change and its impacts were obtained from the Kenyan Ministry of Environment and Forestry. Officially, the main guide for information on climate change strategy is the National Climate Change Response Strategy (NCCRS) enacted in the year 2010 which was the first Kanya national policy document to fully acknowledge the reality of climate change. This strategy provided the evidence of impacts of climate change on several economic sectors together with proposed strategies for mitigation and adaptation. This strategy aims to address the climate change impacts across all sectors.

The National Climate Change Action Plan (NCCAP) was another critical document with the main purpose of operationalization of the NCCRS. The NCCAP development was done through an extensive consultative process that made the document to be acceptable across all the sectors. The NCCAP has been receiving a lot of support from the development partners and various stakeholders from all sectors including energy. The provision of the guidance on the national policy decisions and development is expected to come from NCCAP for all the economic sectors. After every five years, the NCCAP is updated to conform with the national budgetary and planning processes. For this study, the National Climate Change Action (2018 – 2022) was evaluated.

3.10.2 Data analysis for specific objective four

The factors that were evaluated in the existing strategy include (1) defining the objectives of the adaptation strategies, (2) specification of the climate change impacts which are important for the hydropower generation and community livelihood, (3) identification the relevant climate changa adaptation options, (4) examination of the limitations, (5) quantification of the measures and formulation of the alternative strategies, (6) weighting the adaptation objectives and evaluating the trade-offs, and (7) adaptation measures recommendations as outlined in the IPCC technical guidelines for the assessment of the impacts of climate change and climate change adaptations (Carter *et al.,* 1994).

3.10.2.1 Defining the objectives of the adaptation strategies:

The overall objective is to integrate of climate change adaptation measures into the development of hydropower projects within Sondu Miriu Basin specifically determining the most appropriate and sustainable strategies for integrating adaptation measures into the development of hydropower.

3.10.2.2 Specifying the climate change impacts of importance

This involved assessing all the possible impacts of changing climate on the hydropower projects and the livelihoods of the local communities within Sondu Miriu basin. It includes specific details of climatic events expected to affect hydropower generation and local community livelihoods to be able to identify adaptation options that are most appropriate.

3.10.2.3 Identifying the adaptation options

A list detailing all the possible adaptation actions for coping with climate change impacts was compiled through field surveys and literature review. It considered all practices that were previously used or are currently being used as well as other feasible alternative strategies that may be suitable for the basin.

The identification of the strategies for adaptation was guided by the IPCC technical guidelines for adapting to the climate change impacts which include (1) loss prevention that involves anticipatory actions for reducing the susceptibility of an exposure unit to the climate change impacts, (2) loss toleration that involves in the short term accepting adverse impacts that the exposure unit can absorb without causing long term damage, (3) loss sharing or spreading that involves actions intended at distributing burden of climate change impact for covering a larger population or region beyond those affected directly by the climatic event, (4) changing of activity or use that involves switching of resource use or an activity to make it possible to adjust to the positive impacts and the negative impacts of climate change, (5) change of location that involves a situation where an activity preservation is considered to be more important compared to the place where it is located, and migrating to the areas that are considered suitable under the changed climate, and after the modification or damage due to climate change, carry out restoration with an aim of restoring the system to its original condition.

3.10.2.4 Examining the constraints

The existing constraints that may affect the implementation of available climate change adaptation actions choices were examined on how they might affect the possible choices available. These constraints include prevailing social norms and existing legislations, which may prohibit, restrict, or encourage their application.

3.10.2.5 Quantifying the measures and formulating alternative strategies

Each adaptation measure performance was assessed in line with the adaptation objectives for the respective adaptation strategies. Under the different climatic scenarios, expert judgement was used to evaluate the success of different measures. At this stage, risk assessment and uncertainty analysis were also considered. This was a critical step for the development of strategies to maximize the achievements of the adaptation objective while at the same time maintaining the baseline levels of progress towards the other objectives of the adaptation strategies.

3.10.2.6 Weighting the objectives and evaluating the trade-offs

The objective of the strategies was subjective in this step depending on the preferences and then comparative analysis among the success of various strategies in meeting their objective. Standard impact accounting system was applied in the evaluation process. Selection of preferred strategies was determined based on the trade-offs between the available strategies.

3.10.2.7 Recommending adaptation measures

The outcome of the evaluation process was put in the format to provide the policy decision makers and advisers with information on the best strategies available for adaptation. This included the rationale used such as key evaluation principles, decision rules, institutional capability, national and international support, technical capability to narrow the choices and some indication of the uncertainties and assumptions involved in the evaluation procedure.

3.11 Methodology for specific objective five

Specific objective five was to review and identify appropriate policy options for integrating climate change adaptation into the development of hydropower. The policies reviewed covered international, national, and county policies.

Adaptation involved specific dedicated measures together with considerations for integrating adaptation into hydropower development processes that exist and activities in Kenya and particularly in Sondu Miriu River basin. Policy evaluation often uses social science and economic research methods, including quantitative and qualitative techniques, in examining the impacts of the policies. Various types of theories, sources, methods, data, and analyses can be put together in evaluations (European Environment Agency, 2016).

3.11.1 Existing policy documents

A total of 25 policy documents at global, regional, national, and county levels were reviewed touching on hydropower development and climate change. At the global level, United Nations Framework Convention on Climate Change (UNFCCC) document was reviewed. The three regional policy documents reviewed included African Union's Agenda 2063, the Climate Change Policy and Strategy for the East African Community (EAC), and the Climate Change Adaptation Strategy and Action Plan for the Lake Victoria Basin Commission. There were fourteen national policy document collected up to the year 2019 namely the 2010 Constitution of Kenya, Kenya Vision 2030, the Climate Change Act 2016, Kenya's National Climate Change Action Plan (NCCAP), Kenya's National Adaptation Plan 2015-2030 (NAP), Kenya's National Climate Change Response Strategy, Kenya's Nationally Defined Contribution (NDC), The Climate Risk Management Framework for Kenya, The Kenya Climate Smart Agriculture Strategy (KCSAS), The National Climate Finance Policy, The National Climate Change Framework Policy, Water Act of 2016, Energy Act of 2019, and the Government of Kenya's Big Four Agenda. The County Integrated Development Plans (CIDPs) for the eight counties forming part of the Sondu Miriu river basin were collected and studied at the county level.

3.11.2 Policy assessment

Assessment of the local, national, regional, and global policies documents on the energy and climate change were carried with the main aim of identifying policy options to support the integration of adaptation into the development of hydropower for the reduction of the local communities' vulnerability in Sondu Miriu basin.

Theory-based evaluation approach was adopted and focused on how the existing policies intend to work. A more comprehensive picture can be provided through theory-based evaluation since the theory-based assessment depends on a wider mapping of the factors with much impact on achievement or failure and considering the interaction of these factors. A close monitoring of the factors which have critical influence on the policy performance can be evaluated using theory-based evaluation approach. Evaluation of whether the implementation of programmes or policies are done in line with theory or not can also be assessed through theory-based evaluation (Harmelink *et al.*, 2005).

The existing policies for integrating climate change adaptation was assessed using the "theory-based policy evaluation" involving six steps. These steps included;

(1) The policy instrument characterization that involved descriptions of the policy instruments including their targets, active period of the policy instruments, groups being targeted, implementing agencies of the policy instruments, provision of the budget and effectiveness of the policy instruments.

(2) Assessment of the policy implementation programme including assumptions on how the policy instruments are planned to reach their intended impacts. Mapping of the cause-impact relationship including the relationship with other existing policy instruments and documentation of the assumptions in the processes for policy implementation are key components when drawing up policy principles.

(3) Translation of the program principles to quantifiable indicators by drawing up an indicator to measure, for each assumed cause-impact relation, if there was cause-impact relationship and measuring if the policy instruments implementation is what necessitated the change that took place.

(4) Visually reflected in a flowchart the cause-impact relationships and the indicators,

(5) Verified the policy principles. This was done through interviews with implementing

agencies, policy makers, and other relevant actors implementing and monitoring the policy instruments.

(6) Gathered available information for analysis to put together the indicators for making conclusions on the effectiveness and efficiency of the policy instruments using procedures and indicators, analysing the success and failure factors that can be linked to the analysed instruments, and making recommendations for improvement of the effectiveness and efficiency of the policies.

CHAPTER FOUR

RESULTS AND DISCUSSIONS FOR SPECIFIC OBJECTIVE ONE

4.1 Introduction

In this chapter, the results and discussions are presented on the climate change trends within the Sondu Miriu River basin. The results presented include annual and seasonal rainfall and temperature trends.

4.1 Results for specific objective one

Sondu Miriu River basin experiences two wet seasons and two dry seasons. The results are presented in the form of annual and seasonal trends. The seasons are classified as cool season for the period of June to September, short rainfall season for the period of October to December, dry season for the period of January and February, and long rainfall season for the period of March to May.

4.1.1 Historical temperature trends

The results of the ensembled historical trends for minimum and maximum temperatures within Sondu Miriu basin are presented from 1951 to 2005. Generally, the results show that both the minimum and maximum temperatures have been increased within Sondu Miriu River basin in the past from 1951 to 2005.

4.1.1.1 Annual temperature trends

There was a mean increase of 0.02^0C and 0.01^0C per year for the annual minimum and maximum temperatures respectively in the Sondu Miriu River basin (Table 4-1). Therefore, for the period between 1951 and 2005, there was an increase by 0.89^0C and 0.73^0C for the minimum and maximum temperatures respectively within the Sondu Miriu river basin (Table 4-1). This indicates that for the period between 1951 and 2005 the minimum temperature rose by a higher margin compared to the maximum temperature.

Table 4-1: Historical temperature trends

Temperature	Annual (^{0}C)	Change from 1951 to 2005 (^{0}C)
Minimum	0.02	0.89
Maximum	0.01	0.73

The annual minimum and maximum temperatures trends indicate increasing trends for both the minimum and maximum temperatures within the Sondu Miriu River basin (Figure 4-1). The lowest minimum temperature was experienced in 1964 at approximately 11.8^{0}C while the lowest maximum temperatures were experienced in 1964 and 1968 at approximately 22.2^{0}C. The highest minimum temperature was experienced in 2005 at approximately 13.4^{0}C while the highest maximum temperature was experienced in 2005 at approximately 23.8^{0}C (Figure 4-1). The temperature trends indicate that the minimum temperature increase has been higher than the maximum temperature increase.

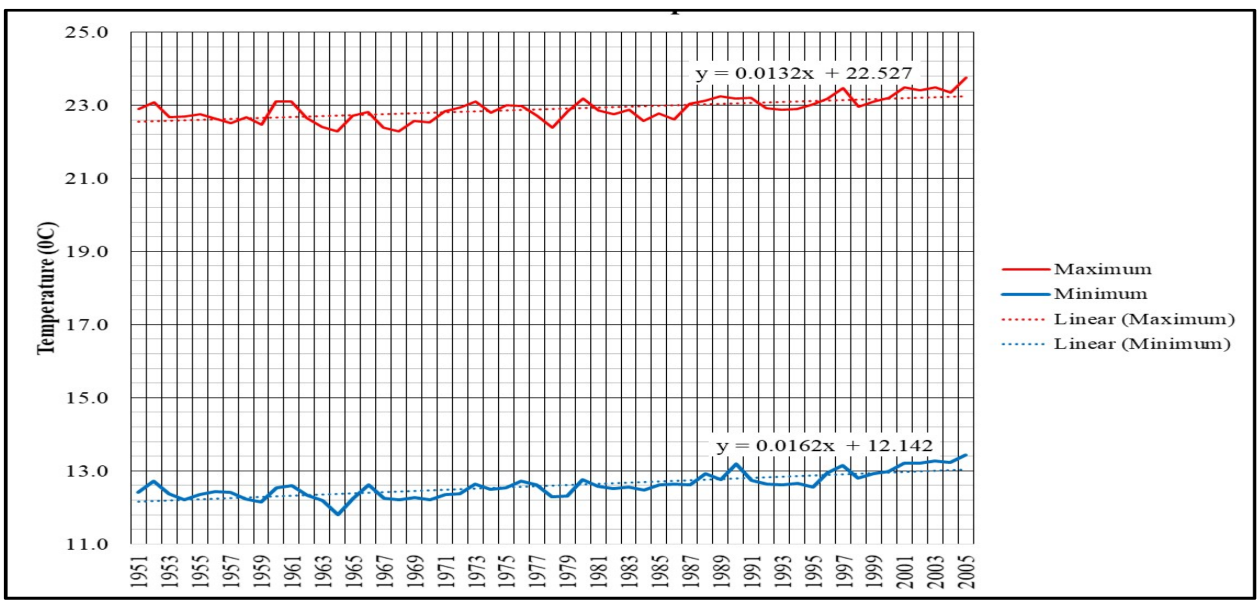

Figure 4-1: Historical trends of annual temperature (1951 – 2005)

4.1.1.2 Trends of seasonal minimum temperature

October to December season presents the highest minimum temperature increase at an average of 0.02^0C annually while January to February season presents the least increase at an average of 0.01^0C annually. March to May seasonal minimum temperature increased at a rate of 0.02^0C while June to September season increased at a rate of 0.02^0C. For the period between 1951 and 2005, the observed temperature increased by 0.81^0C in January to February season, 0.83^0C in the March to May season, 0.85^0C in the June to September season and 0.96^0C in the October to December season (Table 4-2). Comparing all the four seasons, the short rainfall season of October to December period has recorded the highest minimum temperature rise. This is followed by the cold season of June to September and then the long rainfall season of March to May while the dry season of January and February recorded the least minimum temperature rise.

Table 4-2: Historical seasonal minimum temperature trends

Season	Annual (^{0}C)	Change from 1951 to 2005 (^{0}C)
January to February	0.01	0.81
March to May	0.02	0.83
June to September	0.02	0.85
October to December	0.02	0.96

The seasonal temperature trends within the Sondu Miriu River basin indicated that the minimum temperatures have generally increased from 1951 to 2005. The trends vary from season to season. For January to February season, the lowest observed minimum temperature was approximately 11.1^0C in 1964 at while the highest was approximately 13.4^0C in 1990. The lowest observed minimum temperature for the March to May season was approximately 11.6^0C in 1959 while the highest was approximately 13.5^0C in 2003 and 2005. The observed minimum temperatures in the June to September season were generally lower compared to other seasons with the lowest minimum temperature being approximately 10.4^0C in 1970 while the highest being 12.4^0C in 2005. The October to December season recorded lowest minimum temperature of approximately 11.2^0C in 1964 while the highest minimum temperature of approximately 12.9^0C was observed in 2003

(Figure 4-2). From the temperature trend, it is evidence that all the seasons have been recording positive temperature trends.

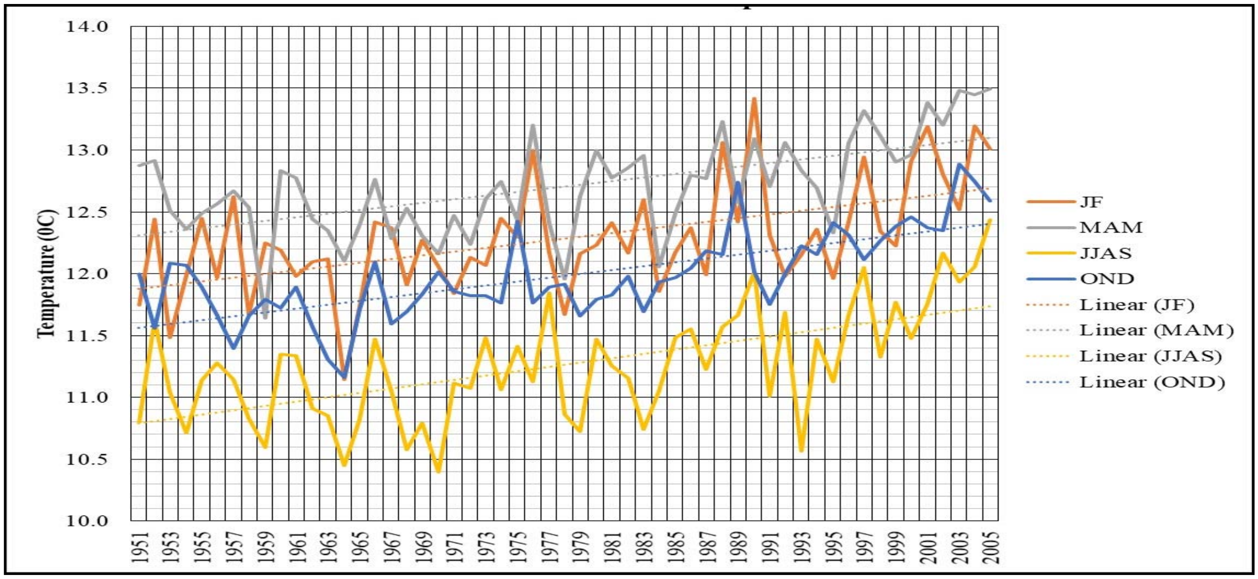

Figure 4-2: Historical seasonal minimum temperature trends (1951 – 2005)

4.1.1.3 Seasonal maximum temperature trends

For the maximum temperature trends, June to September season recorded the highest increase at a rate of approximately 0.02^0C per year. This was followed by long rainfall season of March to May and short rainfall season of October to December at an average rate of approximately 0.02^0C and 0.01^0C per year respectively while the January to February season recorded the lowest increase at a rate of approximately 0.01^0C per year. From 1951 to 2005 (a period of 55 years), the maximum temperatures increased by 0.43^0C in January to February season, 0.90^0C in the March to May season, 0.95^0C in the June to September season and 0.74^0C in the October to December season (Table 4-3). For the maximum temperature, the highest temperature increase was recorded in the cold dry season followed closely with the long rainfall season. The short rainfall season recorded the third highest maximum temperature rise while the least maximum temperature rise was recorded in the hot dry season.

Table 4-3: Historical seasonal maximum temperature trends

Season	Annual (^{0}C)	Change from 1951 to 2005 (^{0}C)
January to February	0.01	0.43
March to May	0.02	0.90
June to September	0.02	0.95
October to December	0.01	0.74

The seasonal maximum temperature trends in the Sondu Miriu basin have generally increased from 1951 to 2005. The January to February season recorded the lowest maximum temperature of approximately 24.9^{0}C in 1969 at with the highest of approximately 26.8^{0}C being recorded in 2001. The lowest recorded maximum temperature for the March to May season was approximately 24.4^{0}C in 1964 while the highest was approximately 26.8^{0}C in 1961 and 1988. The recorded maximum temperatures in the June to September season were generally moderate compared to other seasons. The maximum temperatures in the June to September season were lower than January to February season but higher than the October to December season with the lowest maximum temperature of approximately 23.0^{0}C in 1969 and highest of approximately 24.8^{0}C in 2005. The recorded maximum temperatures in the October to December season were generally lower compared to the other seasons with the lowest recorded maximum temperature of approximately 21.3^{0}C in 1978 while the highest maximum temperature of approximately 23.6^{0}C was recorded in 1989 (Figure 4-3). The maximum seasonal temperature trends also display positive trends for all the seasons.

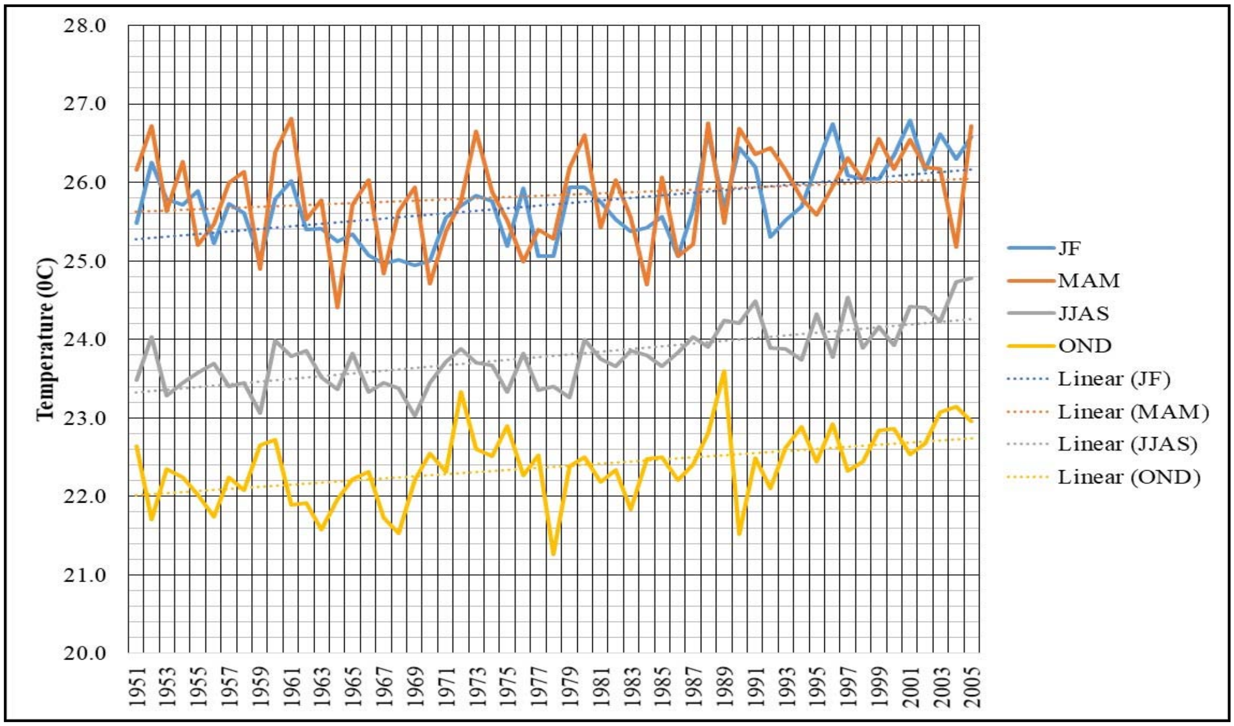

Figure 4-3: Historical seasonal maximum temperature trends (1951 - 2005)

During the period between 1951 and 2005 the temperatures ranges were from 11.1^{0}C to 26.8^{0}C for the January to February season, 11.6^{0}C to 26.8^{0}C for the March to May season, 10.4^{0}C to 24.8^{0}C for the June to September season, and 11.2^{0}C to 23.6^{0}C for the October to December season. This indicate that the hot dry season of January and February recorded the highest maximum temperature variations while the cold dry season recorded the least maximum temperature variation.

4.1.1.4 Discussions on historical temperature change over Sondu Miriu river basin

From 1951 to 2005, there was an annual increase of 0.89^{0}C and 0.73^{0}C for minimum and maximum temperatures, respectively. During the same period, the seasonal minimum temperatures increased by 0.81^{0}C for January and February season, 0.83^{0}C for March to May season, 0.85^{0}C June to September season, and 0.96^{0}C for October to December season. The seasonal maximum temperatures also increased by 0.43^{0}C for January and February season, 0.90^{0}C for March to May season, 0.95^{0}C for June to September season and 0.74^{0}C for October to December season.

The results have shown that the minimum temperatures have recorded higher rise compared to the maximum temperatures within Sondu Miriu river basin. This is consistent with the findings that the eastern Africa equatorial regions have faced a substantial temperature rise since early 1980s (Anyah and Qiu, 2012) and the Famine Early Warning Systems Network (FEWSNET) reports indicating that over the last 50 years Kenya among other countries has experienced an increase in seasonal mean temperature (Funk *et al*., 2012).

4.1.2 Temperature projections

Annual and seasonal temperature projections up the year 2100 within the basin were considered. This study took into consideration both the minimum and maximum temperature projections.

4.1.2.1 Annual temperature projections

For the greenhouse gas emissions scenarios under the intermediate (RCP4.5) and high (RCP8.5), temperatures are projected to increase.

4.1.2.1.1 RCP4.5 temperature projections scenario

Based on the annual temperature projections under RCP4.5 scenario within Sondu Miriu River basin, there is a projected increase for minimum and maximum temperature until the end of the 21^{st} century. In the 21^{st} century, the projected mean rate of temperature increases within the basin is expected be remarkably close for maximum and minimum temperatures. Temperatures are projected to increase by 1.89^0C and 1.85^0C at an annual rate of 0.02^oC and 0.02^0C per year for minimum and maximum temperatures respectively (Table 4.4).

Table 4-4: RCP4.5 temperature projections trends

Temperature	Annual (^{0}C)	Projected change up to 2100 (^{0}C)
Minimum	0.02	1.89
Maximum	0.02	1.85

The annual temperatures are projected to increase by a small margin for both maximum and minimum temperatures. The lowest annual minimum temperature is projected to be 13.2^{0}C in 2007 while the highest is projected to be 15.5^{0}C in the year 2086. The lowest annual maximum temperature is projected to be 23.3^{0}C in 2007 while the highest is projected to be 25.6^{0}C in the years 2080, 2084 and 2096. The temperatures are projected to range between 13.2^{0}C and 25.6^{0}C in the 21st century under the RCP4.5 projection scenario (Figure 4.4). The temperature variations are projected to the same for both maximum and minimum temperatures at 2.3^{0}C each. Based on the observed trends, the annual temperatures are projected to increase at a rate below 0.02^{0}C annually for minimum and maximum temperatures under the RCP4.5 scenario.

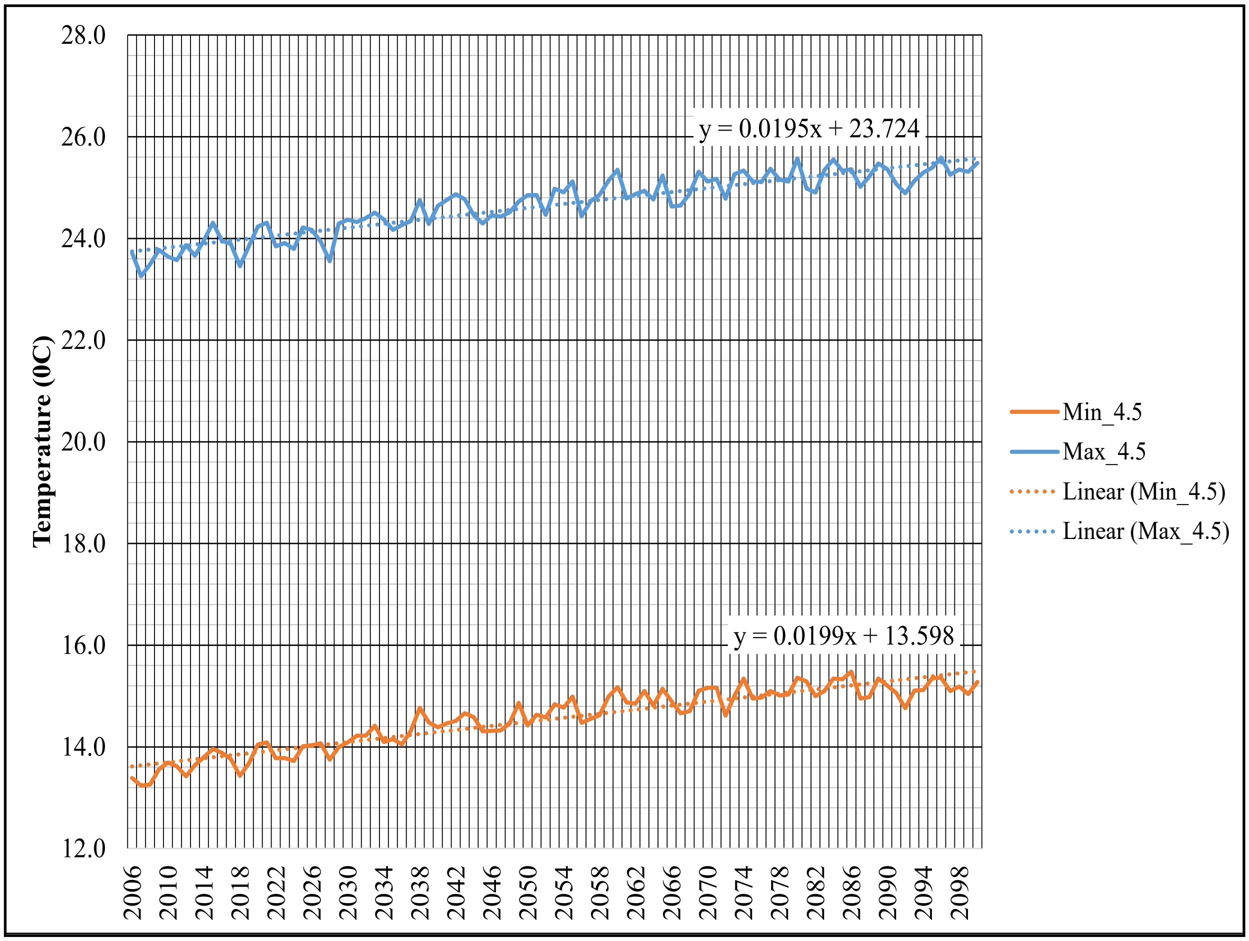

Figure 4-4: RCP4.5 annual temperature projections up to 2100

4.1.2.1.2 RCP8.5 temperature projections

In the case of RCP8.5, the temperature increment rates for minimum and maximum temperature are higher compared to intermediate emission scenario in the Sondu Miriu basin. A mean increase rate of 0.049^0C and 0.047^0C per year is projected for minimum and maximum temperature, respectively. Therefore, under the RCP8.5 projection scenario the temperatures are projected to increase by 4.67^0C and 4.47^0C for minimum and maximum temperatures, respectively in the 21st century within the Sondu Miriu basin (Table 4-5). This indicate that there is also very small difference in maximum and minimum temperature increases under the RCP8.5 scenario.

Table 4-5: RCP8.5 temperature projections trends

Temperature	Annual (^{0}C)	Projected change up to 2100 (^{0}C)
Minimum	0.049	4.67
Maximum	0.047	4.47

There is a projected increase in minimum and maximum temperatures within the 21st century. The projected lowest annual minimum temperature is 13.2^0C in 2008 while the projected highest annual minimum temperature is 18.0^0C in 2098. The projected lowest annual maximum temperature is 23.3^0C in 2008 while the highest is 28.3^0C in 2098. In the 21st century, the temperature is projected to range between 13.2^0C and 28.3^0C (Figure 4-5). The temperature variations for annual maximum temperature are projected to be the highest at 5^0C while the projected annual minimum temperature variation is 4.8^0C. This is an indication that there is little difference in annual temperature variations.

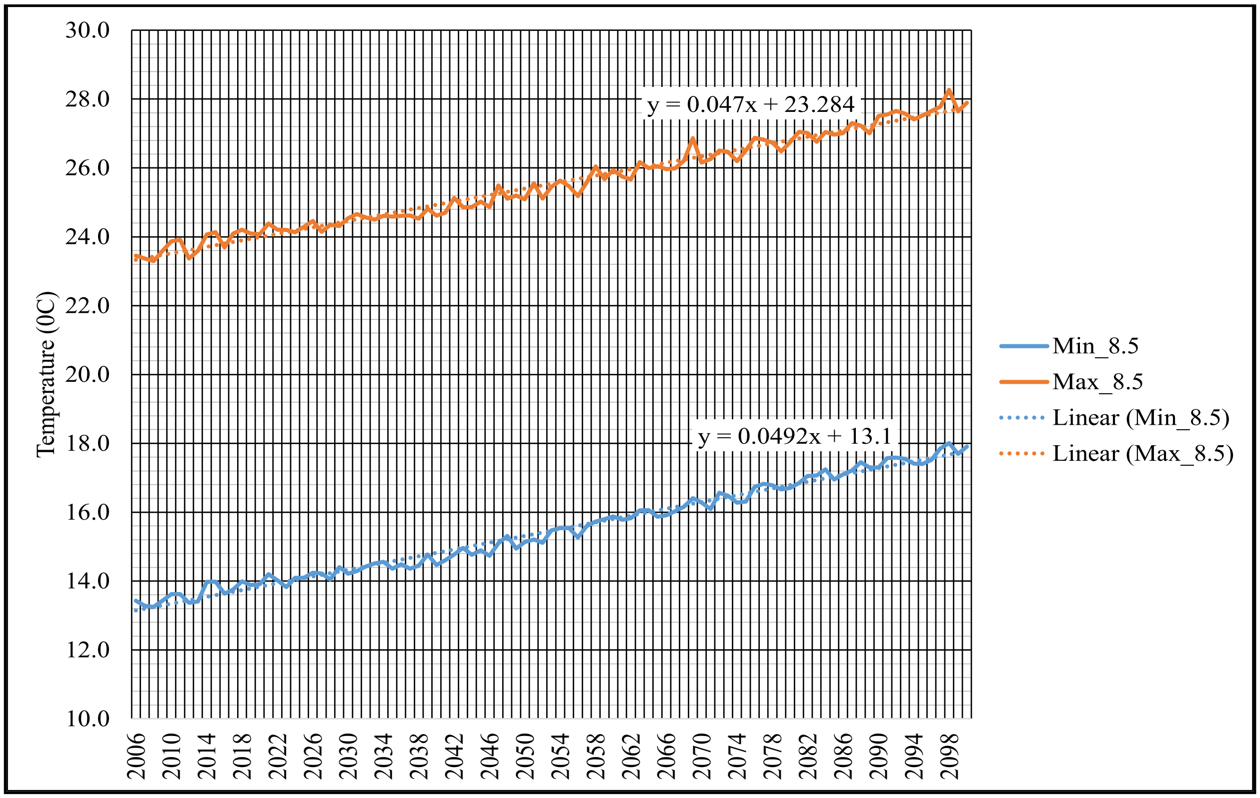

Figure 4-5: RCP8.5 annual temperature projections up to 2100

4.1.2.2 Seasonal temperature projections

The seasonal projections vary from season to season and projection scenario within the Sondu Miriu River basin.

4.1.2.2.1 RCP4.5 seasonal minimum temperature projections

The highest projected minimum temperature trend under the RCP4.5 projection scenario is during the cold season of June to September season while the lowest projected trend is in October to December season. Mean temperature increase rate of 0.02^0C per year is projected for January and February season, 0.02^0C per year for March to May season, 0.02^0C per year for June to September season, and 0.02^0C per year for October to December season. In the 21st century, the seasonal minimum temperatures are projected to increase by 1.86^0C, 1.85^0C, 2.24^0C and 1.62^0C for the January and February season, March to May season, June to September season and October to December seasons respectively (Table 4-6).

The cold dry season from June to September is projected to record the highest minimum temperature increase by 2.24^{0}C compared to the other three seasons in the RCP4.5 scenario. Under the same scenario, the short rainfall season is projected to record the least minimum temperature increase by 1.62^{0}C within the century. The two seasons consisting of hot dry season and the long rainfall season are projected to record an increase in the middle. It can be noted that the dry seasons are projected to record higher minimum temperature increase compared to the wet seasons.

Table 4-6: RCP4.5 projected seasonal minimum temperature trends.

Season	Annual (^{0}C)	Projected change up to 2100 (^{0}C)
January to February	0.02	1.86
March to May	0.02	1.85
June to September	0.02	2.24
October to December	0.02	1.62

In the RCP4.5 projection scenario the minimum temperatures are projected to increase within Sondu Miriu basin. The January to February and March to May seasons are projected to record relatively higher minimum temperatures compared to the June to September and October to December seasons in the 21st century (Figure 4-6).

The projected lowest seasonal minimum temperatures are 12.9^{0}C in 2008 for January and February season, 12.9^{0}C in 2007 for March to May season, 11.7^{0}C in 2006 for June to September season, and 12.5^{0}C in 2006 for October to December season. The projected highest seasonal minimum temperatures are 15.7^{0}C in 2085 for January and February season, 15.5^{0}C in 2086 for March to May season, 15.1^{0}C in 2080 for June to September season, and 14.8^{0}C in 2084 for October to December seasons. The minimum temperatures in the Sondu Miriu river basin are projected to range between 11.7^{0}C and 15.7^{0}C (Figure 4-6).

The cold dry season of June to September is projected to experience the largest minimum temperature variation of up to 3.4^{0}C. This is followed by the hot dry season of January and February with a minimum temperature variation of up to 2.8^{0}C. The rainfall seasons are projected to experience the least minimum temperature variations of up to 2.6^{0}C and 2.3^{0}C for long rains and short rains, respectively. From the trend analysis, it can be noted that the dry seasons are projected to experience larger minimum temperature variations compared to the wet seasons based on the RCP4.5 scenario.

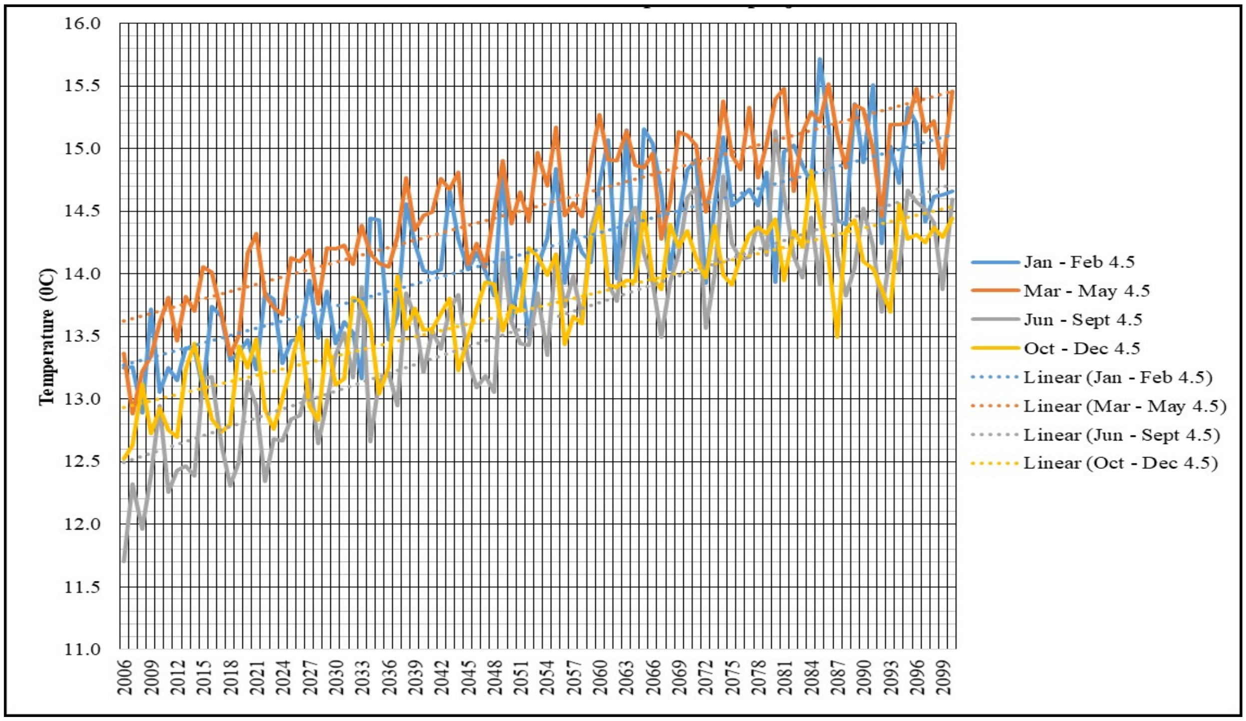

Figure 4-6: RCP4.5 seasonal minimum temperature projections

4.1.2.2.2 RCP8.5 seasonal minimum temperature projections

June to September season is projected to have the highest minimum temperature increase while October to December season is projected to have the lowest increase based on the RCP8.5 scenario. The projections indicate that seasonal temperatures will increase by 0.05^{0}C per year for January and February season, 0.04^{0}C per year for March to May season, 0.06^{0}C per year for June to September season, and 0.04^{0}C per year for October to December season. The projections indicate that seasonal minimum temperatures will increase by 4.58^{0}C for the January and February season, 4.23^{0}C for March to May season, 5.39^{0}C for June to September season, and 4.1^{0}C for October to December season (Table 4-7).

The cold dry season of June to September is projected to record the highest minimum temperature increase by 5.39^{0}C under the RCP8.5 followed by the hot dry season of January and February whose minimum temperature projected to increase by 4.58^{0}C. The minimum temperatures for the wet seasons are projected to record relatively lower increase by 4.23^{0}C and 4.10^{0}C in the long rainfall and short rainfall seasons, respectively.

Table 4-7: RCP8.5 projected seasonal minimum temperature trends.

Season	Annual (^{0}C)	Projected change up to 2100 (^{0}C)
January to February	0.05	4.58
March to May	0.04	4.23
June to September	0.06	5.39
October to December	0.04	4.1

The minimum temperatures are projected to increase under the RCP8.5 projection scenario within the Sondu Miriu River basin. (Figure 4-7). The projected lowest seasonal minimum temperatures are 13.5^{0}C in 2028 for January and February season, 14.0^{0}C in 2023 for March to May season, 12.5^{0}C in 2023 for June to September season 12.7^{0}C in 2023 for October to December season. The projected highest seasonal minimum temperatures are 17.6^{0}C in 2098 for January and February season, 18.1^{0}C in 2098 for March to May season, 17.6^{0}C in 2100 for June to September season and 16.6^{0}C in 2100 for October to December seasons. The minimum temperatures in Sondu Miriu basin under the RCP8.5 scenario are projected to range between 12.1^{0}C and 18.1^{0}C (Figure 4-7).

The cold dry season of June to September is projected to experience the largest maximum temperature variation of up to 5.1^{0}C. This is followed by the hot dry season of January and February and the long rainfall season of March to May with a similar maximum temperature variation of up to 4.1^{0}C each, respectively. The short rainfall season of October to December is projected to experience the least minimum temperature variations of up to 3.8^{0}C in the RCP8.5 scenario. The trend analysis indicate that the dry seasons are projected to experience larger maximum temperature variations compared to the wet seasons in the RCP8.5 scenario.

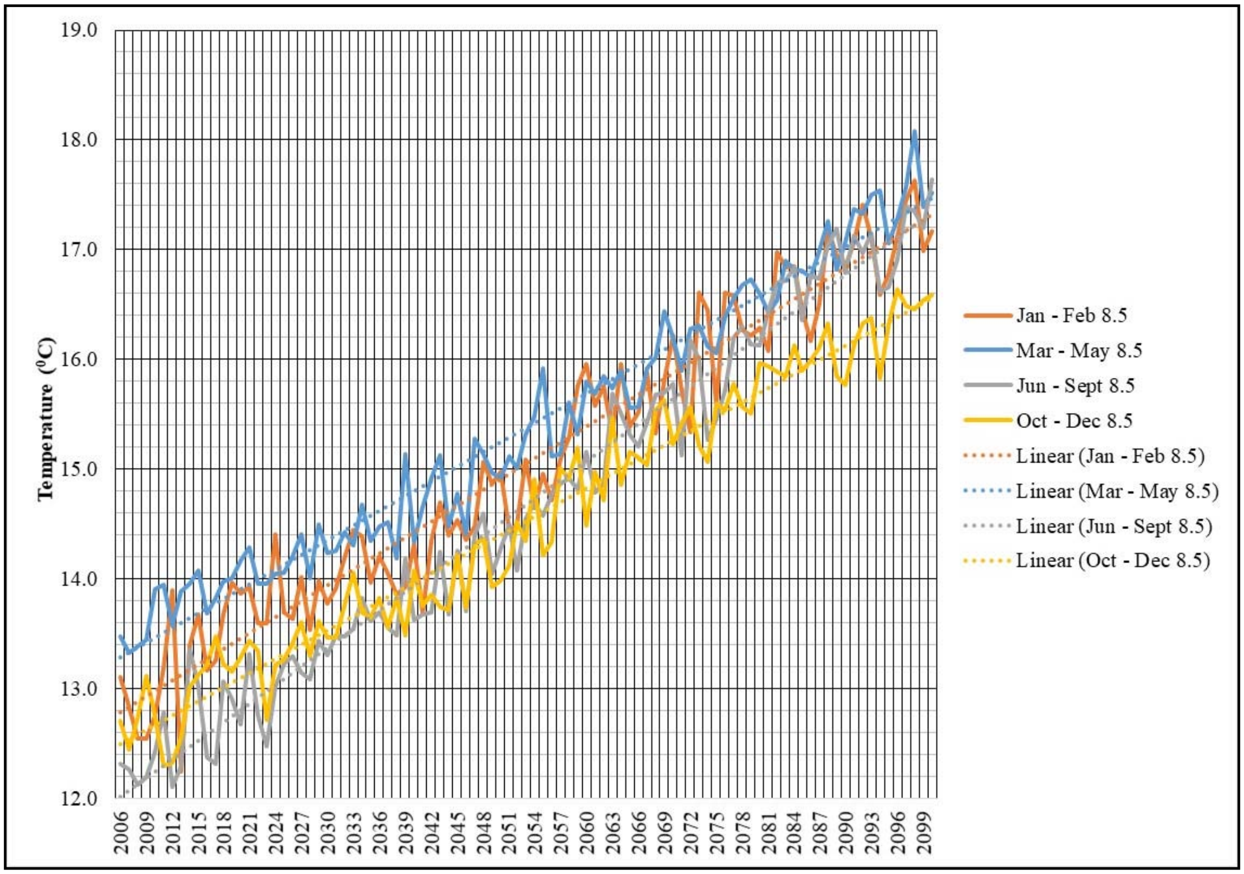

Figure 4-7: RCP8.5 seasonal minimum temperature projections

4.1.2.2.3 RCP4.5 seasonal maximum temperature projections

June to September season is projected to record the highest maximum temperature increase compared to other seasons while October to December season is expected to record the lowest increase. The seasonal maximum temperature increase is projected by a mean of 0.02^{0}C per year for January to February season, 0.02^{0}C per year for March to May season, 0.02^{0}C per year for June to September season, and 0.02^{0}C per year for October to December season. The seasonal maximum temperatures are projected to increase by 1.76^{0}C for the January and February season, 1.64^{0}C, for March to May season 2.34^{0}C for June to September, and 1.49^{0}C for October to December season in the 21st century (Table 4-8).

In the RCP4.5, the cold dry season of June to September is projected to record the highest maximum temperature increase by 2.34^{0}C while the hot dry season of January and February comes second with the maximum temperature projected to increase by 1.76^{0}C. The wet seasons maximum temperatures are projected to record relatively lower increase by 1.76^{0}C and 1.49^{0}C in the long rainfall and short rainfall seasons, respectively. This indicate that the dry seasons are projected to experience higher temperature increase compared to the wet seasons in the RCP4.5 scenario.

Table 4-8: RCP4.5 projected seasonal maximum temperature trends.

Season	**Annual (^{0}C)**	**Projected change up to 2100 (^{0}C)**
January to February	0.02	1.76
March to May	0.02	1.64
June to September	0.02	2.34
October to December	0.02	1.49

The maximum temperatures are projected to increase within the Sondu Miriu River basin. (Figure 4-8). The projected lowest seasonal maximum temperatures are 21.1^{0}C in 2025 for January and February season, 26.3^{0}C in 2037 for March to May season, 24.3^{0}C in 2022 for June to September season, and 22.9^{0}C in 2027 for October to December season. The projected highest seasonal maximum temperatures are 28.8^{0}C in 2077 for January and February season, 29.0^{0}C in 2089 for March to May season, 27.6^{0}C in 2080 for June to September season, and 25.2^{0}C in 2065 for October to December season. The maximum temperatures Sondu Miriu basin under the RCP4.5 scenario are projected to range between 22.3^{0}C and 29.0^{0}C (Figure 4-8).

Based on the RCP4.5 scenario, the largest maximum temperature variation is projected during the hot dry period of January and February season of up to 7.7^{0}C. The second highest maximum temperature variation is projected during the cold dry period of June to September season of up to 3.3^{0}C. The wet seasons are projected to experience the least maximum temperature variations of up to 2.7^{0}C and 2.3^{0}C for long rains and short rains, respectively. The trend analysis indicates a very high maximum temperature variations compared with the other seasons. The RCP4.5 scenario indicate that the dry seasons are projected to experience larger maximum temperature variations compared to the wet seasons.

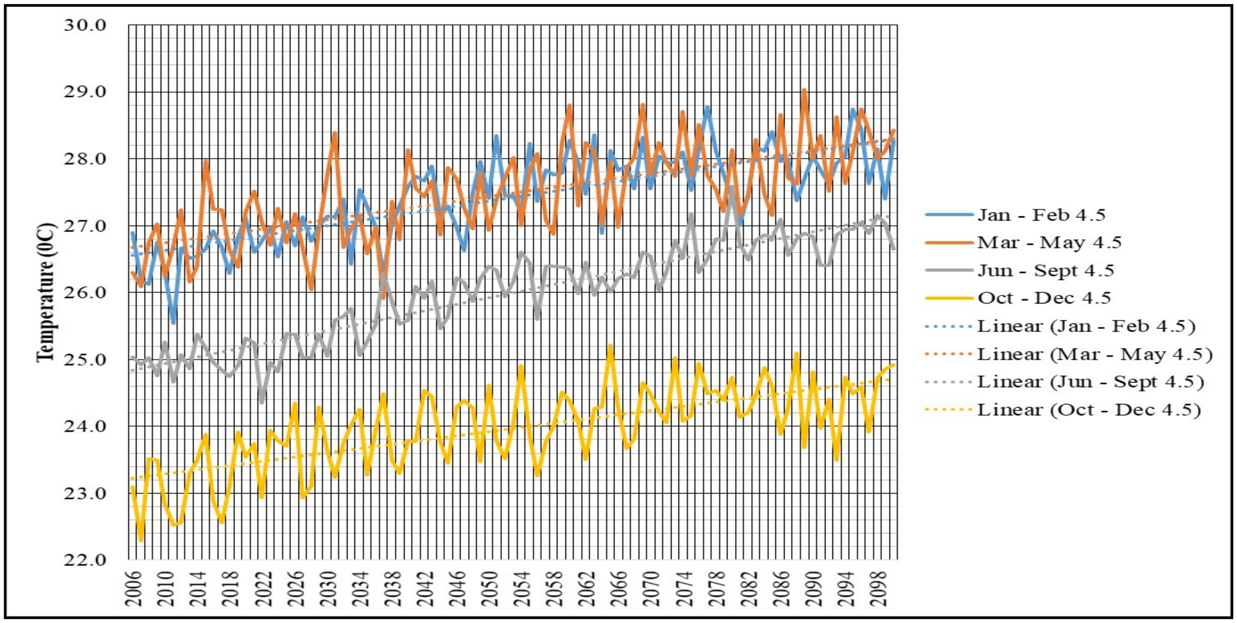

Figure 4-8: RCP4.5 seasonal maximum temperature projections

4.1.2.2.4 RCP8.5 seasonal maximum temperature projections

January to February season is projected to record the highest maximum temperature increase compared to other seasons while June to September season is expected to record the lowest increase under this scenario. The seasonal maximum temperatures are projected to increase under this scenario by a mean of 0.05^{0}C per year for January to February season, 0.05^{0}C per year for March to May season, 0.04^{0}C per year for June to September season, and 0.04^{0}C per year for October to December season. The seasonal maximum temperatures are projected to increase by 5.04^{0}C for the January and February season, 4.93^{0}C for March to May season, 3.46^{0}C for June to September season, and 3.71^{0}C for October to December season in the 21st century (Table 4-9).

The hot dry season of January and February is projected to record the highest maximum temperature increase by 5.04^{0}C under the RCP8.5. This is followed by the long rainfall season of March to May with projected maximum temperature increase by 4.93^{0}C. The cold dry period of June to September and the short rainfall period of October to December are projected to record to record relatively lower increase by 3.46^{0}C and 3.71^{0}C, respectively. In the RCP8.5, the projections indicate that the first two seasons (January and February season and March to May season) of the year will experience higher maximum temperature increase compared to the last two seasons of the year.

Table 4-9: RCP8.5 projected seasonal maximum temperature trends.

Season	Annual (^{0}C)	Projected change up to 2100 (^{0}C)
January to February	0.05	5.04
March to May	0.05	4.93
June to September	0.04	3.46
October to December	0.04	3.71

The maximum temperatures are projected to increase within the Sondu Miriu River basin. The projected lowest seasonal maximum temperatures are 12.2^{0}C in 2013 for January and February season, 13.3^{0}C in 2007 for March to May season, 12.1^{0}C in 2008 for June to September season, and 12.3^{0}C in 2011 for October to December season. The projected highest seasonal minimum temperatures are 17.6^{0}C in 2098 for January and February season, 18.1^{0}C in 2098 for March to May season, 17.6^{0}C in 2100 for June to September season, and 16.6^{0}C in 2096 for October to December season. The maximum temperatures Sondu Miriu basin under the RCP8.5 scenario are projected to range between 12.1^{0}C and 18.1^{0}C (Figure 4-9).

The cold dry season of June to September is projected to experience the largest maximum temperature variation of up to 5.5^{0}C. This is followed by the hot dry season of January and February with maximum temperature variation of up to 5.4^{0}C. The wet seasons are projected to experience the least maximum temperature variations of up to 4.8^{0}C and 4.3^{0}C for long rains and short rains, respectively in the RCP8.5 scenario. The trend analysis indicate that the dry seasons are projected to experience larger maximum temperature variations compared to the wet seasons in the RCP8.5 scenario.

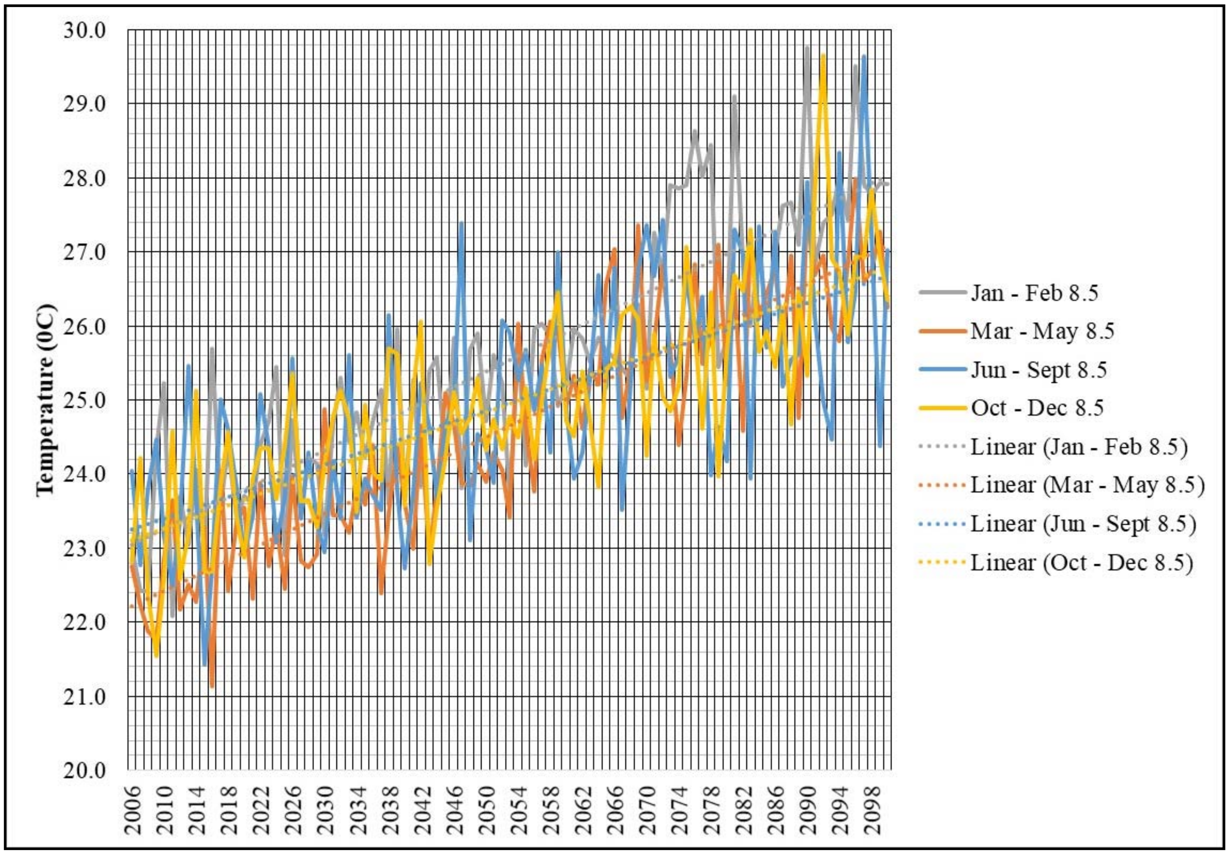

Figure 4-9: RCP8.5 seasonal maximum temperature projections

4.1.2.2.5 General temperature trends

For the historical temperature trends the higher annual temperature change was recorded in the minimum temperatures while the annual maximum temperature recorded the least increment. Based on the seasons, October to December season recorded the highest seasonal minimum temperature while the January and February season recorded the least minimum seasonal increase. The June to September season also recorded the highest seasonal maximum temperature increase while the January and February season recorded the least.

On the projections, the annual minimum temperature is projected to experience highest increase than the annual maximum temperature. The projections indicate that under the RCP4.5 projection scenario, highest temperature increase is projected to occur during the cold dry season of June to September while the least is projected in short rainfall season of October to December. It can be noted that the higher temperature increases under the RCP4.5 scenario is projected during the dry seasons while the lower temperature increase is projected during the wet seasons. The RCP8.5 scenario presents mixed signals as the highest minimum temperature increase is projected in the cold dry season while the highest maximum temperature increase is projected in the hot dry season (January and February) and the least minimum temperature increase is projected in the short rainfall season (October to December while the least maximum temperature is projected in the cold dry season (June to September. In general, it can be noted that the highest temperature increase is projected during the dry seasons.

4.1.2.3 Discussions on temperature projections over Sondu Miriu river basin

Within the 21st century, minimum and maximum temperature increase are projected within Sondu Miriu basin. Minimum temperature is expected to rise by about 1.89^0C annually the RCP4.5 projection scenario and 4.67^0C in the RCP8.5 projection scenario while the maximum temperature in the RCP4.5 projected scenario is projected to increase by 1.85^0C annually and in the RCP8.5 projection scenario projected scenario is projected to increase by 4.47^0C. In the RCP4.5 projection scenario, seasonal minimum temperatures are projected to increase by 1.86^0C, 1.85^0C, 2.24^0C and 1.62^0C for January to February, March to May, June to September and October to December seasons, respectively while under the RCP8.5 projection scenario the seasonal temperatures are projected to increase by 4.58^0C, 4.23^0C, 5.39^0C and 4.10^0C for January to February, March to May, June to September and October to December seasons, respectively.

On the other hand, the seasonal maximum temperatures under the RCP4.5 are projected to increase by 1.76^0C, 1.64^0C, 2.34^0C and 1.49^0C for January to February, March to May, June to September and October to December seasons, respectively while under the RCP8.5 projection scenario the seasonal maximum temperatures are projected to increase by 5.04^0C for January and February season, 4.93^0C for March to May season, 3.46^0C for June to September and 3.71^0C for October to December season.

The drier seasons of January to February and June to September are projected to have higher minimum and maximum temperature increase than the long rainfall and short rainfall season under the RCP4.5 projection scenario. This trend applies also to minimum temperatures in the RCP8.5 projection scenario. The first two seasons of the year (January to February and March to May) have higher maximum temperature increase in the RCP8.5 projection scenario than the last two seasons (June to September and October to December) of the year. March to May rainfall season is projected to have higher increase than the October to December rainfall season. Even though the results agree with the earlier findings that minimum temperature increase is projected to be higher for the June to September season than for the long rainfall and short seasons (Olaka *et al*., 2019), the hot dry (January to February) was omitted in the earlier analysis. Looking at all the four seasons of the year, the cold and dry seasons of the year are projected to experience the highest minimum and maximum increase compared to the rainfall seasons.

Both the minimum and maximum temperatures are projected to increase within the Sondu Miriu river basin within the century. This is expected to enhance the rate of evaporation from open water sources including the main Sondu Miriu river. As a result, the water losses will increase within the basin due to increased water demands from other water users.

4.1.3 Historical rainfall trends

The presented results are for the ensembled historical rainfall trends within Sondu Miriu basin from 1951 to 2005.

4.1.3.1 Annual historical rainfall trends

The annual historical rainfall amounts indicate increasing trends of approximately 1.36 mm annually. This is an indication that the rainfall amounts increased by approximately 74.8mm for the 55 years (1951 to 2005) of the historical data. The lowest annual total rainfall amount received during this period was 1,010mm in 1975 while the highest amount was 1,508mm in 1988 (Figure 4-10).

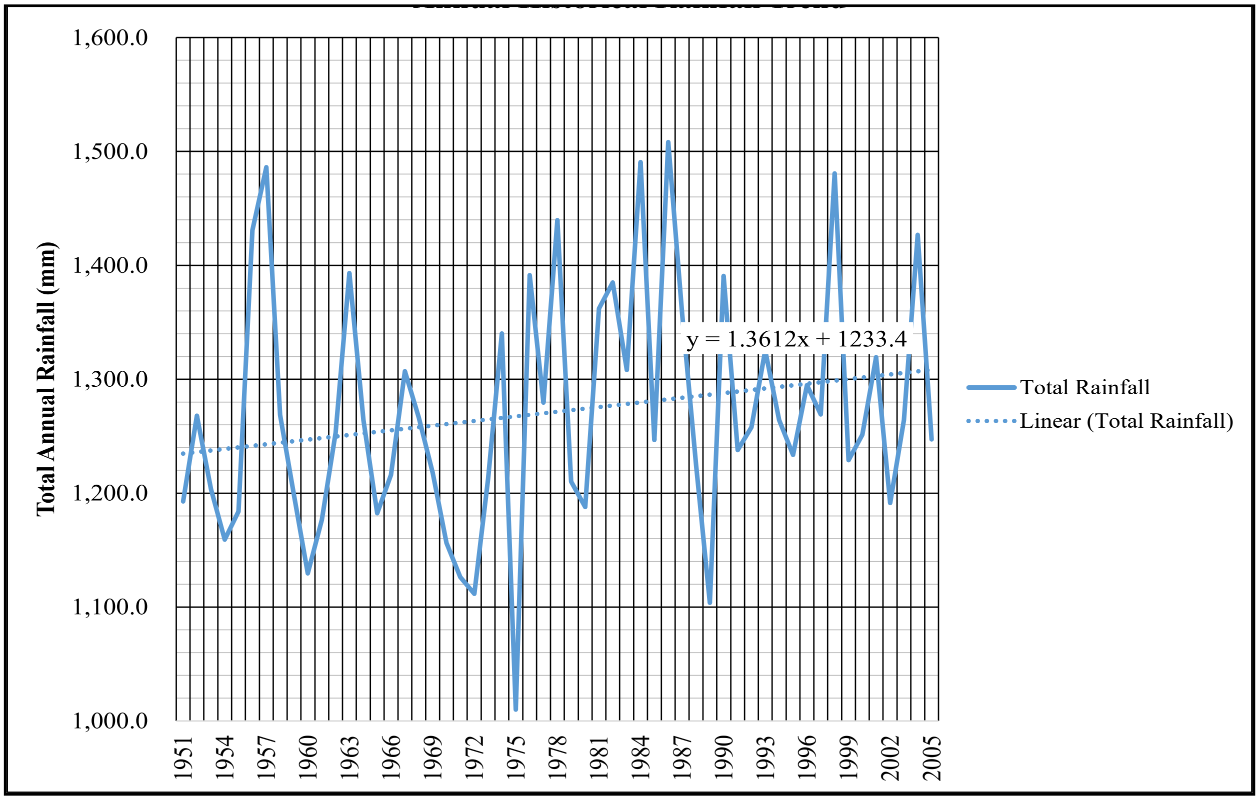

Figure 4-10: Annual historical rainfall trend

4.1.3.2 Seasonal historical rainfall trends

The historical trends within the Sondu Miriu River basin shows that the rainfall amounts have been on the increase for all the seasons except for the June to September season that decreased at an average of 0.33mm per year and 18.27mm for the period from 1951 to 2005. The highest increase was recorded in the March to May season at an average of 1.01mm per year and 55.55mm for the whole period. January to February seasonal rainfall increased by an average of 0.02mm per year and 1.10mm for the whole period while the October to December period increased by an average of 0.66mm per year and 36.30mm for the whole period (Table 4-10).

For the historical period from 1951 to 2005, the highest rainfall increase was recorded in the long rainfall season (March to May) of 55.55mm while the cold dry period (June to September) recorded a decrease in rainfall amount of 18.15mm. the rainfall seasons recorded relatively higher increase in rainfall amounts compared the dry seasons.

Table 4-10: Historical seasonal rainfall trend

Season	Annual (mm)	Change from 1951 to 2005 (mm)
January to February	0.02	1.10
March to May	1.01	55.55
June to September	-0.33	-18.15
October to December	0.66	36.30

Between 1951 and 2005, October to December season received the highest rainfall followed closely by March to May season while June to September and January to February seasons received relatively low rainfall within the Sondu Miriu River basin. The lowest rainfall recorded in each season were 22.57mm for January and February season, 266.22mm for March to May season, 143.39mm for June to September season and 439.50mm for October to December season while the highest rainfall recorded in each season were 105.48mm for January and February season, 682.92mm for March to May season, 291.65mm for June to September season and 758.96mm for and October to December season (Figure 4-11).

The long rainfall season of March to May and the short rainfall season of October to December recorded higher rainfall variation with the long rainfall season recording the highest rainfall variation. The dry period of January and February season and the cold period of June to September season recorded lower rainfall variations with the hot dry season recording the lowest rainfall variation.

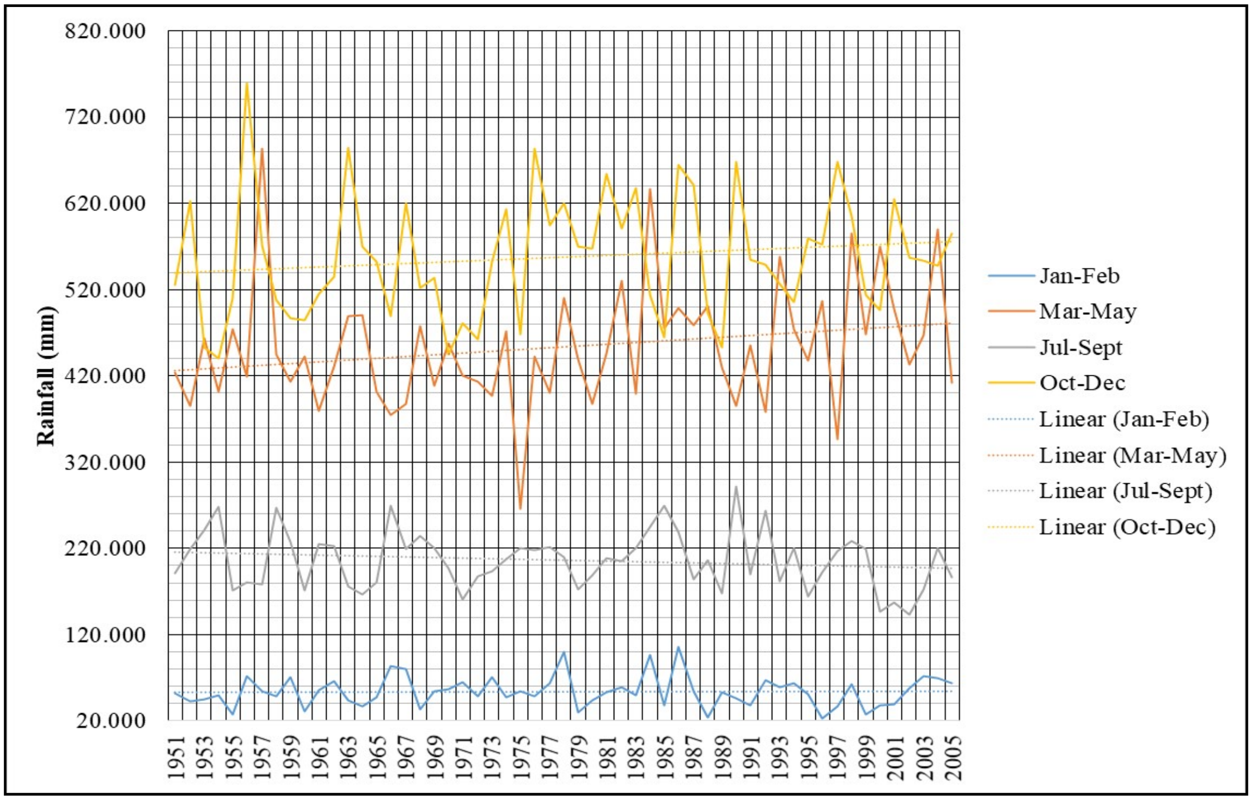

Figure 4-11: Seasonal Historical Rainfall Trends

4.1.3.3 Discussions on historical rainfall over Sondu Miriu river basin

Annual rainfall over Sondu Miriu river basin has increased by about 18.27 mm. The seasonal rainfall has also increased in all the seasons except for the June to September season that has declined. The seasonal rainfall has increased by 1.10 mm for January and February season, 55.55 mm for March to May season, and 36.30 mm for October to December seasons while June to September has decreased by 18.15 mm.

Several studies over the eastern Africa region have indicated a decline in rainfall during the March to May and June to September season in the last three to five decades of the 20th century (Funk *et al*., 2008; Williams and Funk, 2011); Lyon and DeWitt, 2012; Williams *et al*., 2012; Rowell *et al*., 2015). The difference in the historical trends is only in the March to May season which may be attributed to spatial variability controlled by a range of physical processes (Rosell and Holmer, 2007; Hession and Moore, 2011). A study by Rwigi *et al* in 2016 on the "Assessment of Potential Changes in Hydrologically Relevant Rainfall Statistics over the Sondu River Basin in Kenya Under a Changing Climate" also found out that the observed seasonal rainfall variation in overall indicate a possibility of shifting rainfall patterns where the comparatively dry season of January and February season and short rainfall season of October to December are getting relatively wetter while the long rainfall season of March to May and cold season of June to September are getting relatively drier.

4.1.4 Rainfall projections

For the rainfall projections, RCP8.5 and RCP4.5 scenarios were considered. These scenarios are the high and intermediate greenhouse gas emission scenarios. The projections have been based on annual and seasonal projections.

4.1.4.1 Annual rainfall projections

The greenhouse gas emission scenarios for the intermediate and high emissions, indicate that there is a projection for increased annual rainfall within the Sondu Miriu basin. An annual rainfall increase by an average of 0.26 mm per year is projected in the RCP4.5 scenario, while in the RCP8.5 scenario annual rainfall increase by an average of 1.24mm per year is projected. Within the 21st century, the RCP4.5 and RCP8.5 scenarios project the rainfall to increase by 24.70mm and 117.80mm respectively (Table 4-11). The RCP8.5 scenario projects higher annual rainfall increase than the RCP4.5 scenario.

Table 4-11: Projected mean annual rainfall trend

Emission Scenario	Annual (mm)	Projected change up to 2100 (mm)
RCP4.5	0.26	24.70
RCP8.5	1.24	117.80

The projected annual rainfall amounts indicate increasing trends in Sondu Miriu basin. Within the 21st century, the projected lowest annual rainfall under the RCP4.5 scenario is 1016.40mm in 2040 while under RCP8.5 scenario is 934.40mm in 2031. The highest projected annual rainfall is 1562.00mm in 2066 in the RCP4.5 projection scenario and 1552.70mm in 2089 for the RCP8.5 projection scenario. The RCP4.5 scenario projects the annual rainfall amounts to range between 1016.40 mm and 1562.00 mm while the projection from RCP8.5 scenario range between 934.40 mm and 1552.70 mm (Figure 4-12). Even though the RCP8.5 scenario trend projects a higher rate of mean annal rainfall increase than the RCP4.5 scenario, RCP4.5 scenario projects higher rainfall variation and higher annual rainfall peaks. The RCP8.5 scenario projects rainfall variation of 545.60mm while the RCP4.5 scenario projects rainfall variation of 618.30mm.

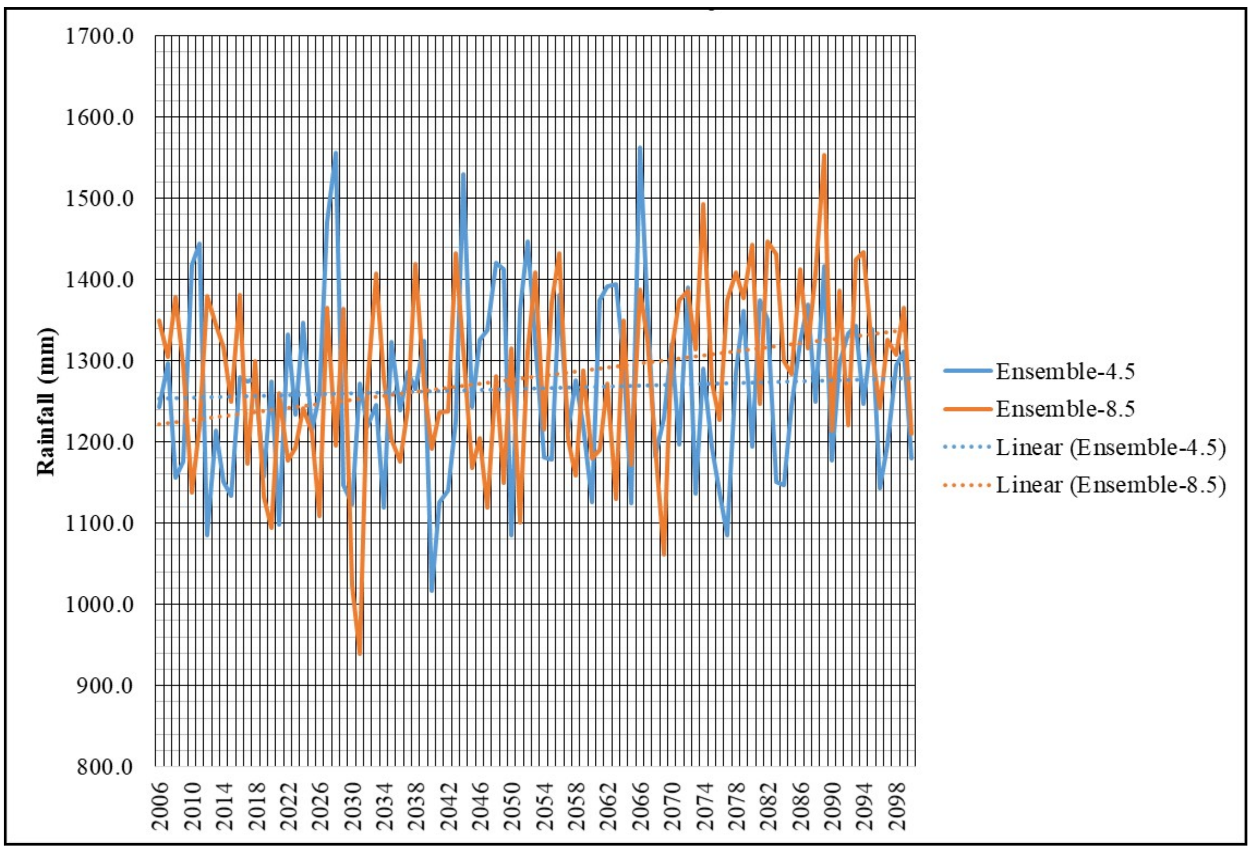

Figure 4-12: Annual rainfall projection

4.1.4.2 Seasonal rainfall projections

The seasonal rainfall is projected to have varying trends from season to season in the RCP4.5 and RCP8.5 projection scenarios within Sondu Miriu River basin.

4.1.4.2.1 RCP4.5 seasonal rainfall projection

The seasonal rainfall amounts under the RCP4.5 are projected to increase during the January to February and October to December seasons and projected to decrease for the March to May and June to September seasons. The highest seasonal rainfall increase is projected in the October to December season at an average of 1.46mm per year while June to September seasonal rainfall is projected to have the highest decrease at an average of 0.21mm per year. January and February seasonal rainfall is projected to increase by an average of 0.14 mm annually while March to May seasonal rainfall is projected to decrease by an average of 0.12mm annually. During the 21st century, the rainfall is projected to increase by 13.30mm and 138.70mm in the January to February and October to December seasons respectively while for the March to May and June to September seasons rainfall is projected to decrease by 11.40mm and 19.95mm respectively (Table 4-12).

The hot dry season and the short rainfall seasons are projected to record increase in seasonal rainfall while the long rainfall and cold dry seasons are projected to record rainfall decrease under the RCP4.5 scenario.

Table 4-12: RCP4.5 Projected mean seasonal rainfall trend.

Season	Annual (mm)	Projected change up to 2100 (mm)
January to February	0.14	13.30
March to May	-0.12	-11.40
June to September	-0.21	-19.95
October to December	1.46	138.70

The October to December season is projected to receive the highest rainfall followed by March to May season, then June to September season and lastly January to February season in that order. The projected lowest seasonal rainfall amounts are 22.6mm in 2094 for January and February season, 306.8mm 2080 for March to May season, 104.2mm in 2070 for June to September season, and 411.0mm in 2034 for October to December. The projected highest seasonal rainfall amounts are 154.7mm in 2081 for January and February season, 599.5mm in 2066 for March to May season, 302.3mm in 2022 for June to September season, and 772.1mm in 2062 for October to December season (Figure 4-13).

For the trend analysis, the wet seasons are projected to experience higher rainfall variations with the short rainfall season experiencing the highest variation of 361.10mm while the dry seasons are projected to experience lower rainfall variations with the hot dry season experiencing the lowest variation of 132.10mm under the RCP4.5 scenario.

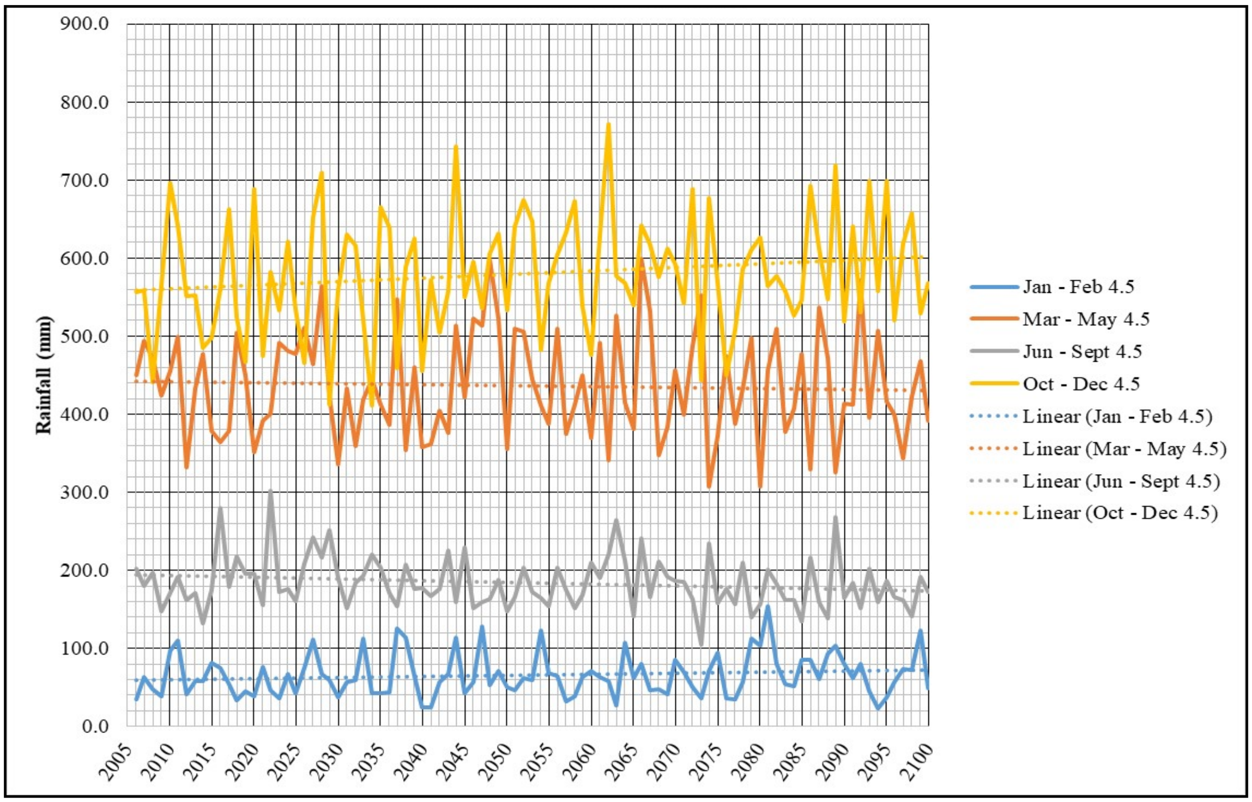

Figure 4-13: RCP4.5 seasonal rainfall projections

4.1.4.2.2 RCP8.5 seasonal rainfall projection

The seasonal rainfall amounts in Sondu Miriu basin under the RCP8.5 are projected to increase in the January and February season, March to May season and October to December season while it is projected to decrease for the June to September season. October to December seasonal rainfall is projected to have the highest increase of rainfall at an average of 0.78mm per year. This is closely followed by March to May season at an average of 0.53mm per year and January to February season at an average of 0.36 while June to September seasonal rainfall is projected to experience a decrease of 0.43mm annually. Within the 21st century, the rainfall is projected to increase by 34.20mm in the January and February season, 50.35mm in the March to May season and 74.10mm in the October to December season under the RCP8.5 scenario while it is projected to decrease by 40.85mm for June to September season (Table 4-13).

For the RCP8.5 projection scenario, the cold dry season of June to September is projected to experience rainfall decrease while the remaining three seasons are projected to experience rainfall increase. The wet seasons are projected to experience high rainfall increase of 50.35mm and 74.10mm for long rainfall season and short rainfall season, respectively. A decrease of 40.85mm of rainfall is projected to be experienced in the cold dry season while the hot dry season is expected to experience an increment of 34.20mm of rainfall.

Table 4-13: RCP8.5 Projected mean seasonal rainfall trend.

Season	Annual (mm)	Projected Change up to 2100 (mm)
January to February	0.36	34.20
March to May	0.53	50.35
June to September	-0.43	-40.85
October to December	0.78	74.10

Based on the RCP8.5, the October to December season is projected to receive the highest rainfall within the Sondu Miriu river basin followed by March to May season, then June to September season and lastly January to February season in that order. The projected lowest seasonal rainfall amounts are 18.2mm in 2028 for January and February season, 288.4mm 2011 for March to May season, 99.5mm in 2086 for June to September season, and 437.9mm in 2031 for October to

December. The projected highest season rainfall amounts are 137.0mm in 2083 for January and February season, 644.7mm in 2033 for March to May season, 251.7mm in 2045 for June to September season, and 883.2mm in 2080 for October to December (Figure 4-14).

In terms of rainfall variation, the wet seasons are projected to experience higher rainfall variation with the short rainfall season projected to experience the highest rainfall variation of 445.30mm while the short rainfall season is projected to experience rainfall variation of 356.30mm. The dry seasons are projected to experience lower rainfall variations with the hot dry season projected to experience the lowest rainfall variation of 118.90mm while the cold dry season is projected to experience rainfall variation of 152.20mm.

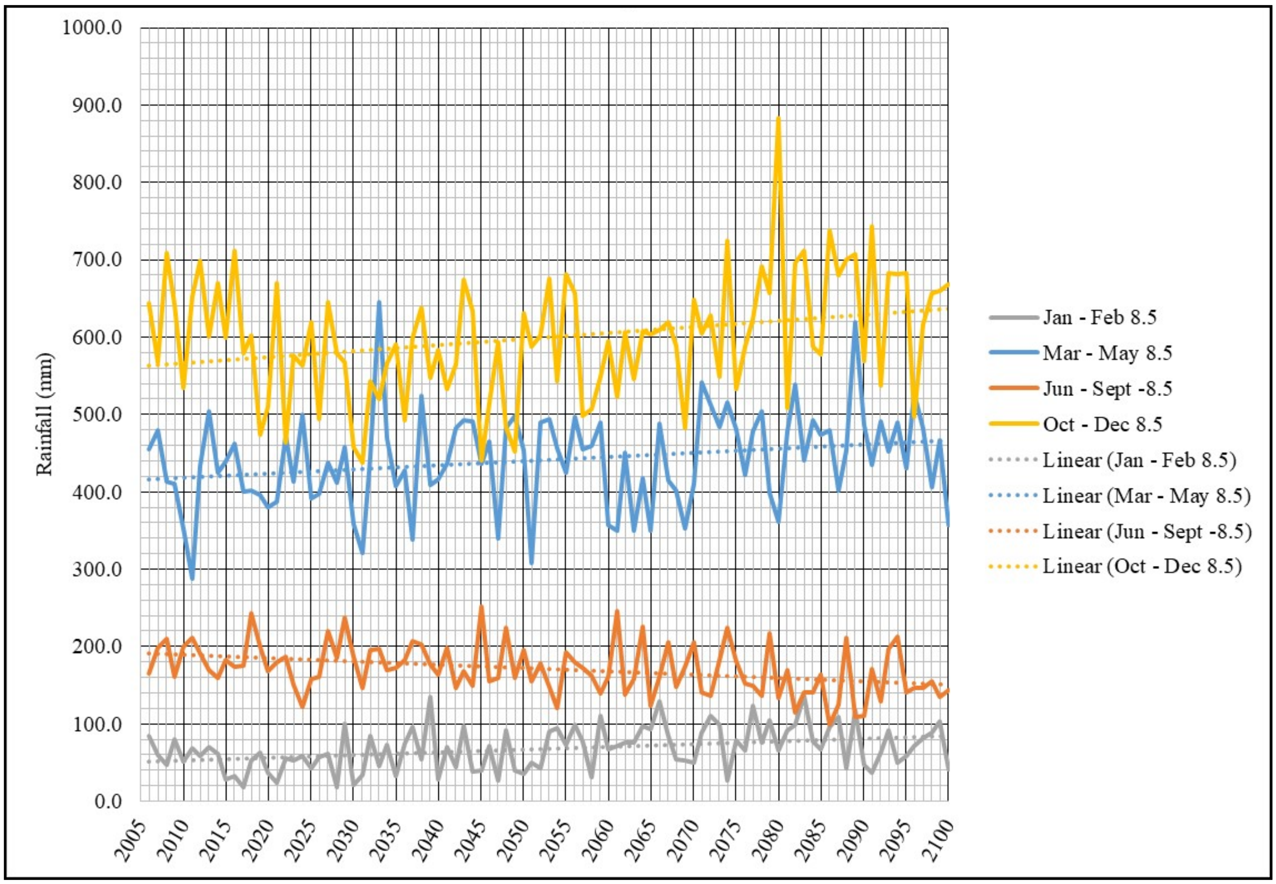

Figure 4-14: RCP8.5 seasonal rainfall projections

4.1.4.3 Discussions on projected rainfall over Sondu Miriu river basin

The rainfall amount is expected to increase annually within Sondu Miriu river basin in the 21st century by 24.70 mm based on the RCP4.5 projection scenario and by 117.80 mm based on the RCP8.5 projection scenario. This also concurs with the finding of Rwigi *et al* in 2016 that found out a general tendency of possible increasing rainfall amounts within the Sondu Miriu river basin together with neighbouring basins moving towards future climate periods. Towards 2030 and 2050, more rainfall is projected to be received within Sondu Miriu basin which will be in terms of rainfall days per month having higher probabilities of more wet days per month (Rwigi *et al.*, 2016).

The seasonal rainfall is projected to decrease in the June to September by 19.95 mm under the RCP4.5 projection scenario and 40.85 mm under the RCP8.5 projection scenario. The seasonal rainfall is projected to increase by 13.30 mm in the January and February season and by 138.70 mm in the October to December season in the RCP4.5 projection scenario, while for the RCP8.5 projection scenario the projected seasonal increase is by 34.20 mm in the January and February season and 74.10 mm in the October to December season. The March to May seasonal rainfall is projected to decrease by 11.40 mm in the RCP4.5 projection scenario and to increase by 50.35 mm in the RCP8.5 within the 21st century.

The findings agree with other recent studies conducted within the region that project rainfall increase within the 21st century including the the long rains of March to May season and short rains of October to December season (Moise and Hudson, 2008; Shongwe *et al*., 2011; Rowell *et al*., 2015; Olaka *et al*., 2019). The study also concurs with other studies in the region that the seasonal rainfall for June to September is projected to decline in the 21st century (Patricola and Cook, 2011). A study by Olaka *et al*., 2019 on "the projected climatic and hydrologic changes to Lake Victoria basin rivers under three RCP emission scenarios for 2015–2100 and impacts on the water sector" indicated that the June to September seasonal rainfall is projected to decrease in the RCP8.5 projection scenario but increase in the RCP4.5 projection scenario (Olaka *et al* 2019).

CHAPTER FIVE

RESULTS AND DISCUSSIONS FOR SPECIFIC OBJECTIVE TWO

5.1 Introduction

In this chapter, the results and discussions are presented on the impacts of climate change on the hydropower generation in the Sondu Miriu River basin. The results presented include annual and seasonal trends for rainfall, temperature, river flows and hydropower production.

5.2 Results for specific objective two

The two wet seasons and two dry seasons experienced in Sondu Miriu River basin determine the water availability for the hydropower generation. The results are presented in the form of observed annual and seasonal rainfall, river flows and energy output trends.

5.2.1 Impacts of climate change on hydrology and hydropower.

Sondu and Sang'oro hydropower projects have been in operation for approximately 13 years and 7 years, respectively. The correlation between the Sondu Miriu mean monthly river flow and monthly total rainfall presents a strong relationship with an R^2 of 0.78 (Figure 5-1). This is an indication that the rainfall within the Sondu Miriu basin has got high influence on the Sondu Miriu river flow and in turn most likely to have more impact on the two-existing hydropower projects that are run-of-river type and even on the future planned hydropower projects within the basin.

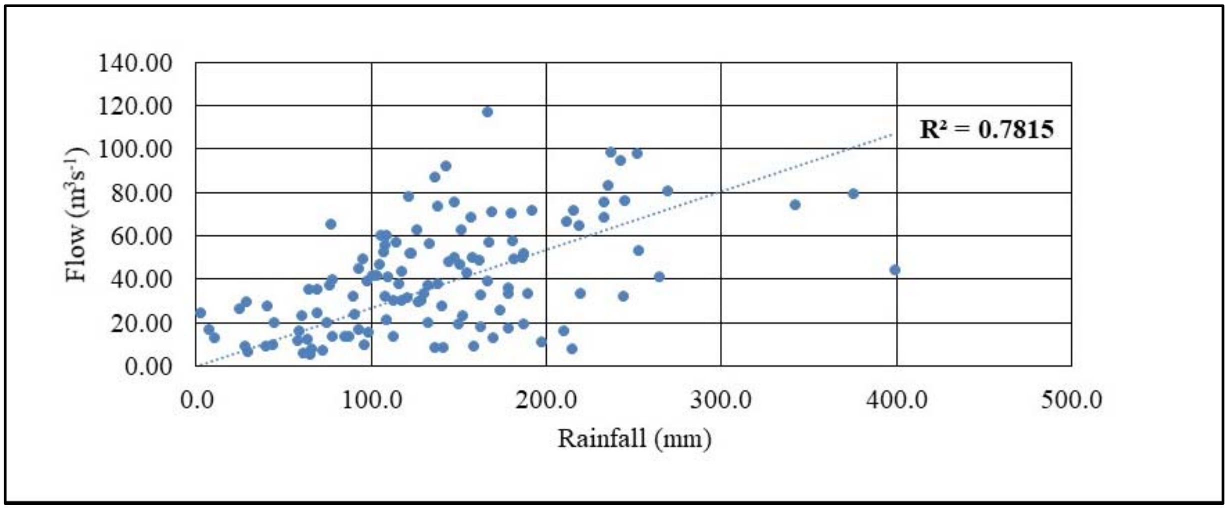

Figure 5-1: Correlation between Sondu Miriu river flow and rainfall

The gridded data from 2008 to 2018 obtained from Kenya meteorological department was applied for the evaluation of the impacts of climate change on hydrology and hydropower. The graphical comparison between monthly rainfall and mean monthly river flows indicate that the river flows respond to the observed rainfall (Figure 5-2). This is evident on the rainfall and river flow patterns including the trends.

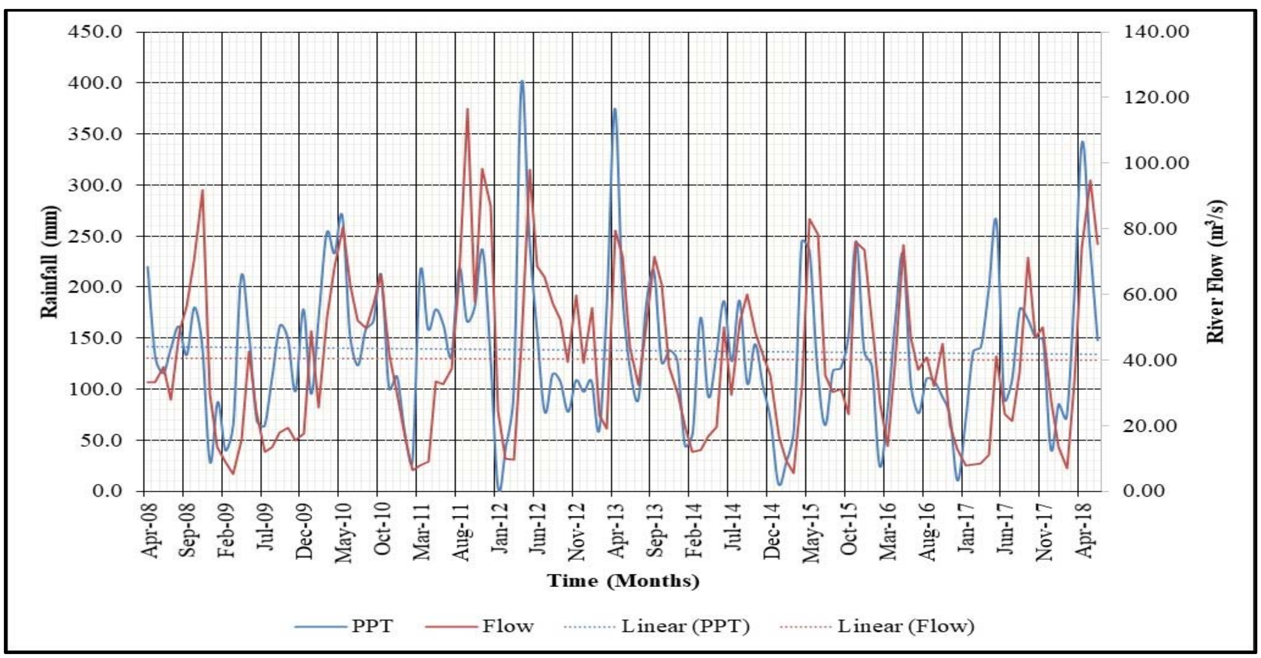

Figure 5-2: Sondu Miriu River basin rainfall and flow trends from 2008 to 2018

Considering the period of study when Sondu Miriu and Sang'oro have been in existence from 2008 to 2018, the observed rainfall has displayed negative trend. The same negative trends have also been displayed under the RCP4.5 and RCP8.5 projection scenarios (Figure 5-3).

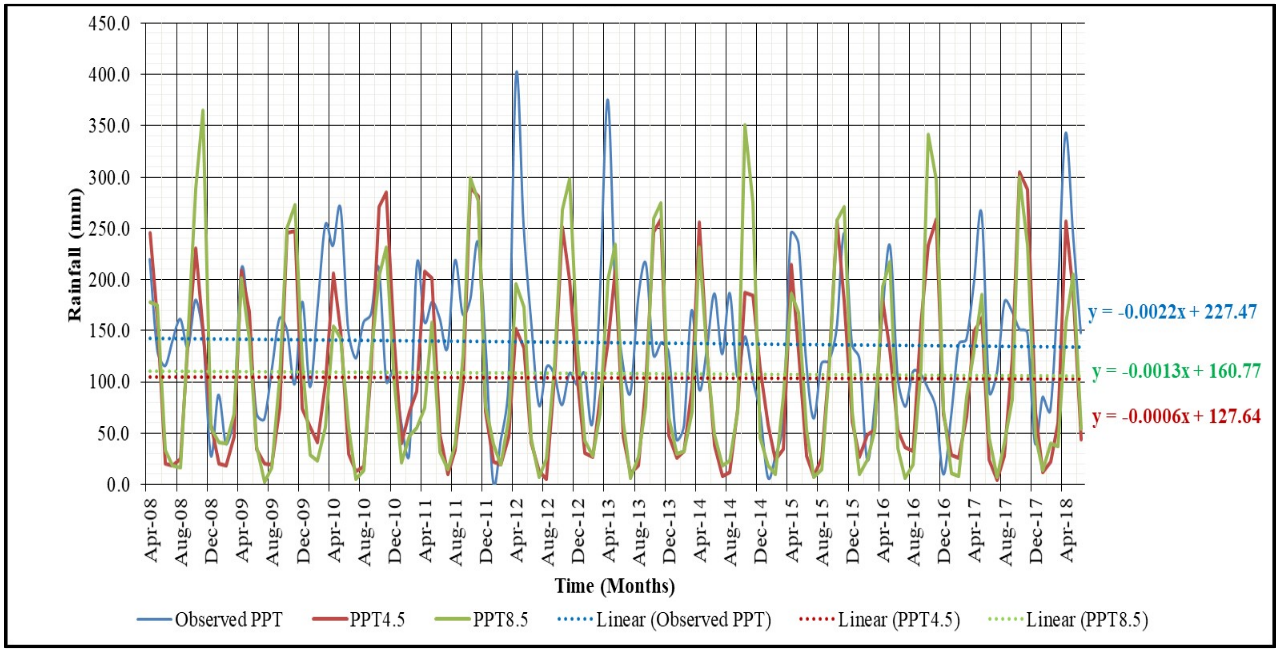

Figure 5-3: Observed and projected rainfall trends

5.2.1.1 Comparison between the observed and projected rainfall trend

For the period from 2008 to 2018, the observed rainfall declined by an average of 23.03 mm annually against a projected decrease of 13.62 mm in the RCP4.5 projection scenario and 14.20 mm annually in the RCP8.5 projection scenario. January to February seasonal rainfall increased by 0.03 mm annually against a projected decrease of 2.4 mm in the RCP4.5 projection scenario and 4.6mm annually in the RCP8.5 projection scenarios. March to May seasonal rainfall increased by 4.1 mm annually against the projected decrease of 1.8 mm in the RCP4.5 scenario and increase of 6.39 mm annually in the RCP8.5 scenario. July to September seasonal rainfall recorded a decrease of 6.4 mm annually against the projected increase of 3.7 mm annually in the RCP4.5 scenario and decrease of 2.9 mm annually in the RCP8.5 scenario. October to December seasonal rainfall decrease by an average of 11.5 mm against the projected increase of 3.1 mm annually in the RCP4.5 scenario and decrease of 2.4 mm annually in the RCP8.5 scenario (Table 5-1).

Table 5-1: Observed and projected rainfall change from 2008 to 2018

	January and February season	March to May season	June to September season	October to December season	Annual
Observed (mm)	0.03	4.11	-6.41	-11.52	-23.03
RCP4.5 scenario (mm)	-2.40	-1.80	3.70	3.08	-13.62
RCP8.5 scenario (mm)	-4.56	6.39	-2.90	-2.44	-14.20

The comparison of the observed rainfall and projected rainfall under the RCP4.5 and RCP8.5 reveal strong correlations between the projected and observed rainfall over the Sondu Miriu river basin with R^2 of 0.63 and 0.6 for the RCP4.5 projection scenario and RCP8.5 projection scenario respectively (Figure 5-4 and figure 5-5). The statistical test of significance using t-test indicates no significant difference between projected and observed rainfall within the Sondu Miriu basin.

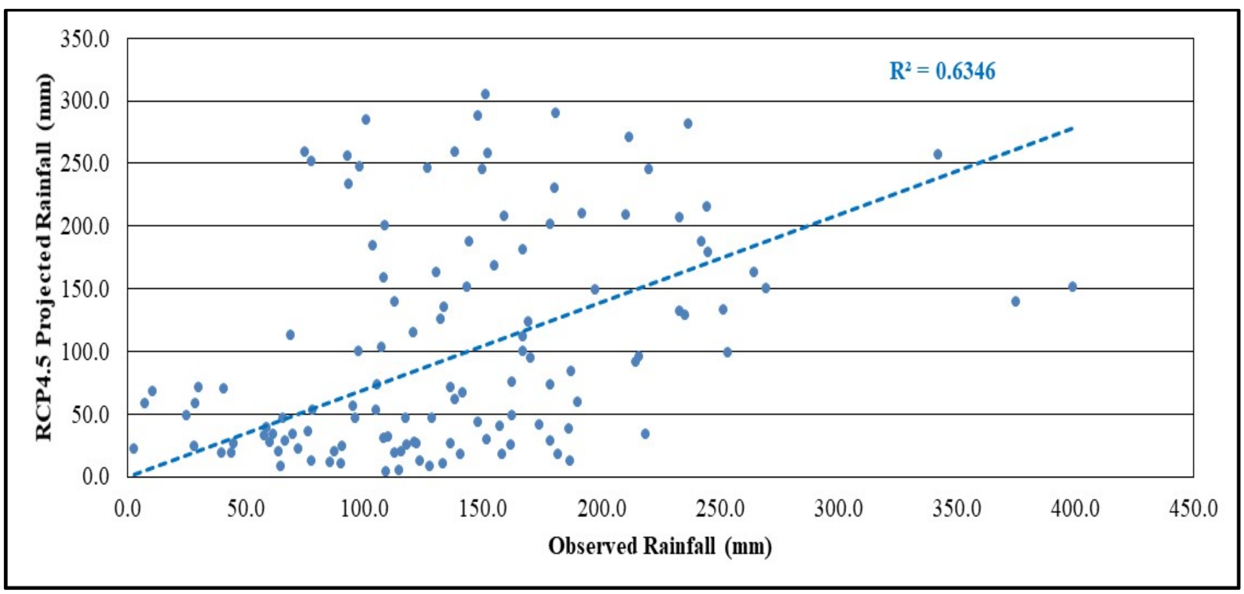

Figure 5-4: Correlation between observed and projected rainfall under RCP4.5 scenario

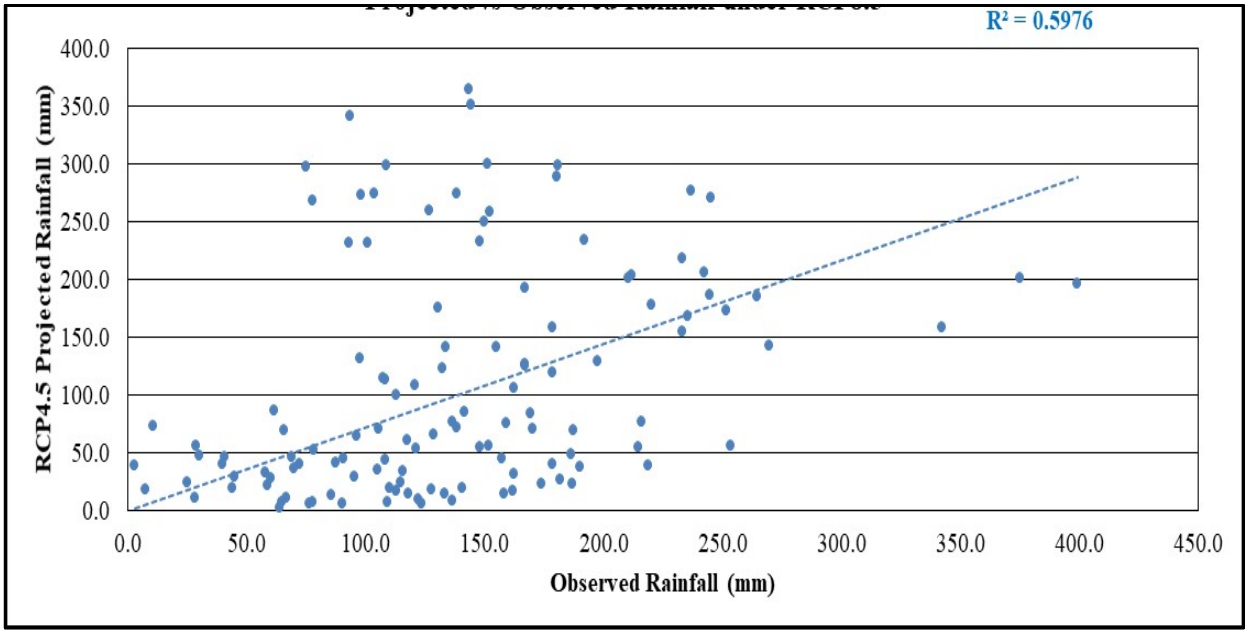

Figure 5-5: Correlation between observed and projected rainfall under RCP8.5 scenario

5.2.1.2 Comparison between the observed and projected temperature trend

During the period the existing tow run-o-river hydropower projects have been in existence in the Sondu Miriu river basin the observed minimum temperature has increased annually by an average of 0.02^{0}C while the maximum temperature has increased annually by 0.44^{0}C against the projected minimum temperature increase of 0.39^{0}C annually and maximum temperature decrease of 0.2^{0}C annually in the RCP4.5 projection scenario, and minimum temperature decrease of 0.39^{0}C annually and maximum temperature decrease of 0.18^{0}C annually in the RCP8.5 projection scenario (Table 4-15 and table 4-16).

For the Minimum temperature, January and February season decreased by 0.07^{0}C annually against the projected increase by 0.02^{0}C annually in the RCP4.5 projection scenario and 0.1^{0}C annually and in the RCP8.5 projection scenario. March to May seasonal minimum temperature decreased by 0.24^{0}C annually against the projected increase by 0.02^{0}C annually in the RCP4.5 projection scenario and 0.05^{0}C annually in the RCP8.5 projection scenario. July to September seasonal minimum temperature increased by 0.07^{0}C annually against the projected increase by 0.1^{0}C annually in the RCP4.5 and 0.06^0C annually in the RCP8.5 scenario. October to December seasonal minimum temperature decreased by an average of 0.05^0C against no projected change in the RCP4.5 scenario and a projected increase by an average of 0.07^0C annually in the RCP8.5 scenario (Table 5-2).

Table 5-2: Observed and projected minimum temperature changes from 2008 to 2018

	January and February season	March to May season	June to September season	October to December season	Annual
Observed (^0C)	-0.07	-0.24	0.07	-0.05	0.02
RCP4.5 scenario (^0C)	0.02	0.02	0.10	0.00	0.39
RCP8.5 scenario (^0C)	0.10	0.05	0.06	0.07	-0.39

January and February seasonal maximum temperature increased by 0.29^0C annually against the projected increase by 0.02^0C annually in the RCP4.5 projection scenario and 0.16^0C annually in the RCP8.5 projection scenario. March to May seasonal maximum temperature increased by 0.04^0C annually against the projected increase by 0.05^0C annually in the RCP4.5 projection scenario and 0.11^0C annually in the RCP8.5 projection scenario. July to September seasonal maximum temperature increased by 0.23^0C annually against the projected increase by 0.03^0C annually for the projection scenarios of RCP4.5 and RCP8.5. October to December seasonal maximum temperature increased by 0.31^0C annually against the projected decrease by 0.01^0C annually in the RCP4.5 scenario and increase by an average of 0.1^0C annually in the RCP8.5 scenario (Table 5-3).

Table 5-3: Observed and projected maximum temperature changes from 2008 to 2018

	January and February season	March to May season	June to September season	October to December season	Annual
Observed (^0C)	0.29	0.04	0.23	0.31	0.44
RCP4.5 scenario (^0C)	0.02	0.05	0.03	-0.01	-0.20
RCP8.5 scenario (^0C)	0.16	0.11	0.03	0.10	-0.18

5.2.1.3 Changes in Sondu Miriu River flows

River flows analyses show that the annual mean flow has been on the declining trend at a rate of 0.3 m^3/s per year between 2008 and 2019 when the two hydropower projects have been in operation. The seasonal flows have displayed varying characteristics whereby the June-July-August-September season has displayed increasing trends while the remaining seasons have displayed declining trends.

Between 2008 and 2019 the trends indicate that the Sondu Miriu seasonal river flows have been reducing by 0.86m^3/s per year for January-February season, 0.19m^3/s per year for March-April-May season and 0.61m^3/s per year for October to December season while the June-July-August-September season has been increasing by an average of 0.14m^3/s per year. In the period these two run-of-river hydropower projects have been in operations, the mean seasonal river flows have reduced by cumulatively 10.32 m^3/s for January-February season, 2.28 m^3/s for March-April-May season and 7.32 m^3/s for October to December season while the mean seasonal flow has increased by 1.68 m3/s in the June to September season (Table 5-4).

Table 5-4: Sondu river seasonal flow trends (2008 – 2019)

Season	Annual (m^3/s)	Change from 2008 to 2019 (m^3/s)
January to February	-0.86	-10.32
March to May	-0.19	-2.28
June to September	0.14	1.68
October to December	-0.61	-7.32

January to February season has been recording the lowest flows from 2008 to 2019. The lowest mean seasonal flows were 6.53 m^3/s in 2019 for January-February season, 9.12 m^3/s in 2019 for March-April-May season, 16.88 m^3/s in 2009 for June-July-August-September season and 17.35 m^3/s in 2009 for October to December season while the highest mean seasonal flows were 39.44 m^3/s in 2013 for January-February season, 67.52 m^3/s in 2018 for March-April-May season, 62.73 m^3/s in 2011 for June-July-August-September season and 81.01 m^3/s in 2011, for October to December season (Figure 5-6).

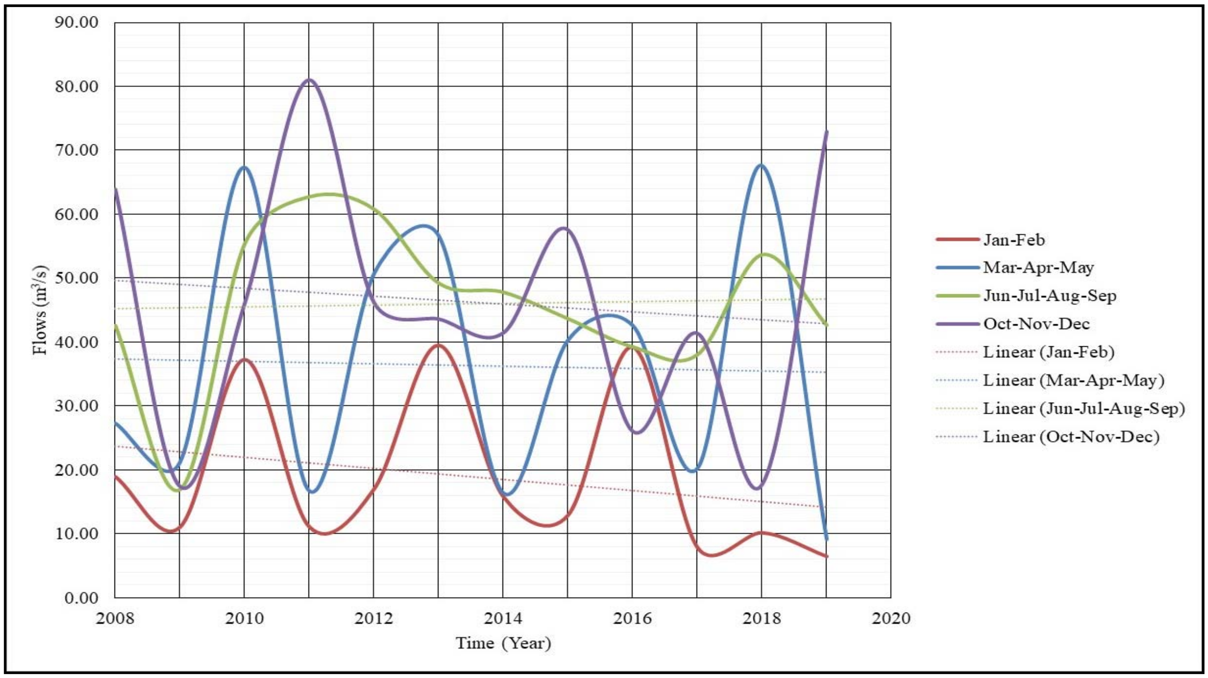

Figure 5-6: Sondu Miriu River seasonal flow trends from 2008 to 2019

The existing hydropower projects (HPPs) output from 2008 to 2019 shows that the electricity output has been declining during the last decade at an average rate of 0.75 GWh and 2.36 GWh per year for Sondu Miriu and Sang'oro hydropower projects, respectively. The seasonal outputs also vary from season to season. The recorded seasonal changes in electricity output from Sondu Miriu and Sang'oro hydropower projects indicate that the output has been declining in the seasons of January and February season, March to May season and October to December season while increasing in the June to September season (Table 5.5).

Table 5-5: Electricity output changes from Sondu Miriu and Sang'oro hydropower projects (HPPs)

	HPP	Annual	January – February season	March – May season	June – September season	October – December season
1	Sondu Miriu (GWh)	-0.75	-0.85	-1.48	1.81	-0.33
2	Sang'oro (GWh)	-2.36	-1.92	-0.02	0.37	-0.80

On average there has been electricity output decline in both the existing hydropower projects in the Sondu Miriu river basin. The lowest output was recorded in 2009 at 218.68 GWh while the highest was recorded in 2010 at 480.79 GWh for Sondu Miriu hydropower project. For the case of Sang'oro, the lowest recorded output was 99.51 GWh in 2017 while the highest was 133.22 GWh in 2016 (Figure 5-7).

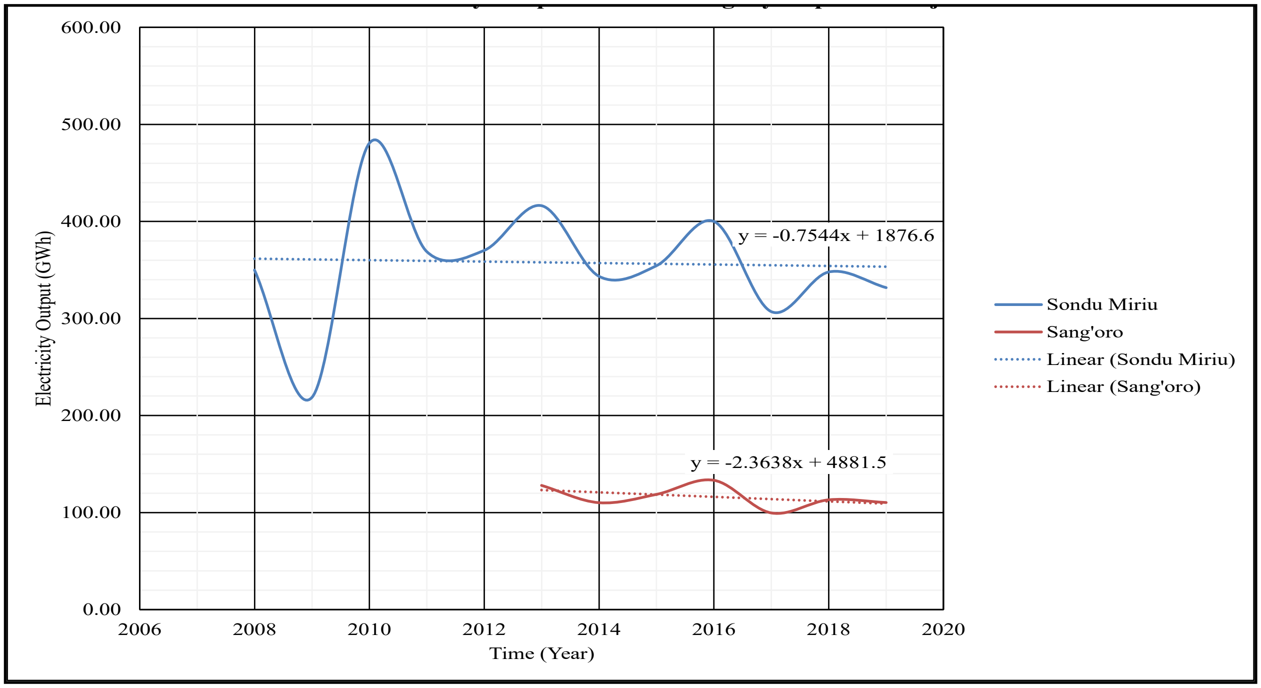

Figure 5-7: Annual energy output trends from the existing hydropower projects

Both the Sondu Miriu and Sang'oro hydropower projects have been recording higher output during the June to September season while the lowest output has been recorded in the January to February season. The critical aspect is the trend whereby a positive trend exists in the June to September season for both the hydropower projects (Figure 5-8 and Figure 5-9).

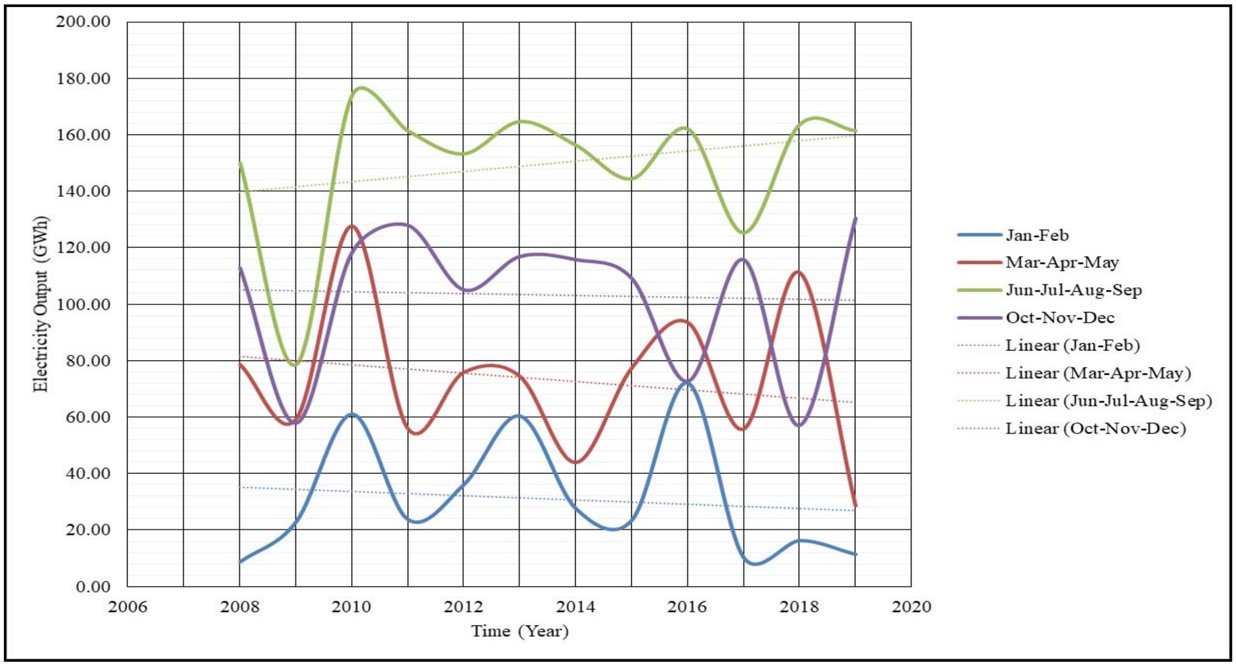

Figure 5-8: Seasonal energy output trends at Sondu Miriu hydropower project

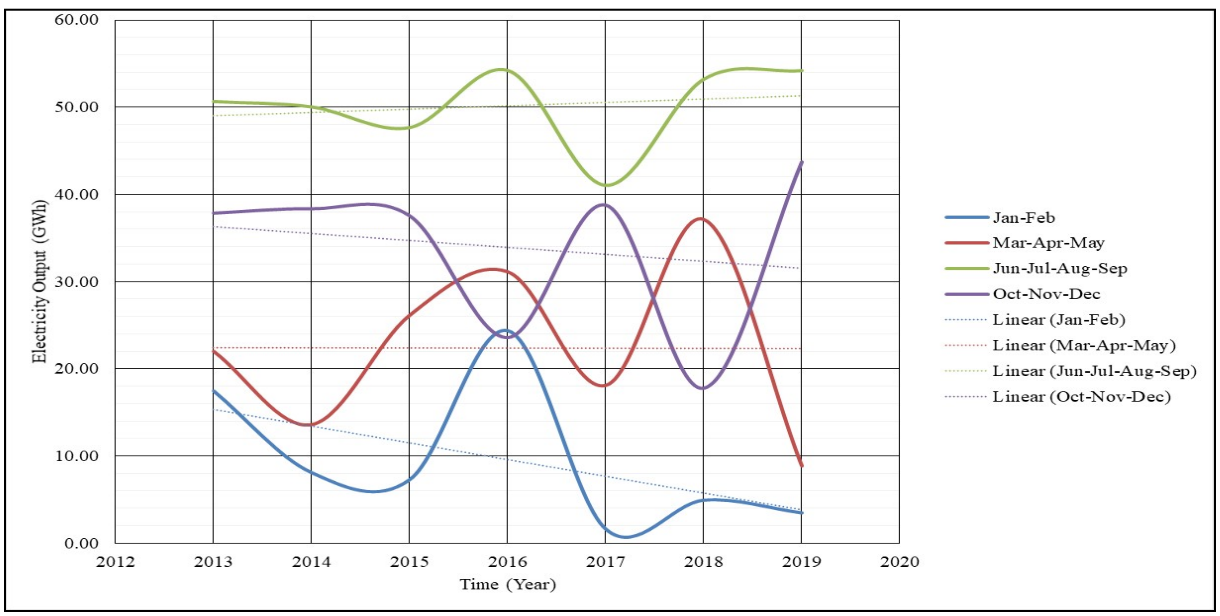

Figure 5-9: Seasonal energy output trends at Sang’oro hydropower project

5.2.1.4 Tests of significance

A test of statistical significance was conducted to determine any significant difference that may exist between the observed river flow and observed rainfall over the basin, and between the observed climate data sets and projected data sets in the projection scenarios of RCP4.5 and RCP8.5 scenarios. The statistical test of significance using t-test indicate that there is no significant difference between the Sondu Miriu river streamflow, and the observed rainfall recorded within the basin from 2008 to 2018 (Table 5-6).

Table 5-6: t-Test results for streamflow and observed rainfall.

	Streamflow	***Observed Rainfall***
Mean	40.33	137.90
Variance	612.69	5084.84
Observations	123.00	123.00
Pearson Correlation	0.53	
Hypothesized Mean Difference	0.00	
df	122.00	
t Stat	-17.46	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.66	
P(T<=t) two-tail	0.00	
t Critical two-tail	1.98	

During the same period from 2008 to 2018 when the two run-of-river hydropower projects have been in existence, the t-test results show no significant difference between the observed and projected rainfall in the RCP4.5 projection scenario (Table 5-7).

Table 5-7: t-Test results for observed rainfall and RCP4.5 projected rainfall.

	Observed Rainfall	***Projected Rainfall (RCP4.5)***
Mean	137.90	104.07
Variance	5084.84	7627.92
Observations	123.00	123.00
Pearson Correlation	0.39	
Hypothesized Mean Difference	0.00	
df	122.00	
t Stat	4.23	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.66	
P(T<=t) two-tail	0.00	
t Critical two-tail	1.98	

Comparison between the observed rainfall over the Sondu Miriu river basin and the projected rainfall over the same period from 2008 to 2018 show no significant difference between the observed and projected rainfall in the RCP8.5 projection scenario (Table 5-8).

Table 5-8: t-Test results for observed rainfall and RCP8.5 projected rainfall.

	Observed Rainfall	*Projected Rainfall (RCP8.5)*
Mean	137.90	107.96
Variance	5084.84	9393.11
Observations	123.00	123.00
Pearson Correlation	0.36	
Hypothesized Mean Difference	0.00	
df	122.00	
t Stat	3.41	
P(T<=t) one-tail	0.00	
t Critical one-tail	1.66	
P(T<=t) two-tail	0.00	
t Critical two-tail	1.98	

5.3 Discussions on Climate change impacts on hydropower Generation

During the period between 2008 and 2019, when the existing two hydropower projects have been in operation within the Sondu Miriu river basin, the annual rainfall has declined. The same trend has been replicated in the seasonal rainfall patterns except the June to September season. The river flow has followed the same pattern with declining annual and seasonal flows except for June to September season.

The hydropower output in the two hydropower projects have also followed the same trend whereby the output has been declining annually and in all the seasons except for June to September season. This is an indication that the hydrology and hydropower production will respond to rainfall pattern in the region. This concurs with the Olaka *et al.*, 2019 that high variability in projected discharge will have impacts on hydropower production in Sondu Miriu river and this could have the potential to reduce the average electricity production during the drought years (Olaka *et al.,* 2019).

With the rainfall projected to increase within the basin, hydropower generation is expected to remain stable, and this presents an opportunity for more hydropower development within the basin. Generally, the climate change impacts on hydropower output could vary a lot and differ locally, depending on the flow regime change. The impacts of the changing climate are expected to be felt more on the run-of-river hydropower systems compared to other systems with storage (Storage hydropower systems). Since rainfall is projected to increase, storage hydropower systems should be considered to manage the climate variability. A special report on "renewable energy sources and climate change mitigation" by IPCC in 2011 made a conclusion that the expected overall climate change impacts on existing hydropower generation may be small, or even marginally positive. However, the possibility of substantial variation within countries and even across regions are indicated in results (Berga,2016).

The correlation between the observed river flows and observed rainfall within the Sondu basin is a strong with an R^2 of 0.78, an indication that rainfall data in the basin can be utilised to estimate the streamflow and how it can influence the hydropower production. The strong correlation between the observed rainfall and projected rainfall with R^2 of 0.63 for the RCP4.5 projection scenario, and 0.60 for the RCP8.5 projection scenario indicate the reliability of climate change projection scenarios. Therefore, the climate change projections can be used to develop trends that can guide on the future water resource availability for development within the Sondu Miriu river basin.

5.3.1 Statistical significance

The statistical test of significance using the t-test has indicates no significant difference between the streamflow characteristics in Sondu Miriu basin. Based on the period the two run-of-river hydropower projects have been in existence, the t-test for significance indicates no significant difference between the observed and the projected rainfall characteristics within the basin.

CHAPTER SIX

RESULTS AND DISCUSSIONS FOR SPECIFIC OBJECTIVE THREE

6.1 Introduction

The results and discussions on the impacts of the changing climate and development of hydropower activities on the livelihoods of the local communities in Sondu Miriu basin are presented in this chapter.

6.2 Results for specific objective three

The results of the socioeconomic analysis within Sondu Miriu basin are presented in this section. It includes the results from the administration of questionnaires at household levels, focus group discussions and key informants.

6.2.1 Socio-economic status within the Sondu Miriu basin

There are four main sources of income within the basin. These are from formal employment, private enterprises, skilled casual labour and unskilled casual labour. The main source of income within the Sondu Miriu River basin is private enterprises which accounts for 31% followed by casual unskilled labour at 25% and then casual skilled labour and formal employment at 22% each (Figure 6-1). The results indicate that the households' incomes are fairly distributed among the four main sources of income. The high income dominated by private enterprises is an indicator of economic opportunities in the area.

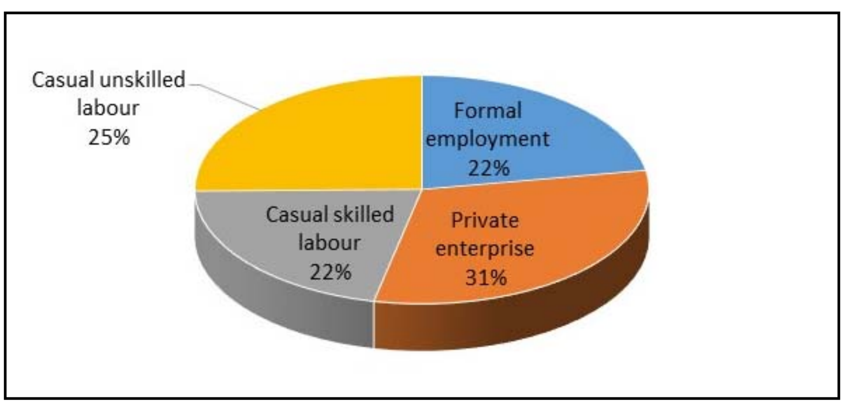

Figure 6-1: Main source of income for the households

During the period of data collection, between January and March 2017, The Central Bank of Kenya mean exchange rate for the period was one United States Dollar was equivalent to Kenya shillings 103 (1 USD = Ksh. 103). Most of the households in Sondu Miriu basin representing 59% earn monthly income of below Ksh. 25,000 (242 USD) while the households that earn above Ksh. 25,000 (242 USD) are 41%. Households representing 32% earn below Ksh. 10,000 (97 USD) monthly on average, 27% of the households earn between Ksh. 10,000 (96 USD) and Kshs. 25,000 (242 USD), 15% earn between Ksh. 25,000 (242 USD) and Kshs. 50,000 (484 USD), 16% earn between Ksh. 50,000 (484 USD) and Ksh. 100,000 (967 USD), and 10% earn above Ksh. 100,000 (967 USD) (Figure 6-2). The results indicate that households living below poverty line are more than 32% within Sondu Miriu river basin.

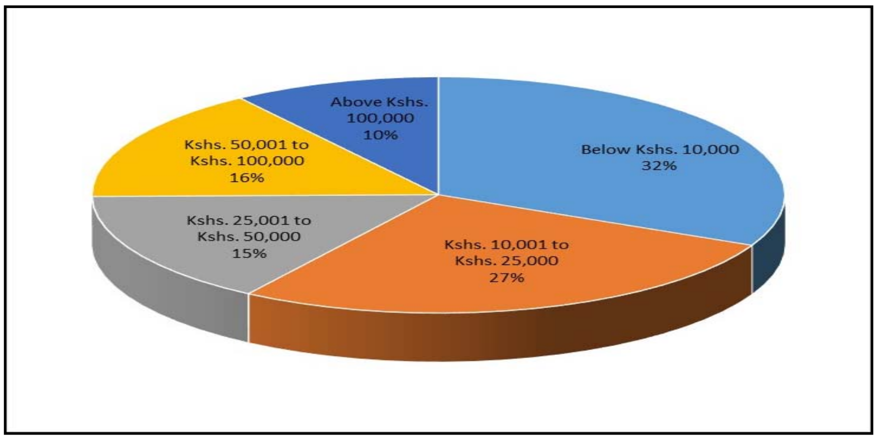

Figure 6-2: Average monthly household income

Five sources of energy were identified within the basin. These sources include electricity, charcoal, LPG, kerosene, and wood fuel. The most used sources of energy in this basin are charcoal and wood fuel accounting for 25% and 24% respectively as illustrated in Figure 5-3. The two sources account for approximately a half of the energy sources within the basin. The intensive use of the two sources of energy may accelerate the land degradation that impacts on water catchment areas leading to siltation of rivers within the Sondu Miriu River basin. This if not checked may end up impacting on the hydropower production through changing river flow regimes. LPG and kerosene accounts for 18% each while electricity accounts for 15% of the energy use in the Sondu Miriu river basin (Figure 6-3).

The indication that only 15% use electricity is sign that there is need to enhance electricity connectivity in the area for the benefit of catchment conservation as a large percentage still use charcoal and wood fuel comprising 49% and an additional 18 percent use fossil fuel (kerosene) that has a high contribution of the greenhouse gases.

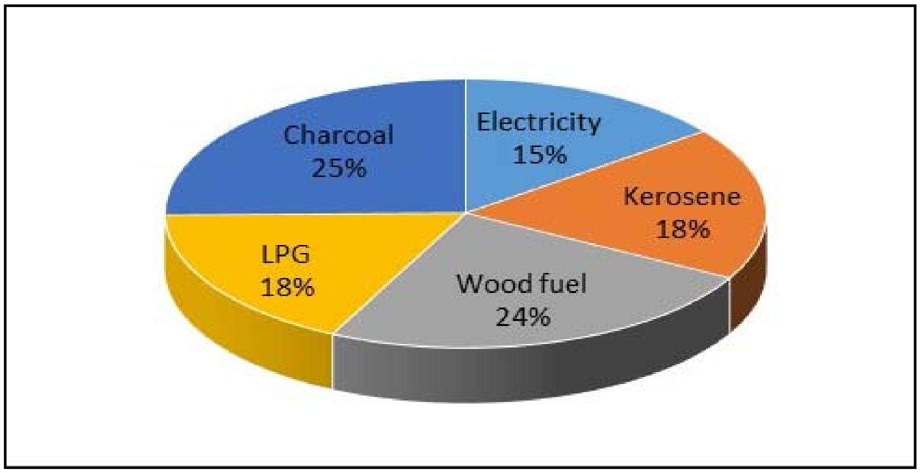

Figure 6-3: Sources of energy used by the households.

The main primary activities within the basin are crop production, animal production, forestry, quarrying, fisheries, and logging. The primary economic activities are well distributed within the basin. Fisheries accounts for the highest primary economic activity at 26%. Crop production accounts for 17%, animal production and logging accounts for 16% each, forestry accounts for 13% while quarrying activities account for 12% of the primary activities within the basin (Figure 6-4).

The primary economic activities within the basin need to be managed well to promote catchment conservation. Forestry activities need to be enhanced to a larger percentage more than the current 13% while the other activities like fisheries, animal production, crop production, logging, and quarrying need to be practiced in a sustainable manner that promotes catchment conservation and management.

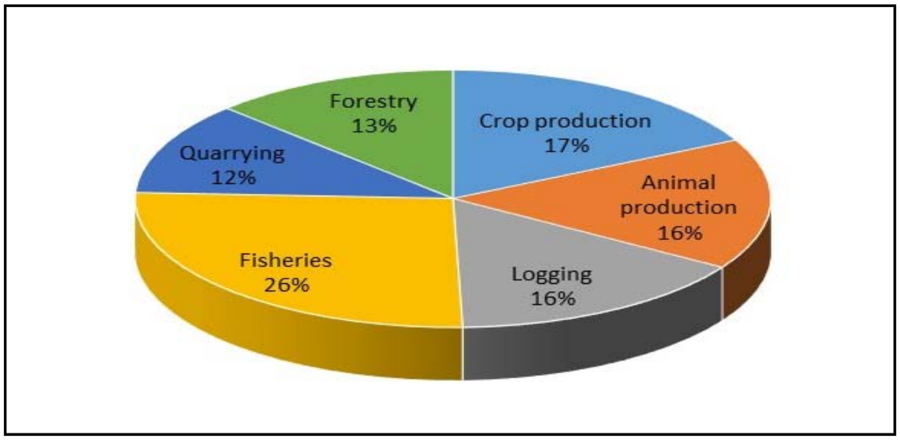

Figure 6-4: Primary economic activities for the households

Secondary economic activities also seem to be relatively balanced with the construction accounting for 31%, trade accounting for 26%, housing accounting for 24% and manufacturing accounting for 19%. (Figure 6-5).

The higher percentage of the households engaging in construction is an indication of more infrastructural developments within the basin which need to be managed well so that such secondary activities do not impact on the hydropower operations negatively. Many households also take part in trading that can improve the economic status of the basin. Hydropower projects can also be used to support manufacturing that is being practised by 19% of the households within the Sondu Miriu river basin.

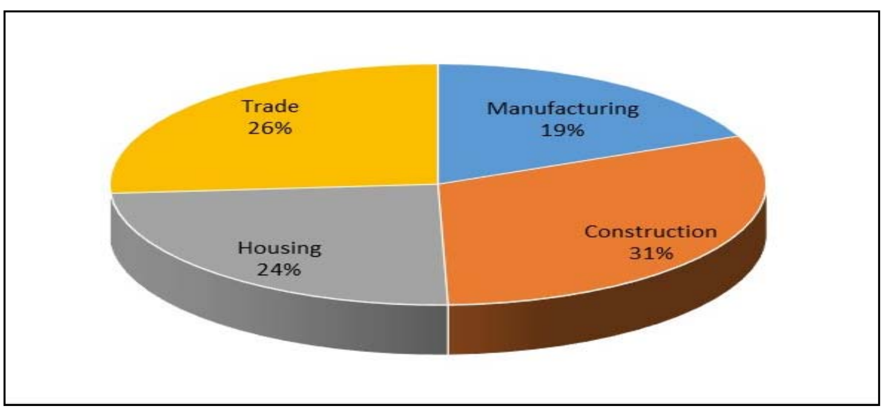

Figure 6-5: Secondary economic activities for the households

The four main water sources in the area include river, ponds, water wells and piped water supply. Majority of the community still fetch water from the rivers representing 39% of the households. Water supply from the wells represent 29%, while ponds and piped water represent 16% each (Figure 6-6).

Accessibility to water supply is of great concern as only 16% of the households are connected to piped water within the basin while the majority still fetch water directly from the river, ponds, or water wells. This is an exposure of the local communities to water borne and water related illnesses which can have negative impacts on the socioeconomic activities at the local level especially during flooding and drought.

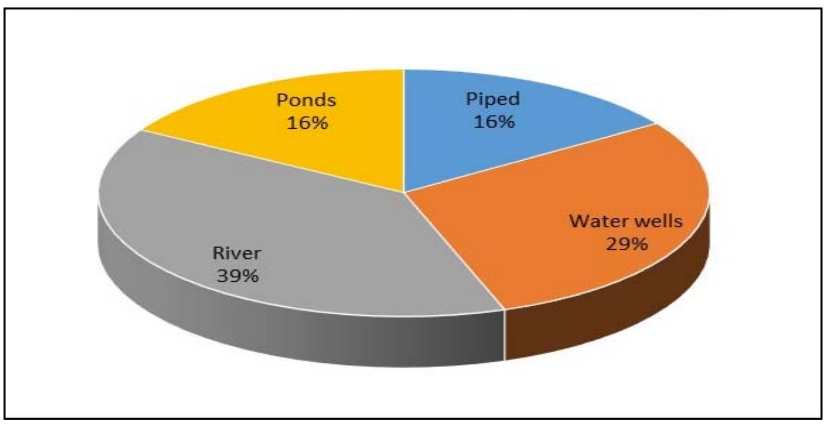

Figure 6-6: Domestic water sources in households

On health, many households within the basin spend less than Ksh. 10,000.00 (96.72 USD) annually on their health representing 38%. Only 4% of the households spend more than Ksh. 75,000 (725 USD) annually on their health. The households representing 33% spend between Ksh. 10,000 (96 USD) and Ksh. 25,000 (242 USD) annually, 18% spend between Ksh. 25,000 (242 USD) and Ksh. 50,000 (484 USD) while 7% spend between Ksh. 50,00 (484 USD) and Ksh. 75,000 (725 USD) annually (Figure 6-7).

With most of the households at 38% spending less than one hundred US dollars (100 USD) annually on healthcare is an indication that the community health status within the Sondu Miriu river basin is good.

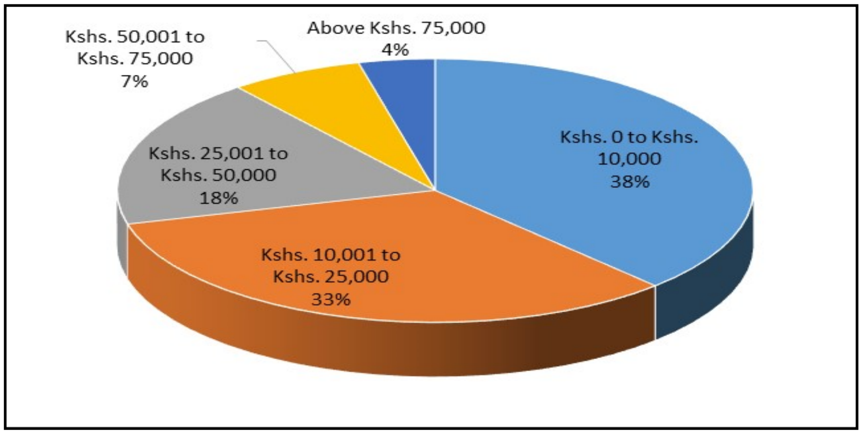

Figure 6-7: Money spent by households on health per annum.

6.2.2 Discussions on Socioeconomic status of Sondu Miriu river basin

The socioeconomic parameters considered include source of income, household income, source of energy for the households, primary and secondary economic activities, water supply sources, household expenditure on heath and accessibility of health services. The socioeconomic status of the Sondu Miriu river basin indicates that majority of the households constituting about 59% are poor and earning below 241 US dollars a month. This translates to below 8 US dollars per day per household.

The high income dominated by private enterprises is an indicator of economic opportunities in the area. The employment rate also is exceptionally low within the basin with only 22% in formal employment while the remaining 78% are either in private enterprises or engaged as casual labourers. Even though majority of the households within the basin earn very low incomes, the results indicate that the households' incomes are fairly distributed among the four main sources of income. About 49% of the households use wood fuel and charcoal as energy sources which can be considered a threat to catchment conservation. Promotion of catchment conservation and management is critical within the basin because the existing primary economic activities within the Sondu Miriu river basin if not handled well can lead to catchment destruction. Enhancement of the forest cover is key through support to programmes the promote afforestation activities so that more households can take part in forestry to a larger percentage more than the current 13%.

There is need to ensure sustainable utilization of the existing basin resources as a source of livelihood. The communities' activities practiced within the basin that are dependent on the basin resources include crop production, logging, animal production, fisheries and quarrying that promotes catchment conservation and management. About 84% of the households in the basin still fetch ware from the rivers, wells and ponds indicating access to portable water is still a challenge within the basin. This may expose the local communities to water borne and water related diseases. The expenditure on health services is generally exceptionally low that can be a sign of a healthy community or a community too poor to afford health services.

6.2.3 Feedback on the interview with the local leaders

The public consultation involved the local communities and other various stakeholders within and outside the Sondu Miriu River basin. This could be termed as all-inclusive as most of the stakeholders participated in the consultations. Land issues are always very delicate to deal with in Kenya and this includes the Sondu Miriu River basin. The community leadership acknowledged that the land compensation for the landowners was handled well.

During the discussions with the local leaders, that included the chiefs and assistant chiefs, their opinion was that major economic activities within the Sondu Miriu River basin include fishing, farming, livestock keeping, agroforestry, trade, and logging. This concurred with findings during the household surveys within the Sondu Miriu river basin where fishing accounted for higher percentage on the primary economic activities.

Opinion from the local leaders indicated that some climate change impacts that were experienced by the local communities included reduction in agricultural production, reduction in rainfall amounts, disruption of food production and animal health because of changing climatic conditions, reduction in pasture for the animals, reduction in fish population and reduction in forest cover.

Highlighted impacts of the development of hydropower on the local communities within the basin include improved power supply and reliability, improved environmental conservation and management through environmental conservation projects supported by the hydropower development project, improved infrastructure in the area, change of land use from agricultural/forests to other uses such as roads, canals, tunnel among others, employment for the local people and other business enterprises within the basin.

There exists positive attitude from some communities towards the hydropower development projects within the Sondu Miriu River basin. These communities feel that the existing hydropower projects have brought a lot of socioeconomic development activities within the basin. On the other hand, some communities especially those on the upstream have got negative attitude towards the existing hydropower projects where they feel that they did not receive enough benefits from the existing hydropower projects.

During the development of the existing hydropower projects within the Basin, some of the benefits cited by the community include road network, watering points for the livestock and the local community, provision of a primary school and a resource centre and provision of a health centre. All these were done within the proximity of the project area. Some of the major benefits the communities were expecting during the development of the existing hydropower projects included irrigation infrastructure and piped water supply scheme for the local communities.

Even though the consultations were handled well especially within the proximity of the hydropower project area, there was no consultation at the initial stages and the consultation did not cover the entire Sondu Miriu River basin. The community leadership recommended that it is critical to have wide consultation covering the entire basin to ensure harmonious coexistence of all the communities sharing the same resource without any suspicion.

For the sake of sustainability of the catchment area for the hydropower project, several initiatives need to be introduced to support livelihoods for the communities living within the Sondu Miriu River basin. These include but not limited to irrigation projects, fish processing plants, agricultural produce processing plants for tea, potatoes, pineapples, bananas among others, afforestation programmes within the basin and environmental conservation and monitoring programmes. These when implemented within the basin will enhance resilience to climate change impacts.

6.2.4 Feedback on the interview with the local actors

From the local actors' perspective, the real livelihood challenges associated with climate change within the basin included poverty, crop failure, water-born and water related diseases, poor water quality and water availability. Other challenges in addition to those that are associated with the changing climate include those associated with construction of the existing hydropower plants such as resettlements, noise pollution, air pollution and water pollution.

To address these challenges, it is recommended that several interventions could have been put in place during the project development cycle. These include awareness creation and education for local communities within Sondu Miriu River basin, provision of social amenities in advance before the construction works for the project to improve the local communities' resilience and promotion of livelihood projects capable of supporting adaptation to actions within the basin.

Climate change adaptation is critical for the sustainability of the hydropower development projects and provision of alternative livelihood activities within the Sondu Miriu River basin. To achieve this, several actions need to be integrated into hydropower development such as human resources and trans-disciplinary systems perspectives for dealing with climate change, integration of environmental conservation, appropriate agricultural practices, activities that are pro-poor community-based for adapting to climate change and use of sustainable technologies and strengthening research and development capacity.

During development of the two run-of-river systems, some of the benefits expected by the community such as irrigation scheme and water supply system were not implemented due to budget constraints and prioritization. With the hydropower development in the Sondu Miriu River basin, the community expected improved access to electricity within the basin to many community households if not all of them. This did not happen as this function was left to the national government through the power off-taker (Kenya Power) which undertakes electricity distribution and connectivity tasks.

To support the stated actions, legal instruments are needed. These include official policies for addressing the impacts of climate change and adaptation actions for Sondu Miriu River basin, laws to compel all development actors within the basin to set aside a budget for adaptation actions within project area and by-laws for ensuring everyone within the basin participates in climate change adaptation actions.

6.2.5 Discussions on the feedback from the local leaders and local development actors

6.2.5.1 Benefits and impacts of the existing run-of-river hydropower projects.

Hydropower project can support several adaptation actions that contributes to its sustainability. The success of adaptation actions usually depends on the socioeconomic status of a community. From the discussions with the community leadership, the community view is that climate change has resulted in reduction in agricultural production, reduction in rainfall which is also evidence from the analysis curried out for the last decade, and disruption of food production and health.

On the other hand, the existing hydropower projects have brought with them several benefits. Some of their benefits include improved power supply and reliability, improved environmental management through environmental conservation projects supported by the existing projects, improved infrastructure, land use change, employment, and education facilities. Besides the benefits associated with the existing projects, the community leadership believe that more can still be done especially irrigation system and piped water supply project.

This discussions with the other local actors in the areas also reveal that there exist some livelihood challenges that are associated with climate change in the basin. These include poverty, crop failure, poor water quality, water availability and water-born and water related diseases. These challenges could have been addressed from initial stages of the existing projects through several interventions. These include awareness creation and education for the local communities within the Sondu Miriu River basin, provision of social amenities in advance before the construction works for the project to improve the local communities' resilience and promotion of livelihood projects capable of supporting climate change adaptation within the basin.

For sustainability hydropower development projects and provision of alternative livelihood activities within the Sondu Miriu River basin, climate change adaptation actions are necessary. There is need to integrate adaptation actions into development of hydropower such as integration of environmental conservation, appropriate agricultural practices, activities that are pro-poor community-based for adapting to the changing climate and sustainable technologies use, strengthening research and development capacity, human resources, and trans-disciplinary systems perspectives for dealing with impacts of climate change.

Research findings have indicated that developing hydropower technology can yield various social and economic co-benefits like better energy services access in rural areas, energy security, and employment, (Shrestha and Pradhan, 2010; IPCC, 2013). These can contribute to building resilience among the local communities and sustainability of the hydroelectric power development projects within the basin. Major impacts of the opportunities provided by hydropower projects in the basin is most likely to be felt in several sectors including agriculture, manufacturing, disaster risk management, environment, trade, and health among others (Bruckner, *et al.*, 2014).

Research carried out by Chandy *et al*., 2012 in Sikkim, India recommended that Governments should provide investment advisory services the future hydropower project to the beneficiaries that receive compensatory payments for long-term livelihood security by investment in enterprises that are appropriate. Opportunities for employment in the villages is a socioeconomic benefit which is very important, but most of the employment opportunities available are during the construction phase which are short term. Depending on the technology type adopted in the design, the depletion related to hydropower project of water, forests land and agricultural land can be a natural capital loss while creation of opportunities for employment is an enhancement of human and financial investment for the local communities. Run-of-river systems have got the least impact on natural capital. The temporary nature of the direct employment during construction phase may constitute a livelihood vulnerability issue that may need to be addressed. The development of infrastructure, electricity, and markets resulting from hydropower projects also create potential for economic activity in new areas, like small-scale industries (Chandy *et al.*, 2012).

Within Sondu Miriu River basin, there exist various land use patterns that can be associated with the present community socioeconomic activities for their livelihoods. This is expected to have impacts on the catchment conservation efforts and management. Research done by Masese *et al.*, in 2012 discovered the existence of cumulative impacts in the catchment areas and on the riparian associated with human activities within Sondu Miriu basin. This was observed to have resulted from the intensified agricultural activities and clearing of forest by the local communities for their socioeconomic benefits (Masese *et al.*, 2012). The development of the existing run-of-river hydropower projects can act as a catalyst for further degradation of the catchment if not well managed or if alternatives livelihoods are not presented.

6.2.5.2 Managing Community Livelihood activities in the Sondu Miriu river basin

Good knowledge concerning expected future climate change patterns can inform the preparations for building communities' resilience to the anticipated climate change impacts. Knowing the trends for the past climate change can assist in explaining the reasons why the local communities take some actions for their survival. The results have demonstrated that the communities can engage in various activities with the basin that if managed well can assist in both building the community resilience and safeguarding the sustainability of other development activities in the area. For a successful climate change adaptation integration, more focus needs to be put on improving the socioeconomic status of the local communities in a sustainable manner.

Involvement of community social groups, which can be established within the Sondu Miriu river basin as consultative fora, water resource user associations, forest user associations and community lobby groups can be explored to create awareness in implementation of sustainable livelihood activities within the basin. Other community-based institution/organizations can be formed as development groups focusing on specific water subbasins or reservoirs. These community-based groups can add a lot of value to stakeholder participation in implementation of sustainable livelihood activities that contribute towards water resource and catchment conservation and management. Ong'or in 2005 considered the various community participation approaches that were being developed by the local communities to be included in the water resources management and to achieve higher levels of integration in the watershed resources management within the Lake Victoria Basin. It has been proposed that watershed management within the Sondu Miriu river basin should primarily involve several activities including protection, conservation, and development of water resources (Ong'or, 2005). The proposed integrated approach also involves management of the resources in a sustainable way for the benefit of livelihood activities especially general development, pottery and brick making, papyrus harvesting and utilization, irrigation, and farming as well as conserving the river basin resources. Unfortunately, these have not been implemented due to lack of incentives and implementation strategy.

Some of the community livelihood activities and most likely to impact negatively on the catchment status. It has been demonstrated that some catchments within the area were experiencing a lot of pressure resulting from community livelihood activities within the subbasins or basin of the rivers and streams draining into the main river (Kairu, 2001; Osumba *et al*., 2010; Morrison and Harper, 2009; Masese *et al* 2012; Morrison *et al*., 2012). The activities included agricultural practices, livestock keeping, forestry and settlement, solid waste disposal, water over-abstractions, wastewater disposal, and introduction of alien species (Masese *et al*, 2012). Makalle *et al* in 2008 concluded that there are conspicuous changes in community livelihoods resulting from intensive land use practices. These land use practices included cultivation expansion, overgrazing along the riverbanks, increased utilization of wetlands, and decreased forest cover. Makalle *et al* in 2008 also concluded that there is scarcity of original natural common resources which has forced the local farmers to explore intensification and diversification of the activities for their farm production but with limited success which can be associated with poor traditional farming practices.

The current local initiatives to be implemented within the basin will require integration of approaches that embrace policy studies and reforms, economic analysis, technical research, and indigenous knowledge (Makalle *et al* in 2008).

CHAPTER SEVEN

RESULTS AND DISCUSSIONS FOR SPECIFIC OBJECTIVE FOUR

7.1 Introduction

In this chapter, results and discussions are presented on climate change adaptation strategies within Sondu Miriu Basin. It looks at the existing strategies aimed at making the basin to be able to adapt to the climate change impacts.

7.2 Results from objective four

This section presents the results of the assessment of existing strategies for climate change adaptation in Sondu Miriu basin.

7.2.1 Defining the objectives of the adaptation strategies

The objective was to identify adaptation strategies within Sondu Miriu River basin that can be applied in hydropower development projects. It looked at the national and local strategies and how these strategies can be improved locally. The main objective of the strategies was to identify adaptation actions that can be implemented within the Sondu Miriu River basin to support sustainable hydropower development and building resilience to the communities locally in coping with the climate change impacts within the basin.

7.2.2 Climatic change impacts of significance in Sondu Miriu river basin

There were several climate change impacts within Sondu Miriu basin highlighted by the local leaders and development actors during the interviews. These impacts include displacement of populations, water scarcity, drought, land and ecosystem degradation, negative impacts on humans and livestock health, food and nutrition insecurity, declining agricultural and livestock productivity, and flooding. Within Sondu Miriu basin, there are impacts of climate change on existing hydropower projects and local community livelihoods. With the projected increased rainfall amounts and temperature, the frequency of the meteorological extremes is expected to increase and may make the current impacts worse. Droughts will lower hydropower, agricultural and livestock production, flooding will destroy property and cause displacement of the people in low land areas, food and nutrition insecurity will lead to malnutrition, negative health impacts will strain the existing health facilities, land and ecosystem degradation will compromise the hydropower and livelihood sustainability while water scarcity and displacement will weaken the communities' resilience.

7.2.3 Policy and adaptation options

Since the launch of NCCRS in 2010, it has been the guide for policy decisions in Kenya. The first national policy document was National Climate Change Response Strategy (NCCRS) enacted in 2010 that fully acknowledged the reality of climate change. The evidence of climate change impacts was provided by the NCCRS on various economic sectors together with the proposed strategies for climate change adaptation and mitigation (Government of Kenya, 2010a).

The NCCRS implementation has been taken forward by the National Climate Change Action Plan (NCCAP). An extensively consultative process was adopted for the development of the NCCAP. There was a lot of assistance received from many development partners and stakeholders for the NCCAP. The NCCAP brief results included.

i. Recommendations for capacity development and knowledge management,
ii. A development pathway for low carbon and climate resilient,
iii. A national performance and benefit measurement (NPBM) system
iv. Recommendations for a regulatory framework and an enabling policy,
v. Consolidations for technology requirements,
vi. Priority actions and adaptation analysis,
vii. A financing mechanism for climate change,
viii. Mitigation options,

The national policy and development decisions are expected to be guided by the NCCAP in all the sectors of economy. Various actors including civil society organizations, private sector, and Government institutions are required to participate in the implementing the NCCAP. Planning of climate change is considered as a process that is dynamic and cross-cutting. Therefore, it is expected to continuously track the recommended actions while a revision and update of the NCCAP will require to be conducted every five (5) years to conform with budgetary and planning processes at the national level.

Kenya as a country has very minimal current or historical responsibility for the global climate change if any. This is due to the country's very minor emissions in relation to the entire global emissions. The vulnerability of country to climate change impacts, in spite of all these, is still very highly. One of the Kenya's main priorities is adaptation to climate change and particularly in the hydropower development.

During the period for preparing National Climate Change Action Plan (NCCAP), the climate risk-based adaptation analysis that was performed relied majorly on the findings of the National Climate Change Response Strategy (Government of Kenya, 2010a). The aims of the adaptation analysis were:

(1) Climate change impacts assessment in all the sectors,
(2) Provision of the evidence to Kenya as a country of key climate risks,
(3) Documentation of all the recommended, planned, or on-going activities on climate adaptation,
(4) Giving support to the integration of climate change adaptation into appropriate strategies in the existing and new sector, budgetary and planning processes, development, and policies across different levels.
(5) Development of potential adaptation actions and a set of priority for addressing the projected climate change impacts in each sector for feeding into the Kenya's National Adaptation Plan (NAP),

In Kenya, National Climate Change Secretariat (NCCS) is currently tasked with coordination of all the activities related to climate change. Administratively, the NCCS falls within the Ministry of Environment and Natural Resources. The NCCS is also the UNFCCC's National Focal Point. In various agencies, departments and ministries, climate change coordination units work with

NCCS for ensuring mainstreaming of climate change into the several sectors of economy (Government of Kenya, 2016b).

Kenya National Climate Change Action Plan covering the period from 2018 to 2022 has highlighted several adaptation actions for implementation to address the climate change impacts at county and national level (Government of Kenya, 2018). Based on the County integrated development plans of 2018, there are several actions that are most appropriate for the Sondu Miriu basin to address some impacts of climate change that have been identified to be of significance in the basin (Table 7.1). These actions will enhance resilience for both the hydropower projects and community livelihoods within the basin.

Table 7-1: Adaptation actions appropriate for Sondu Miriu river basin

Impacts	Adaptation Action
Drought	• Harvesting of flood water. • Early warning systems establishment for droughts. • Nutritional and food supplements like school feeding programmes. • Diversification of livelihoods.
Flooding	• Strategic placement of dykes and dams. • Early warning systems establishment for floods. • Storm water harvesting and storm waters drainage systems. • Riparian areas protection along rivers. • Insurance cover for losses caused by flooding.
Food security crops	• Climate-smart agriculture. • Crop diversification. • Farm forestry/agroforestry. • Establishing irrigation systems, such as drip irrigation up-scaling, and constructing dams for irrigation. • Drought tolerant crops. • Conservation agriculture and soil and water conservation. • Promoting non-rainfed agricultural practices such as greenhouse farming. • Improvement of agricultural extension services. • Efficient water-use technologies. • Climate information services for the local community.
Livestock	• Adopting new techniques for animal husbandry. • Proper management of fodder banks, controlled grazing, and pasture lands.
Fisheries	• Fish harvesting. • Fish farming.

Impacts	Adaptation Action
Water scarcity	• Protection of water catchment areas and springs • Water harvesting. • Water storage. • Water pans, boreholes, and dams. • Ground water management. • Water treatment.
Ecosystem degradation	• Protection of wetlands. • Water catchment areas restoration. • Rehabilitation of degraded rivers. • Control of erosion (gabions, terracing) and soil conservation. • Promotion of the natural resources' conservation.
Infrastructure	• Infrastructure that are climate proof through use of concrete for roads, bridges, and dykes.
Health	• Promote family planning. • Vaccination/immunization campaigns. • Mosquito nets. • Disease surveillance and reporting.

These adaptation actions are in line with the six types of strategy identified by IPCC technical guidelines for adapting to the impact of climate change that include restoration of the ecosystem, changing location, changing use or activity, spreading, or sharing loss, tolerating loss, and prevention of loss (Government of Kenya, 2018; Carter *et al.*, 1994).

7.2.4 The constraints

The current policies and laws do not compel any development action within the Sondu Miriu River basin to provide for integration of adaptation actions into the development planning for approvals. This makes integration of adaptation actions into any planned development difficult to enforce within the basin including hydropower development despite good adaptation actions contained in the Kenya National Climate Change Action plans.

7.2.5 Quantifying the measures and formulating alternative strategies

For the adaptation strategy to be effective, both devolved and national governments should pull together for targeted development. The centralized national government oversighting gives an overarching, strong leadership, and national framework while local and regional involvement integrates specific issues locally and increases buy-in by stakeholders which facilitates implementation. This is critical for the Sondu Miriu River basin for the local solutions that can be owned and well understood by the local communities within the project area and basin.

Assessing the risks or vulnerability and strategy implementation using sector-by-sector approach is pragmatic due to its mapping into the already existing stakeholder groups and government structure. Assessing risks or vulnerability at the national level is resource intensive and more complex than sector by sector assessment. Having an effective stakeholder engagement process and a robust regional and sectoral risk assessments to build upon is critical for the success. At this stage, it will be effective to group all the identified appropriate actions into relevant sectors for robust evaluation and implementation strategy within the basin.

Adaptation strategies within the Sondu Miriu River basin may gain from providing more comprehensive attention to relationships between adaptation and mitigation policies, social justice, and treatment of the international impacts in making them acceptable, both locally and internationally.

7.2.6 Weighting the objectives and evaluating the trade-offs in Sondu Miriu river basin

At present there is no well-defined strategy for the integration of adaptation measures into the development of hydroelectric power projects. No specific objectives have been put in place that can be weighted and evaluated for trade-offs. This can be cited as a major gap for developing and implementing adaptation actions within Sondu Miriu basin. At the inception of any hydropower development in Sondu Miriu basin, the objectives need to be developed that can be weighed based on the local, national, regional and global and then different strategies are evaluated based on their effectiveness in achieving the objectives. The process can be evaluated using standard impact accounting systems. This will lead to selection of preferred strategies based on the trade-offs among the available strategies.

7.2.7 Recommended adaptation measures within the Sondu Miriu river basin.

Currently, there is no evidence of a properly organized and coordinated adaptation actions being implemented within the basin with the main objective of integrating adaptation to climate change into the development of hydropower within the basin.

The current adaptation actions are mostly at the national level as proposed in the National adaptaion action plans. These adaptation actions need to be translated to the local level for the to be active and effective. Based on the International Federation of Red Cross and Red Crescent Societies (IFRC), Red Crescent Climate Centre and ProVention Consortium guidelines, some of the most approapriate strategies in Sondu Miriu basin for integration of adaptation measures locally are outlined as follows;

1. Incorporation of the projected changing climate trends into the present risk and vulnerability assessments depending on the present climate variability,
2. Prioritize adaptation measures in zones where vulnerabilities are highest and there is greatest need for resilience and safety,
3. Fully integrate climate change adaptation actions into the poverty reduction strategies, and long term local and national sustainable development,
4. Prioritize and strengthen existing local capacities such as private sector, civil society organizations and local authorities. Opportunities will be created by this strategy for effective local governance and community-based risk reduction to achieve rapid up-scaling of adaptation actions, and a comprehensive climate risk management,
5. Leverage on the available opportunities in the disaster response and prevention. This can be done through improvement of contingency planning, early warning systems, and integrated response for the promotion of effective community-based risk reduction and adaptation,
6. Development of a robust mechanisms for mobilization of resources for adaptation to ensure continuous flow of support to local actors in the form of financial and technical.

There is need to motivate local communities to participate in adaptive actions. The communities can be motivated for actions through some shared community values such as:

i. Social equity and community cohesion,
ii. Community identification with the surrounding ecosystems or natural resources,
iii. Need to enhance, sustain, or revitalize social and economic situations.

The community actions for an efficient strategy for adaptation can incorporate some initiatives such as.

i. Actions related to grey and green infrastructure,
ii. Adaptive capacity enhancement,
iii. Management of natural resources or ecosystems,
iv. Bolster and develop human and social capital,

Two critical factors need to be put in place for the effective adaptation actions implementation. They include building community support and effective leadership. The description of the prerequisites for these factors are as follows.

(a) Building community support

i. Guide community climate change debates to be in line with public and local political attitudes,
ii. Support enhancement through community organizations or grassroots,
iii. A focus on co-benefits to broaden the support,
iv. Engage more vulnerable populations,

(b) Effective Leadership Requirements

i. Ability to work together as a coalition,
ii. Ability to enact change through sustenance of effectiveness for a long duration,
iii. Ability to supply a vision for change and identify needs,

7.3 Discussions on the adaptation strategies

With expected rise in temperature and increase in rainfall the Sondu Miriu is expected to get warmer and wetter. But due to climate variability some episodes of meteorological extremes are expected. This might increase vulnerability of the hydropower development and local community livelihood. The meteorological extremes are more likely to affect the run-of-river (RoR) development projects than storage-type hydropower development projects due to flow variability. The climate change also varies from season to season.

There seem to be climate adaptation strategies only at national level without reaching river basin or local level. It will be critical to develop strategies for climate change adaptation for the whole Sondu Miriu basin for future hydropower development projects. The basin wide strategy need to be complemented with another strategy at the ward or village level for effectiveness. When the strategies at the basin wide scale is integrated with the ward or village level strategies, the impacts will be more.

The main objective of the adaptation strategies for development of hydropower to integrate adaptation actions into hydropower development for sustainable hydropower generation and building resilience for the local community. To be able to respond effectively to the climate change impacts, a multi sectoral adaptation strategy need to be put in place that can be to cascade the national adaptation actions from the national level to county level and eventually to local level. A study in Southern Africa in 2018 proposed several climate change adaptation strategies for their region and among them being promoting renewable energies with low carbon footprint (Mpandeli *et al*., 2018).

Climate change impacts of significance within Sondu Miriu basin include displacement of populations, water scarcity, land and ecosystem degradation, negative impacts on humans and livestock health, food and nutrition insecurity, declining agricultural and livestock productivity, flooding, and drought. These impacts affect the existing hydropower projects and local community livelihoods. With the projected increased rainfall amounts and temperature, the frequency of the meteorological extremes is expected to increase and may make the current impacts worse.

Since the launch of NCCRS in 2010, it has been the guide for policy decisions in Kenya. The first national policy document was National Climate Change Response Strategy (NCCRS) enacted in 2010 that fully acknowledged the reality of climate change. The evidence of climate change impacts was provided by the NCCRS on various economic sectors together with the proposed strategies for climate change adaptation and mitigation. The NCCRS implementation has been taken forward by the National Climate Change Action Plan (NCCAP).

An extensively consultative process was adopted for the development of the NCCAP. There was a huge assistance received from several development partners and stakeholders for the NCCAP. The national decisions on policy and development are expected to be guided by the NCCAP in all the sectors of economy with various actors like civil society organizations, private sector and Government institutions are expected to participate in the NCCAP implementation.

Planning for climate change is a dynamic and cross-cutting process. The Kenya National Climate Change Action Plan for the period from 2018 to 2022 and the County Integrated Development Plans (CIDPs) has highlighted several adaptation actions that are most appropriate for Sondu Miriu basin to address impacts of climate change identified as of significance in the basin. These actions are expected to enhance resilience for both the hydropower projects and community livelihoods within the basin. The proposed adaptation measures will be effective if the local community is fully involved.

The National and County governments should play complementary roles in implementing adaptation actions towards integration of adaptation into the development of hydropower on the basis governance structure. It has been noted that the number of planned adaptation responses have been significantly increasing in the developing countries particularly within the rural communities locally since the fourth assessment report (IPCC, 2014).

Adaptation to climate change is uniquely linked to location as it is context dependent making it a community and local government level of action predominantly (Corfee-Morlot *et al.*, 2009; Glaas *et al*., 2010; Mukheibir *et al*., 2013). Adaptation plans that utilize local knowledge form these efforts as adaptation based on local knowledge focuses using the traditional knowledge for the community adaptive capacity enhancement locally. The local knowledge can also highlight impacts of climate change and vulnerabilities that may not be well known in addition to adaptive capacity, (Majule *et al*., 2013).

Most River basins globally are vulnerable to direct climate change impacts that can be attributed to inadequate abilities for adapting to climate change. There are rapidly developments within the river basins in the developing countries especially in the areas of socioeconomic status of the communities and water system infrastructure (Evers and Pathirana, 2018). For adaptation strategies to be effective, there is need to recognize cross-sectoral coordination internally as crucial and encouraged within the suitable institutional structures (Pardoe *et al*., 2018) within Sondu Miriu basin. In a collaborative process, data sharing is also a crucial component. A data sharing platform among various stakeholders including government departments would be useful in fostering collaboration and promoting efficiency. These collaborative efforts require trade-offs and political blessing that can be addressed on a wider scale (Pardoe *et al*., 2018).

Based on the experience in Mekong River basin, the negative impacts of climate change can be reduced potentially by the human interventions, while in contrast climate change can also lead to increased negative impacts on human interventions. A good understanding of the complex interrelations between water use, land use, technological interventions, climate change, and socioeconomic activities both upstream and downstream is required for better support of the strategies for climate change adaptation (Evers and Pathirana, 2018).

Once there is a good knowledge on the past climate change trends and future projected scenarios together with community livelihood actions within the Sondu river basin, it will be possible to evaluate these actions to determine how they may impact on the water resource availability and hydropower projects. This will help in identifying adaptation actions that may be appropriate for hydropower development and sustainability within the basin. Through stakeholders' participation including the local communities, local development actors and local leadership, strategies for responding the climate change impacts can be prepared that incorporates the interests of all the groups for their acceptability and ownership. These strategies are expected to offer local solutions with or without some improvements to enhance catchment conservation and management for hydropower development sustainability.

CHAPTER EIGHT

RESULTS AND DISCUSSIONS FOR SPECIFIC OBJECTIVE FIVE

8.1 Introduction

The chapter presents the results and discussion on the policy options for the integration of adaptation measures into the development of hydropower within Sondu Miriu basin. It considers the policies that are existing and discusses their possible utilization in facilitating and supporting the adaptation measures integration into the development of hydroelectric power projects. Enabling legal framework and policy are key for the successful integration of adaptation into any development.

8.2 Results for objective five

The presented results are on the basis of assessment of one global framework, three regional policy frameworks, fourteen national policy documents and eight county integrated policy frameworks.

8.2.1 International legal and policy framework

Being a global problem, climate change impacts are governed by several international conventions and treaties, and national policies and laws. The United Nations Framework Convention on Climate Change (UNFCCC) guides the international response to climate change. Kenya has signed several treaties that aim at addressing the challenges associated with climate change. They include the Kyoto protocol that came up with the Clean Development Mechanism (CDM) where the developing countries' projects that were aimed at GHG emissions reduction and making contributions to the sustainable development, were to earn credits to be sold to companies or countries with commitments for GHG emissions reduction and contributes to sustainable development.

The Kyoto protocol was succeeded by the Paris Agreement with an aim of strengthening the response against the climate change threat globally by maintaining the temperature rise below 2°C globally above the pre-industrial levels during the 21st century. In addition, strengthen the countries' ability to deal with impacts of climate change. The developing countries were to be supported to meet these goals by putting in place appropriate financial flows, enhanced capacity building framework and a new technology framework.

8.2.2 The regional legal and policy framework

Three legal and policy frameworks were assessed for the region. They included the African Union's Agenda 2063, East African Community (EAC) Climate Change Strategy and Policy published in 2010, and the Climate Change Adaptation Action Plan (from 2018 to 2023) and Strategy for the Lake Victoria Basin Commission.

The African Union's Agenda 2063, at the regional level, has committed to support climate change actions that prioritize adaptation. This agenda calls on the member states to implement climate change programmes and actions in Africa that includes programmes for climate resilient agricultural development. The Agenda 2063 also committed to building communities and economies that are climate resilient and puts more emphasis on participating in global efforts for mitigating climate change to create opportunities for supporting and broadening the policy space for sustainable developments.

Climate Change Policy and Strategy was developed by the East African Community (EAC) Secretariat in 2010 for guiding the member states to prepare and implement collaborative and collective actions for addressing climate change within the region. The statements and actions prescribed by policy give guidance on reduction of climate change vulnerability of the region, climate change adaptation and mitigation, building social and economic resilience of vulnerable ecosystems and population, and enhancement of adaptive capacity for climate change. EAC is in the process of developing a forest policy and strategy and climate change bill with consideration of establishing a partnership on climate finance and carbon markets.

For the purpose of addressing and adapting to impacts of climate change, a Climate Change Adaptation Strategy and Action Plan covering the period from 2018 to 2023 has been developed by Lake Victoria Basin Commission.

8.2.3 The national legal and policy framework

In Kenya, at the county and national levels, a comprehensive framework of institutions, plans, and policies is progressively being established for addressing climate change. The 2010 Constitution of Kenya forms the foundation of legal and institutional framework for the actions related to climate change. The national values and principles of governance are sets out in Article 10 of the constitution, such as public participation, devolution of government, and sustainable development, which have been made mandatory when implementing or making any public policy decisions or law, including those that are climate change related. In the same constitution, the right to a healthy and clean environment for all Kenyans is provided for in Article 42, including the right for environmental protection to ensure the present and future generations benefit through legislative and other measures.

A devolved system of governance is also provided in The Constitution of Kenya (2010) comprising of 47 County Governments and the National Government (Government of Kenya, 2010b). The concept of devolution provides for a process of sharing of resources equitably as a form of self-governance at the local level and decentralization of government services. For the implementation of Climate Change policies, County Governments plays a critical role at the local levels, as provided for in the Constitution, over the climate change action relevant sectors, such as health, tourism, water and sanitation, forestry, soil and water conservation, and agriculture which affect hydropower development and operations. The Kenyan Constitution has got a provision for allocation of the national revenue received annually to the County Governments, which gives them significant opportunity for influencing investments in climate change actions.

The key legislation that guides how Kenya responds to climate change is the Climate Change Act, enacted in 2016. It provides the legal foundation for considering climate change and actions mainstreaming into sector activities and forms the legal foundation for National Climate Change Action Plans (NCCAPs) (Government of Kenya, 2016b). The NCCAP updates after every five years is a response to that requirement of Climate Change Act, 2016 provisions (Government of Kenya, 2018).

By the end of 2019, a total of fourteen legal and policy frameworks for supporting climate change actions within Kenya were assessed.

(1) The country's development, blueprint Kenya Vision 2030 of 2007, recognizes climate change as a threat with high potential to slow down the development of Kenya. Actions associated with climate change have been incorporated in the Medium-Term Plans (MTPs) and recognized as a cross-cutting thematic area. This has made actions associated with climate change to be mainstreamed in the sector plans (Government of Kenya, 2007).

(2) The Kenya's first national policy document on climate change, National Climate Change Response Strategy of 2010 with an aim to enhance integration of adaptation and mitigation into all development objectives, planning, and budgeting of the Government (Government of Kenya, 2010a).

(3) The National Climate Change Framework Policy of 2016 aims to ensure that climate change considerations are integrated into the National and County levels planning, budgeting, implementation, and decision-making, and across all sectors activities (Government of Kenya, 2016f).

(4) The Kenya's Climate Risk Management Framework of 2016 provides for the integration of sustainable development, climate change adaptation, and disaster risk reduction, to pursue them as mutually supportive instead of stand-alone goals. An integrated climate risk management approach is promoted as a central component of the National and County levels policy and planning (Government of Kenya, 2016a).

(5) The first comprehensive climate change governance legal framework in Kenya being the Climate Change Act of 2016 has the objective to enhance climate change resilience and low carbon development for sustainable development in Kenya. The Act establishes the National Climate Change Council, Climate Change Directorate and Climate Change Fund (Government of Kenya, 2016b).

(6) The National Adaptation Plan 2015-2030 (NAP) of 2016 for Kenya submitted in 2017 to the UNFCCC sets out priority actions for adaptation and provides a vulnerability and climate hazard assessment in the 21 planning sectors in Medium Term Plans (Government of Kenya, (2016d).

(7) The National Policy on Climate Finance enacted in 2016 promotes the establishment of legal, institutional, and reporting frameworks for access to and management of climate finance. The goal of this policy is to further Kenya's national development goals through enhanced mobilization of climate finance that contributes to low carbon climate resilient development goals (Government of Kenya, 2016e).

(8) Water Act of 2016 provides a framework for collaborative efforts with other relevant institutions in developing incentive programmes for management water resources including climate change adaptation and mitigation and disaster management, (Government of Kenya, 2016g).

(9) The Kenya Climate Smart Agriculture Strategy (KCSAS) of 2017 was established with an aim of adapting to climate change and building resilience of agricultural systems, while minimizing GHG emissions. Planned actions will lead to enhanced food and nutritional security, and improved livelihoods (Government of Kenya, 2017a).

(10) The Nationally Defined Contribution (NDC) for Kenya enacted in 2017 under the Paris Agreement of the UNFCCC includes contributions to mitigation and adaptation. Regarding adaptation, Kenya undertakes to ensure enhancement of resilience to climate change in the direction of attaining Vision 2030, by implementing adaptation actions and climate change mainstreaming into Medium Term Plans. Achievement of Kenya's NDC is dependent on the international support in form of capacity development, technology development and transfer, investment, and finance (Government of Kenya, 2017b).

(11) The current National Climate Change Action Plan (NCCAP) published in 2018 covering the period from 2018 to 2022 aims at furthering the development goals for Kenya through the application of a low carbon climate resilient approach. This plan sets out enabling, mitigation, and adaptation actions in all sectors of development (Government of Kenya, 2018).

(12) Energy Act of 2019 promotes the renewable energy technologies development in addressing climate change and adaptation in collaboration with other agencies (Government of Kenya, 2019).

(13) The Big Four Agenda for the Government of Kenya's establishes areas of priority from 2018 to 2022 for ensuring Universal Health Coverage, Enhanced Manufacturing, Affordable Housing, and Food and Nutrition Security. Sector budgets and plans are therefore required to be aligned to the Big Four Agenda (Government of Kenya, 2018).

Climate change units together with climate change related policies and plans have been established in several departments and ministries at the national level for the guidance of climate actions mainstreaming in their respective sectors.

8.2.4 The County legal and policy framework

County Governments have started the process of developing climate change regulatory frameworks in their respective counties. Through the Climate Change Act of 2016, it is a requirement for all the County Governments to incorporate climate change mainstreaming in their County Integrated Development Plans (CIDPs). A regulatory framework has been provided for in the Climate Change Act of 2016 for enhancing climate change response, providing for measures and mechanism for achieving low carbon climate development, and for associated purposes. The county governments are required by the Climate Change Act of 2016 to mainstream and integrate climate change actions, duties and interventions specified in the Act, and the National Climate Change Action Plan into various sectors for climate change actions mainstreaming into County Governments functions (CG of Bomet, 2018; CG of Homabay, 2018; CG of Kericho, 2018; CG of Kisii, 2018; CG of Kisumu, 2018; CG of Nakuru, 2018; CG of Narok, 2018; and CG of Nyamira, 2018). It is also a requirement for the county Governments' participation in the development, updates, and approval of the County Sectoral and Integrated Development Plans for mainstreaming the implementation of the National Climate Change Action Plan with consideration of county and national priorities.

The county governments, through their respective designated County Executive Committee Members, are required to submit reports at the end of every financial year on the climate change actions implementation progress to their respective County Assemblies for reviews and debate. For information purposes, the copies of these reports also forwarded to the Directorate of Climate Change.

8.2.5 Sondu Miriu river basin legal and policy framework

The developments within the Sondu Miriu River basin are governed by various legal and policy frameworks at different levels. These levels range from global to regional, national, county, and local. Since it is a requirement for the County Governments to mainstream climate change in their respective CIDPs, the eight (8) counties touching on the Sondu Miriu River basin have developed their CIDPs for 2018-2022. These counties are Bomet, Homabay, Kericho, Kisii, Kisumu, Nakuru, Narok and Nyamira. All the 8 CIDPs have covered climate change issues in the chapter of Environment and Climate Change that have identified actions to address the climate change impacts. All these County Governments have identified adaptation actions as a priority.

Some of the actions proposed in the CIDPs include (1) awareness forums on Climate Change, (2) establishment of ward and village climate change committees and capacity building for them, (3) improvement of climate change information access, (4) Counties gazettement of Climate Change councils/boards, Climate Change trust fund, Technical working committees, Monitoring and evaluation of projects and (5) preparation of ward and village action plans based on the county climate change action plans (CCCAPs).

Several stake holders who operate in the Sondu Miriu River basin have also been identified in an all-inclusive approach for the implementation of climate change actions within the basin. They include local communities, Water Resources Authority (WRA), Kenya Forestry Research Institute (KEFRI), County Government Environment department, Lake Victoria Basin Commission (LVBC), Lake Victoria Environmental Management Programme (LVEMP), National Environment Management Authority (NEMA), Lake Basin Development Authority (LBDA), Kenya Forestry Services (KFS), National Environment Trust Fund (NETFUND) and Kenya Maritime Authority.

8.3 Discussions on policy options

There are four key principles around which the Adaptation Policy Framework should be built as a basis developing integrated climate change adaptation actions. The first principle is adapting to short term extreme events and climate variability to serve as the beginning point for vulnerability reduction to long term climate change. The second principle is that the occurrence of adaptation in the society is at different levels including the local level. The third principle is assessing adaptation measures and policies in a development context. The last principle is that the adaptation strategies and the stakeholder processes for implementation are equally important (Lim *et at.*, 2005).

There are adequate existing policy and legal frameworks to support integration of adaptation measures into the development of hydropower within Sondu Miriu basin. It provides for support for adaptation to climate change right from international level to the local level. There is clear definition of the climate changes actions to be taken at each level. The guidelines for the legal and policy frameworks for the Sondu Miriu River basin are well developed together with all associated institution frameworks and well stipulated responsibilities. However, the only existing gap is the reinforcement of the already developed policies and laws.

The legal and policy frameworks provide avenues for development of adaptation actions for short-term extreme events and climate variability as a basis for vulnerability reduction to longer-term climate change within the Sondu Miriu River basin. They give guidance on the preparation of long-term, medium-term, and short-term adaptation plans considering international, regional, national, and local priorities.

By making the existing policies the centre piece of adaptation within the Sondu Miriu River basin, it will be possible to effectively assess adaptation projects individually as a response to impacts of climate change, and fundamentally towards integrating adaptation into key planning and policy processes for hydropower development. No single best option is suitable for climate change adaptation action. The best option would be integration of various options to address adaptation challenges in the hydropower development. The best policies should incorporate (1) adaptation fund to consider the most affected and least able to cope as a priority, (2) integration of adaptation measures into other long term plans, (3) building of resilient society by integrating climate change measures together with combining learning, innovation and sustainable livelihood framework, (4) policies that recognise, strengthening and supporting Kenya's National Adaptation Plan 2015-2030, (5) capacity building policy to increase awareness and knowledge on adaptation, vulnerability, and impacts of climate change, (6) technology transfer policy for providing access for the local poor communities to utilize environmentally friendly technology as open resource, (7) policy for strengthening environmental governance from local to national level, (8) information and communication strengthening especially for climate and weather services, and (9) policy to support early warning system and response to crisis, disaster and risk.

The first comprehensive legal framework in Kenya is the Climate Change Act enacted in 2016 for climate change governance which has attempted to integrate various options in addressing adaptation and integration of climate change into the exercising power and functions at all governance levels and enhancing cooperative governance in climate change between the county governments and the national government. This has been supported by climate change mainstreaming in all the counties through their respective County sectoral frameworks and Integrated Development Plans.

The measures in the climate change adaptation policy options for hydropower can be looked at as broad strategies instead of specific policies for complementing specific policies in addressing climate change challenges within energy sector (Smith and Lenhart, 1996). The climate change integration into the national-level strategies, plans and policies is an important for encouraging climate change actions. Studies in policy coherence put a lot of emphasis on the value of policies that are coordinated across sectors for avoiding conflicts among sectors or maladaptation (Pardoe *et al*., 2018).

In Tanzania for example, more integration of specific climate change adaptation strategies and climate change into planning documents and policies followed publication of National Adaptation Programme of Action (NAPA). Other sectors such as water and agriculture have made a lot of progress in integrations of climate change and specific plans. Even though there has been integration of climate change into the energy sector, the focus has been on diversification involving increase of natural gas and coal powered electricity into the national electricity grid. This is a reflection of differing pressures and priorities being put on the energy sector in comparison to the agriculture and water sectors, essentially undermining efforts being put in place by the agriculture and water sectors on climate change (Pardoe *et al*., 2018).

The three distinguishable fundamental political dimensions of climate change adaptation problem are usually related to disparity in responsibilities, the unbalanced production of vulnerability globally, and inequitable relations of power in climate change adaptation decision-making. Based on research, climate change adaptation mainstreaming into the existing development decisions does not address the political aspects of the problems associated with climate change adaptation (Scoville-Simonds *et al*., 2020). Based on the challenges experienced in Mekong River basin and Tanzania, the policy interventions should incorporate the climate change and human impacts on sediment flows, nutrient, and water, and adaptation in rural areas and urban centres within the Sondu Miriu basin (Evers and Pathirana, 2018; Pardoe *et al*., 2018).

CHAPTER NINE

SYNTHESIS AND DISCUSSION

The climate change trends indicate that the minimum temperature increased by 0.89^0C while maximum temperature increased by 0.73^0C annually for the period between 1950 and 2005. During the same period, the seasonal minimum temperatures increased by between 0.81^0C and 0.96^0C while the seasonal maximum temperatures increased by between 0.43^0C and 0.95^0C. This is an indication that the minimum temperatures have recorded higher rise than the maximum temperatures within Sondu Miriu river basin both an annual and seasonal scale. This supports the findings that the area has experienced significant increase in temperatures for the last 50 years (Anyah and Qiu, 2012; Funk *et al*., 2012).

The projections reveal that the minimum and maximum temperatures are expected to continue increasing within the Sondu Miriu river basin in 21st century. The minimum temperature is projected to increase by 1.89^0C and 4.67^0C annually for RCP4.5 projection scenario and RCP8.5 projection scenario respectively while the maximum temperature is projected to increase by 1.85^0C and 4.47^0C annually for RCP4.5 projection scenario and RCP8.5 projection scenario, respectively. In the RCP4.5 projection scenario, the seasonal minimum temperature is expected to have an increase of between 1.62^0C and 2.24^0C annually while under the RCP8.5 they are projected to increase by between 4.10^0C and 5.39^0C annually. The seasonal maximum temperature is expected to have an increase of between 1.49^0C and 2.34^0C annually in the RCP4.5 projection scenario while in the RCP8.5 projection scenario they are projected to have an increase of between 3.46^0C and 5.04^0C.

The dry seasons are projected to experience higher temperature increase than the wet seasons except for maximum temperatures in the RCP8.5 projection scenario. In the RCP8.5 projection scenario, the maximum temperature is projected to experience higher increase in the first half of the year than the second half of the year. The long rainfall seasons (March to May) are projected to experience higher temperature increase than the short rainfall seasons (October to December).

The projected increase in minimum and maximum temperatures are expected to enhance the rate of evaporation from open water sources including the main Sondu Miriu river. As a result, the water losses will increase within the basin.

The annual rainfall over the Sondu Miriu river basin has increased by 18.27 mm. The seasonal rainfall has also increased in all the seasons except for the cold dry season (June to September) that has declined. The seasonal rainfall has increased by between 1.10 mm, and 55.55 mm. The cold dry season declined by 18.15 mm.

The annual rainfall is projected to increase in Sondu Miriu basin in 21st century by between 24.70 mm and 117.80 mm. The cold dry seasonal rainfall is projected to decrease by between 19.95 mm and 40.85 mm while the hot and dry (January to February) seasonal rainfall will increase according to the projections by between 13.30 mm and 138.70 mm. The short rains are projected to increase by between 34.20 mm and 74.10 mm. The long rains are projected to decrease by 11.40 mm in the RCP4.5 projection scenario while an increase of 50.35 mm annually is projected for the RCP8.5 scenario in the 21st century.

The annual rainfall has declined for the period between 2008 and 2019, when the existing two run-of-river hydropower projects have been in operation. The same trend has been replicated in the seasonal rainfall patterns except the June to September season. The river flow has followed the same pattern with declining annual and seasonal flows except for June to September season. The hydropower output in the two hydropower projects have also followed the same trend whereby the output has been declining annually and in all the seasons except for June to September season. This is an indication that the hydrology and hydropower production will respond to rainfall pattern in the basin.

With the projected increase in rainfall within the basin, hydropower generation is expected to remain stable, and this presents an opportunity for more hydropower development within the basin. Generally, the climate change impacts on generation hydropower could be locally different and very variable, depending on the flow regimes changes. The run-of-river hydropower systems more are most likely to be impacted on more by Climate change on compared to other systems with storage (Storage hydropower systems). Since rainfall is projected to increase, storage hydropower systems should be considered to manage the climate variability.

The socioeconomic status of the Sondu Miriu river basin indicates that 59% of the households are poor and earning less than 241 US dollars a month or less than 8 US dollars per day per household. The employment rate low with only 22% in formal employment while the remaining 78% are either in private enterprises or casual labourer. The use of wood fuel and charcoal that stand at 49% of the households can be considered a threat to catchment conservation due to catchment destruction. Most of the households at 84% still fetch water from the rivers, wells and ponds presenting access to portable water as a challenge within the basin. The expenditure on health services being low within the basin can be a sign of a healthy community or a community too poor to afford health services.

The community view is that climate change has resulted in reduction in agricultural production, reduction in rainfall which is also evidence from the analysis curried out for the last decade, and disruption of food production and health. On the other hand, the existing hydropower projects have brought with them several benefits such as improved power supply and reliability, improved environmental management through environmental conservation projects supported by the existing projects, improved infrastructure, land use change, employment, and education facilities. Despite all these, more still can be done especially irrigation system and piped water supply project.

The local development actors observed that there exist some livelihood challenges associated with change climate in Sondu Miriu basin including poverty, crop failure, poor water quality, water availability and water related and water-borne diseases. These challenges can be addressed through integration of climate change adaptation actions into the planning processes for the development of hydropower including awareness creation and education local communities within the Sondu Miriu River basin, provision of social amenities in advance before the construction works for the project to improve the local communities' resilience and promotion of livelihood projects capable of supporting adaptation to the impacts of climate change within the basin. Adaptation actions need to be integrated into hydropower development such as integration of environmental conservation, appropriate agricultural practices, sustainable technologies applications and community-based pro-poor activities for climate change adaptation, human resources to handle impacts of climate change, trans-disciplinary systems perspectives, and strengthening research and capacity development.

With expected rise in temperature and increase in rainfall the Sondu Miriu is expected to get warmer and wetter. But due to climate variability some episodes of meteorological extremes are expected. This might increase vulnerability of the hydropower development and local community livelihood. Run-of-river (RoR) development projects have higher chances of being affected by these meteorological extremes compared with storage-type hydropower development projects due to flow variability.

Currently, climate adaptation strategies are being implemented at national level, but the implementation is weak at the river basin and local level. Climate change adaptation strategy is necessary for future hydropower development projects in Sondu Miriu river basin. There is need for another strategy at the ward or village level in addition to the basin wide strategy, for effectiveness. To be able to respond effectively to the climate change impacts, a multi sectoral adaptation strategy need to be put in place requiring cascading the national adaptation actions from the national level to county level and eventually to local level.

Climate change adaptation and mitigation strategies were proposed in the National Climate Change Response Strategy (NCCRS) of 2010 which also provided climate change impacts evidence on various economic sectors. The NCCRS implementation has been taken forward by the National Climate Change Action Plan (NCCAP). In all sectors of the economy, the development and policy decisions at national level are guided by the NCCAP and participation of various actors such as civil society organizations, private sector, and Government institutions are expected towards the NCCAP implementation. The National Climate Change Action Plan for Kenya for the period from 2018 to 2022 and the County Integrated Development Plans (CIDPs) have highlighted several adaptation actions that are most appropriate for the Sondu Miriu basin in addressing the climate change impacts of significance identified in the basin. Climate change adaptation actions are to enhance resilience for both the hydropower projects and community livelihoods within the basin. The proposed adaptation measures can be effective if the local community is fully involved. The National and County governments should play complementary roles in implementing adaptation actions towards integrating adaptation into the development of hydropower as prescribed in the governance structure. The number of planned adaptation responses have been significantly increasing in rural communities at the local level.

The existing legal and policy frameworks are adequate to support the integration of adaptation into the development of hydropower within Sondu Miriu basin. They have provided clear definition of adaptation actions for implementation at each level. The guidelines for the legal and policy frameworks for the Sondu Miriu River basin are well developed together with all associated institution frameworks and well stipulated responsibilities. However, the only existing gap is the reinforcement of the already developed policies and laws.

Avenues for development of adaptation actions for short-term extreme events and climate variability are provided in the existing legal and policy frameworks as the basis for vulnerability reduction to climate change in the longer-term within the Sondu Miriu River basin. They give guidance on the preparation of long-term, medium-term, and short-term adaptation plans considering local, national, regional, and international priorities.

It will be possible to effectively assess the adaptation projects individually and how they respond to impacts of climate change, and fundamentally integrating adaptation into key planning and policy processes for hydropower development by making the existing policies the centre piece of adaptation within the Sondu Miriu River basin. The best option for climate change adaptation would be integration of various options to address adaptation challenges in the hydropower development. The best policies should incorporate (1) adaptation fund to consider the most affected and least able to cope as a priority, (2) integration of adaptation measures into other plans in the long term, (3) building of resilient society by integrating climate change measures together with combining learning, innovation and sustainable livelihood framework, (4) policies that recognise, strengthening and supporting Kenya's National Adaptation Plan, (5) capacity building policy to increase awareness and knowledge on adaptation, vulnerability, and impacts of climate change, (6) technology transfer policy to provide access for the local poor communities to utilize environmentally friendly technology as open resource, (7) policy for strengthening environmental governance from local to national level, (8) information and communication strengthening especially for climate and weather services, and (9) policy to support early warning system and response to crisis, disaster and risk. The Climate Change Act enacted in 2016 has made an attempt for integrating various options in addressing adaptation and integrating climate change into the exercising of functions and power of governance at all levels and enhancing climate change governance in a cooperative manner between the county governments and national government. This has been supported by mainstreaming of climate change in all the counties through their respective County sectoral frameworks and Integrated Development Plans (CIDPs).

With the climate change trends determination within the Sondu Miriu river basin, it can be possible to determine the impact these trends can have on the hydropower production and how a combination of hydropower development and climate change can have an impact on the local community. Having known the impact it is possible to design appropriate adaptation strategies with the palatable actions that can enhance the community resilience and also supported by the existing policies.

CHAPTER TEN

CONCLUSIONS AND RECOMMENDATIONS

10.1 Conclusions

Hydropower development could significantly be undermined by Climate change especially for instances where critical resources such as water are threatened, and the incidence and severity of climate extremes such as droughts and floods are increased. In recognizing that some climate change impacts are now unavoidable, the push for adaptation has been on the increase to respond to climate change effectively and minimise the impacts on both people and ecosystems. Integration of climate change adaptation objectives into the policies and hydropower development plans can bring many benefits. Integration of climate change adaptation into the development of hydropower can increase the success rate of hydropower projects under the changing climate.

The existing hydropower projects in the Sondu Miriu river basin, which are run-of-river type, are vulnerable due to the projected climate variability and climate change in the 21st century. Therefore, implementing hydropower projects with storage in the basin will help in adaptation to the climate change and climate variability. As the climate change projections indicate that the rainfall is projected to increase as well as temperature, water resources management may be a challenge due to increased evapotranspiration and rainfall variability that may affect the existing run-of-river generation projects in the Sondu Miriu river basin. To minimize the impacts will require putting in place structural and nonstructural measures. The projected climate change trends can be made use of in determining future availability of water resource within Sondu Miriu river basin for hydropower development by influencing the non-structural and structural measures to be established.

The hydropower development and climate change projects impact on the livelihood of the local communities. As the climate variability and change climate impact negatively on the local communities, hydropower projects can support adaptation actions that can assist the local communities to adapt to these impacts. The socioeconomic status of the communities around the run-of-river hydropower plants can be associated with the existence of opportunities created by the presence the two hydropower projects in the area. With the knowledge of future climate change trends, the communities within the Sondu Miriu river basin can be guided on the most appropriate and sustainable livelihood activities to implement within the basin.

There exist several strategies for the purpose of integrating climate change into various sectors for reduction of vulnerability to impacts of climate change nationally. These strategies are expected to trickle to the Sondu Miriu river basin through multisectoral approach guided by the Kenya's national adaptation plan and county integrated development plans. These plans have well elaborate programmes and actions that if implemented will enhance climate change adaptation integration not only in the hydropower development but also other sectors within the Sondu Miriu River basin.

There exist several policies for supporting integration of climate change into the development of hydropower adequately at local, national, regional, and global levels. The only gap missing is enforcement of these policies. The existing policies at various levels provide for support for climate change adaptation right from international all the way to the local level with clear definition of the climate changes actions to be taken at each level.

With well determined and understood future trends of climate change within Sondu Miriu basin, identification of appropriate and sustainable livelihood activities can be achieved through research. This can lead to developing appropriate strategies for implementing community livelihood activities and climate change adaptation actions through comprehensive stakeholders' participation and involvement. To entrench these actions and strategies to ensure their implementation, a mix of relevant policies at international, national, and local level must be applied for facilitation purposes.

10.2 Recommendations

Both technological and management innovative interventions which are proven through research are required for the management of anticipated changes to minimize the negative impacts climate change may have on the existing hydropower plants in terms of hydropower energy production and future planned hydropower projects in the basin. There should be a close collaboration between the research institutions and the hydropower development institutions interested in the Sondu Miriu river basin to enhance regular updates on climate change trends. This will assist hydropower development institutions in planning appropriately based on the projected climate change trends to minimize any negative impacts that may occur on hydropower generation within the basin. The collaborations should be based on the proposed strategies and backed up by the relevant policy options. The current existing County Development Integrated Plans for the relevant counties should be implemented, monitored, and evaluated based on their effectiveness and improvements suggested to make the better. The research institutions and hydropower development institutions should also actively be involved in the processes for developing policies that are aimed at integrating adaptation into the development of hydropower in particular and energy sector in general at national level and in the relevant counties interacting with Sondu Miriu river basin. Further research is required for understanding the detailed interaction between catchment conservation and management practices and basin climate change characteristics. This will assist in proposing relevant and appropriate strategies and policies to promote climate change adaptation within the Sondu Miriu river basin.

The community vulnerability to the climate change impacts can be addressed through hydropower development benefits. Establishing climate change programmes supported by the projects on hydropower development could help in achieving this goal within the river basin for its long-term sustainability. The programmes should target the local communities living both in the upstream and downstream of the existing and proposed projects on hydropower. These programmes should be integral part of the larger hydropower project to make integration of adaptation sustainable. The strategies for integration of adaptation need to incorporate the local solutions to make the effective and acceptable to the local communities. This will bring about the sense of ownership and hence the community groups actively taking part in the development of these strategies to address the improvement of community livelihoods and build resilience in coping with the impacts of climate change.

It is necessary for policymakers and development practitioners to recognize the need to prepare for and anticipate in addressing climate change impacts within Sondu Miriu river basin. It is critical to include climate change adaptation objectives in the national and local hydropower development policies to integrate resilience strategies into hydropower planning. The process for National Adaptation Planning (NAP) and the existing climate finance institutions should be relied upon to help in accelerating the integration of climate change adaptation into the development of hydropower in Sondu Miriu basin. Since there are several existing policies to support integration of adaptation into the development of hydropower at national and county levels, there is need for the policy makers to formulate rules and regulations to operationalize these policies in order to realize adaptation objectives at national, county and community levels. Preparation of regulations and rules is required specifically for the integration of adaptation into the development of hydropower and other renewable energy projects and other sector development programmes. This will help in enhancing the integration of adaptation both locally and nationally into development programmes.

Funding and financing of hydropower development is very key as energy is identified by the Kenya vision 2030 blueprint as one of the economic pillars. Currently the Development Finance Institutions (DFIs) are very critical in funding various hydropower development projects in the country and Sondu Miriu in particular. For sustainability, the Development Finance Institutions (DFIs) should ensure that one of the conditions for approval of funds for hydropower projects in Sondu Miriu basin should be a clear strategy for integration of adaptation into the development of hydropower project. This should clearly demonstrate enhancement of community resilience to impacts of climate change and reduction of community vulnerability through specific programmes to be supported by hydropower project. The proposed programmes for integration of adaptation should demonstrate their sustainability and specific budget lines for implementation.

There should be a close collaboration between the County Government, local community, and the developer at all the stages of the hydropower project development to comprehensively address the relevant climate change impacts related to hydropower operations. The local communities should be part of the implementation process for the success of the project. To ensure that climate change adaptation is integrated into the development of hydropower within Sondu Miriu basin, a procedure need to be put in place to be followed with necessary approvals that guarantee climate change adaptation integration at all development stages. All the stakeholders participating in the hydropower project should be sensitized on the existing and proposed strategies for climate change adaptation integration into the development of hydropower and be made aware through awareness creation on all the existing policies to be followed to avoid any conflicts during the project implementation.

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APPENDIX I: QUESTIONNAIRE FOR HOUSEHOLDS

1. What are the main sources on income for the household?
   a. Formal employment ☐
   b. Private enterprise ☐
   c. Casual skilled labour ☐
   d. Casual unskilled labour ☐

2. What is the average household income per month?
   a. Below Kshs. 10,000 ☐
   b. Kshs. 10,001 to Kshs. 25,000 ☐
   c. Kshs. 25,001 to Kshs. 50,000 ☐
   d. Kshs. 50,001 to Kshs. 100,000 ☐
   e. Above Kshs. 100,000 ☐

3. What are the sources of energy used by the household?
   a. Electricity ☐
   b. Kerosene ☐
   c. Wood fuel ☐
   d. LPG ☐
   e. Charcoal ☐

4. What are the primary economic activities for the household?
   a. Crop production ☐
   b. Animal production ☐
   c. Logging ☐
   d. Fisheries ☐
   e. Mining ☐
   f. Quarrying ☐
   g. Forestry ☐

5. What are the secondary economic activities for the household?
    a. Manufacturing
    b. Construction
    c. Housing
    d. Trade

6. What is the domestic water source in your household?
    a. Pipeline
    b. From well
    c. From the river
    d. Pond

7. How much money does your household spend on health per annum?
    a. Kshs. 0 to Kshs. 10,000
    b. Kshs. 10,001 to Kshs. 25,000
    c. Kshs. 25,001 to Kshs. 50,000
    d. Kshs. 50,001 to Kshs. 75,000
    e. Above Kshs. 75,000

8. How far is the nearest health centre from your home?
    a. Less than 5Km
    b. Between 5 and 10 Km
    c. Between 10 and 15 Km
    d. Between 15 and 20 Km
    e. More than 20 Km

APPENDIX II: INTERVIEW QUESTIONS FOR LOCAL LEADERS

1. What are the major economic activities in the area?

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2. How has the climate change affected the local community?

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3. How has the development of hydropower affected the local community?

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4. What is the community's attitude towards hydropower development in the area?

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5. What were the benefits to the local community during the development on existing hydropower projects?

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6. What benefits were left out?

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7. What benefits need to be improved?

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8. How were the community and other stakeholders involved in the project development stages?

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9. During the existing hydropower projects development, what was done well and what was done poorly?

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10. What programmes can be introduced within the community that can cushion them against the impacts of climate change and at the same time improve their livelihood?

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APPENDIX III: INTERVIEW QUESTIONS FOR LOCAL ACTORS

1. What are the real livelihood challenges associated with climate change in the area?

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2. What are the challenges caused by the construction of the existing hydropower plants?

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3. What could have been put in place to avoid these challenges?

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4. What actions should be supported by hydropower projects in the future to avoid negative impacts or provide alternative livelihood activities?

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5. What legal instruments do we need to put in place to support the suggested actions?

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