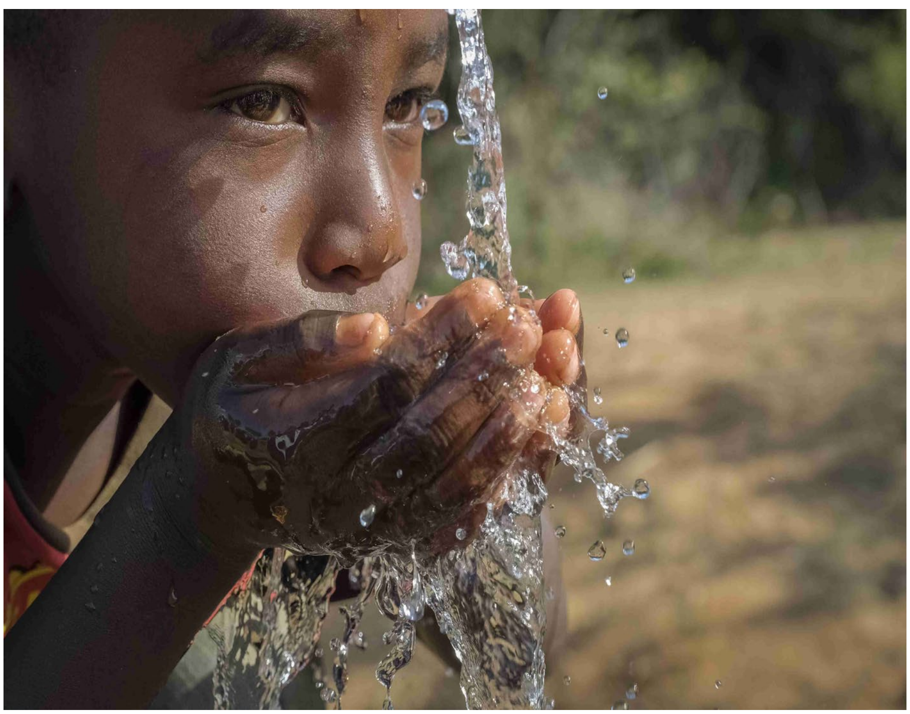
Feasibility Study

Feasibility Study Report

Enhancing the Resilience of Communities and Ecosystems in the Upper Athi River Catchment Area, Kenya



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Contents

List of Figures

List of Tables

Acronyms

ACA	Athi Catchment Area
AHP	Delphi-Analytic Hierarchy Process
APCC	APEC Climate Center
ASAL	arid and semi-arid land
B/C	Benefit and Cost
BWRC	Basin Water Resource Committee
CAAC	Catchment Areas Advisory Committees
CBD	Central Business District
CMIP3	Coupled Model Intercomparison Project Phase 3
CMIP5	Coupled Model Intercomparison Project Phase 5

CMS	Catchment Management Strategy
CoK	Constitution of Kenya
DBMS	Database Management Software
DMC	Dam Management Committee
DRI	Disaster Risk Index
EIA	Environmental Impact Assessment
EMCA	Environment Management and Coordination Act
ENNCA	Ewaso Ng'iro North Catchment Area
GCF	Green Climate Fund
GCMs	Global Climate Models
GDP	The Gross Domestic Product
GPRS	General Packet Radio Services
GSM	Global System for Mobile Communications
ICAO	International Civil Aviation Organization
IDRI	Integrated Drought Risk Index
IFRI	Integrated Flood Risk Index
IPCC	Inter-governmental Panel Climate Change
IRI	Integrated Risk Index
IRR	Internal Rate of Return
IRWR	Internal Renewable Water Resources
ITCZ	Inter Tropical Convergence Zone
IWRM	Integrated Water Resource Management
JICA	Japan International Cooperation Agency
JMP	Joint Monitoring Programme for Water Supply and Sanitation
KACCAL	Kenya Water Security and Climate Resilience Project, Adaptation to Climate Change in Arid and Semi-Arid Lands
KEITI	Korea Environment Institute Technology and Industry
KFS	Kenya Forest Service
KMD	Kenya Meteorological Department
KRC	Korean Rural Community Corporation
LVNCA	Lake Victoria North Catchment Area
LVSCA	Lake Victoria South Catchment Area
MEF	Ministry of Environment and Forestry
MWS	Ministry of Water and Sanitation
NADMA	National Disaster Risk Management Authority
NDA	National Designated Authority
NDMP	National Disaster Management Policy

NEMA	National Environment Management Authority
NPV	Net Present Value
NPWRMD	National Policy on Water Resources Management and Development
NPWS	National Public Weather Services
NWHSA	National Water Harvesting and Storage Authority
NWMP	National Water Management Plan
NWQMS	National Water Quality Management Strategy
NWRB	National Water Resources Board
NWRSM	National Water Resources Management Strategy
OS	Operation Software
PPP	Public Private Partnership
PSC	Project Steering Committee
RGS	Regular Gauging Station
RQOs	Resource Quality Objectives
RTU	Remote Terminal Unit
RVCA	Rift Valley Catchment Area
SAGAs	Semi-Autonomous Government Agencies
SCMP	Sub-Catchment Water Conservation Plans
SPD	Surge Protective Device
TCA	Tana Catchment Area
UARCA	Upper Athi River Catchment Area
UNDP	United Nations Development Programme
UNFCCC	The United Nations Framework Convention on Climate Change
UPS	Uninterruptible Power Supply system
WASH	Water and Sanitation and Hygiene
WASREB	Water Services Regulatory Board
WDC	WRUA Development Cycle
WMO	World Meteorological Organization
WQM	Water Quality Management
WRA	Water Resources Authority
WRMA	Water Resources Management Authority
WRMIS	Water Resources Management Information System
WRUAs	Water Resource User Associations
WSPs	Water Services Providers
WSTF	Water Sector Trust Fund
WWDAs	Water Works Development Agencies

Executive Summary

Kenya lies approximately between latitudes 5° 20' N and 4° 40' S and between longitudes 33° 50' E and 41° 45' E. It is one of the fast developing country within East Africa, with a population of 46.7million of which 42% live below the poverty line. The major cities in Kenya are Nairobi (headquarter), Mombasa and Kisumu. The country has mean annual rainfall of 680mm and per capita water resources estimated to be 692 m^3/year per capita as in 2014, which is expected to decline with time if conditions remain unchanged. Hydrologically, the country is divided into 6 hydrological basins; Athi, Tana, Ewaso Ngiro, Rift Valley, Lake Victoria South and Lake Victoria North.

The country is highly vulnerable to erratic climatic patterns and limited water availability due to its reliance on Agriculture, tourism, hydro-energy, etc that are susceptible to rainfall and water availability. Out of the country's area of 582,646 km^2, 80% is classified as Arid and Semi-Arid lands with over 80% of the population directly involved in and dependent on agriculture for their livelihoods. The agriculture sector directly contributing 24% to national GDP, with multiplier effects on subsidiary industries that provides 62% of formal employment, 60% of exports, and 45% of government revenue.

Kenya's national climate change adaptation framework is anchored to its Constitution of 2010 and Climate Change Act of 2016, which operationalized the key institutions coordinated by National Climate Change Council (NCCC). The water sector, spearheaded by the Ministry of Water and Sanitation (MWS), has adopted Integrated Water Resources Management (IWRM) based on a basin-wide approach to water budgeting and management. The Water Act 2016 created an appropriate institutional framework to achieve the national objectives of attaining water security through the IWRM principles and of successfully adapting to the effects of climate change. In this context, the National Water Master Plan 2030 was made to lay out detailed plans andcoordination and implementation frameworks for effective management of water resources in Kenya.

This Feasibility Study was conducted between March and August 2018 to assess the country's vulnerability against climate change and to identify and evaluate proposed project interventions. Of the six hydrological basins, namely Athi, Tana, Ewaso Ngiro, Rift Valley, Lake Victoria South and Lake Victoria North, the Athi Catchment Area (ACA) has been identified as the most populated, water scarce area, which is also among the highest flood and drought prone areas within the country.

The following four counties within ACA were selected as a result of extensive stakeholder consultations: Nyandarua, Kiambu, Nairobi, and Machakos. These counties are located in the upper region of ACA, and the majority of their workforces engage in subsistence, small-scale agriculture, which makes them increasingly vulnerable to the impacts of climate change such as floods and droughts. According to the flood risk assessment conducted as part of this feasibility study, the magnitude of flood risk in the historical period was substantial in order of Machakos, Kiambu, Nairobi, and Nyandarua, andsimilar trends were projected in the coming decades. Drought risk, on the other hand, was the highest in Machakos,while Nyandarua being the least prone area to both flood and drought events.. Although the levels of flood and drought risks vary, all four counties are projected to be increasingly vulnerable to the negative impacts of climate change, and therefore it is necessary to propose appropriate interventions to make the communities in the target areas more climate resilient.

It is proposed that the project will implement the following interventions:

- **Establishment of Water Resources Monitoring System for Data Acquisition**

The objective of this intervention is to strengthen the water resources monitoring networks to enhance data collection and improve information management system. The proposed activities are;

(i) Upgrading of Water Resources Management Information System at WRA headquarters; establishing 38 telemetric monitoring stations (23 surface water, 5 rainfall and 10 ground water stations) that are capable of data logging and transmission to the National Water Resource Information Centre at WRA headquarters.

(ii) Capacity Building and Institutional Strengthening for NEMA, WRA, KMD, and MWS. County governments and Water Resource Users Associations within the target area will be also trained and strengthened on prudent project management and monitoring, operation and maintenance, and sustainability. Cooperation with local institutions such as UoN, Kenya Water Institute, Metrological Training and Research among others is much recommended for successful project implementation.

- **Improvement of Water Conservation and Storage Measures]**

The objective of this intervention is to increase access to clean, potable water. Extensive field missions and stakeholder consultations as well as desktop analyses have been done to identify potential sites for water storage structures rehabilitation. The work was organized to respond to the data that was collected through interview/discussions with the various stakeholders, observations and measurements using various instruments. As a result, a total of 46 sites were assessed for technical feasibility, and technical designs were made available to guide project activities.

It is proposed that the project is implemented on a broad-based institutional coordination framework. The scope of the project falls under the mandates of the following two ministries: Ministry of Water and Sanitation (MWS) and Ministry of Environment and Forestry (MEF). Also, the participation of the county governments is the key to the success of the proposed project. NEMA as the accredited entity is responsible for project preparation, coordination, and overall accountability. WRA, on the other hand, will be responsible for the implementation of the water resources activities while KMD will be responsible for meteorological monitoring system. The Project Management will therefore be mainly steered by NEMA, which is responsible for reporting to GCF, National Project Steering Committee (NPSC) and National Treasury (NDA). NPSC will address the cross ministerial issues and guide on policy issues of the project.

The project report is structured into six chapters as follows;

Chapter 1: This chapter describes the country's context with respect to geographical, socio-economic, and climate impact on the country's water resources and socio-development program. The chapter is concluded by highlighting the project background and objectives.

Chapter 2: Chapter 2 elaborates the Climate Risk Profile of Kenya, highlighting major risks of Climate Change impact in Kenya, Policy and regulations. A detailed climate risk profile of the Athi catchment area is elucidated with a vulnerability, risk assessment, which prioritizes target counties based on their vulnerability to the impacts of flood and drought events. .

Chapter 3: Chapter 3 presents key policy frameworks based on various government policies, laws and regulations. National development plans as well as the institutional frameworks of the water sector and the proposed project are presented.

Chapter 4: Chapter 4 includes a detailed description of the field investigation and reports on the observations and recommendations made on; water resources monitoring system, water resources management information systems, meteorological monitoring and information systems and capacity building measures. The chapter includes costing of the proposed measures.

Chapter 5: Chapter 5 shows the results of the technical feasibility study conducted on the proposed interventions to improve access to potable water. The study mainly looked at the rehabilitation of the existing water storage and supply infrastructures including water pans, boreholes, sand dams water tanks etc.

Chapter 6: This Chapter presents the methodology employed for the Economic Analysis, Cost Benefit Analysis, Cost Analysis and Sensitivity Analysis

Chapter 7: In this chapter, a summary and conclusion of the report are presented.

Miscellaneous: The other sections of the report such as Annexes and Appendices are presented.

Feasibility Study: Enhancing the resilience of communities and ecosystems in the Upper Athi River Catchment Area, Kenya

CHAPTER 1: Introduction

1.1 Country Context

1.1.1 Poverty and Income

Kenya is one the most developed countries in East Africa. Agriculture, Forestry, and Fishing is the largest sector in the Kenyan economy, accounting for about 22 percent of the Gross Domestic Product (GDP). Manufacturing is the second largest sector and represents around 11 percent of the GDP. Other major sectors include Real Estate (about 8 percent of the GDP), Wholesale and Retail Trade (around 7 percent), Transport and Storage (around 7 percent), Education (about 7 percent), Financial and Insurance Activity (around 6 percent), and Construction (around 5 percent)[1].

The GDP in Kenya was worth 74.94 billion US dollars in 2017. The GDP value of Kenya represents 0.12 percent of the world economy. GDP in Kenya averaged 15.38 USD Billion from 1960 until 2017[2].

Kenya is a country of many contrasts: in its landscape and demographics, as well as in its social and economic inequalities. Kenya is one of the most unequal countries in the sub-region. Forty-two percent of its population of 44 million lives below the poverty line. Access to basic facilities such as health care, education, clean water, and sanitation, is often a luxury for many people. Large segments of the population, including the burgeoning urban poor, are highly vulnerable to climatic, economic, and social shocks[3].

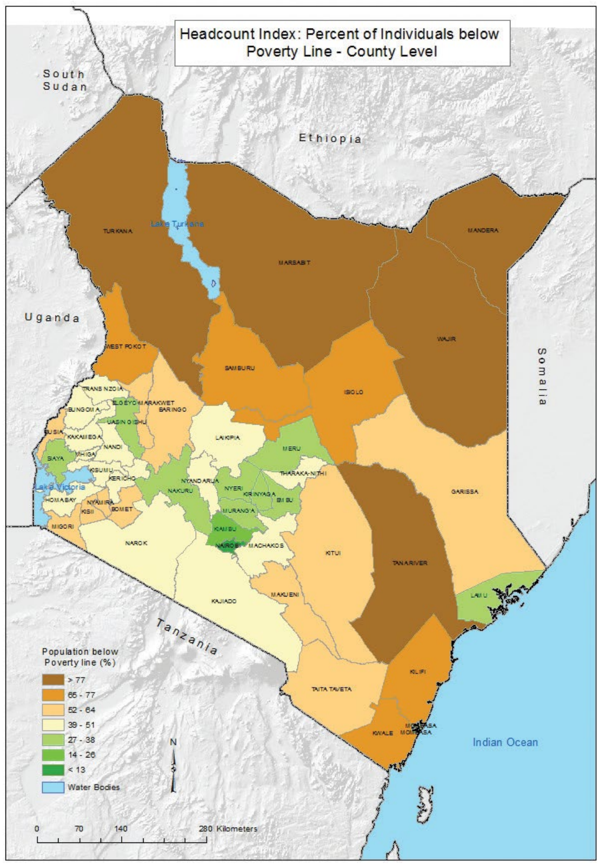
About 1 out of 3 people in Kenya live below the international poverty line. The daily consumption expenditure for 35.6 percent of the population was below US$ 1.90 in 2011 PPP. For 63.7 percent of the population it was below US$ 3.20 in 2011 PPP. The poverty rate has reduced moderately over the past decade with respect to both international poverty lines, dropping from 8 percentage points below the US$ 1.90 line and 5 percentage points below the US$ 3.20 line between 2005 and 2011. Poverty reduction has been steady over the past decade, except for a shock to consumption in the years following the 2008 global economic crisis[4].

At the county level, there are significant inequalities in the incidence of poverty. The proportion of individuals below the poverty line in Turkana (87.5 percent), Mandera (85.8 percent), and Wajir (84.2 percent) is four times that of Nairobi, which has the lowest incidence of poverty at 21.8 percent, and almost double that of Laikipia (47.9 percent), the median county. The national inequalities in poverty across

[1] https://tradingeconomics.com/kenya/gdp-growth-annual
[2] https://tradingeconomics.com/kenya/gdp?user=analyst29326.
[3] https://www.unicef.org/kenya/overview_4616.html.
[4] Kenya Economic Update, April 2018, No. 17 : Policy Options to Advance the Big 4 https://openknowledge.worldbank.org/handle/10986/29676

counties are depicted in Figure 1[5], where the incidence of poverty is higher in the northern and coastal parts of the country and significantly lower in other areas, especially in Nairobi and the central parts of the country. These differences are more pronounced at the constituency level. The proportion of the population below the poverty line in the poorest constituency (Turkana East) is 93.1 percent. This amount is nine times greater than the proportion in the least poor constituency (Embakasi West) where only 10.3 percent of the population lives below the poverty line. In total, 25 counties and 148 constituencies have more than 45.2% of their population below the national poverty line.

Figure 1: Proportion of Population Below Poverty Line (Headcount Index) by County



Source: Exploring Kenya's Inequality

1.1.2 Land, Topography and Physiography

Kenya is located on the east coast of Africa, with the equator running almost straight along the middle of the country. It lies approximately between latitudes 5°20'N and 4°40'S and between longitudes 33°50'E and

[5] Exploring Kenya's Inequality
http://inequalities.sidint.net/kenya/wp-content/uploads/sites/3/2013/11/Expenditure%20and%20poverty.pdf

41°45'E, as shown in the location map, and has a territorial area of 582,646 km^2 according to the Ministry of Lands.

The territorial area of Kenya is divided into water area of 11,230 km^2 and land area of 571,416 km^2. The major portion of the inland water surface area is covered by parts of Lake Victoria and Lake Turkana. Of the land area, approximately 490,000 km^2 (more than 80% of the land area) are classified as arid and semi-arid lands (ASALs). Though the ASALs has few soil or water resources, it supports almost 30% of the human population and 70% of the livestock production in the country. The remaining area, which extends to about 81,000 km^2, is classified as profitably usable lands, which sustain a substantial portion of Kenya's economy and human population.

Kenya is characterized by tremendous topographical diversity, ranging from glaciated mountains to desert landscapes. The elevation varies greatly from sea level at the Indian Ocean to 5,199 m at the Batian Peak of Mount Kenya, which is the second highest mountain on the African continent.

Kenya shares borders with Somalia, Ethiopia, and South Sudan in the north, Uganda in the west, Tanzania in the south, and the Indian Ocean in the east[6].

1.1.3 Climate and Meteorology

The climate in Kenya is primarily controlled by the movement of the Inter Tropical Convergence Zone (ITCZ) and by topographic relief, especially elevation. The rainfall in Kenya is affected by the presence of large water bodies such as Lake Victoria, the complex topography of the Great Rift Valley, and high mountains such as Mt. Kenya and Mt. Elgon. Furthermore, local influences such as land-sea breezes and vegetation complicate the distribution of rainfall.

A relatively wet and narrow tropical belt lies along the coast of the Indian Ocean. Behind the coastline are large areas of semi-arid and arid lands. The land then rises steeply to a highland plateau through which the Rift Valley runs. Kenya generally experiences two seasonal rainfall peaks (bimodal) in most places. However, some stations in the western and central parts of the Rift Valley experience a trimodal rainfall pattern.

Kenya has a wide range of temperatures: from below freezing point on the snow-capped Mt. Kenya (minimum) to over 40 °C in the arid and semi-arid areas in the north and northeast regions (maximum). The average daily temperature varies from 22.4 °C to 30.3 °C in the coastal town of Mombasa (altitude 17 m); from 13.6 °C to 25.2 °C in the capital city of Nairobi (altitude of 1,661 m); from 9.5 °C to 23.6 °C in Eldoret (altitude of 2,085 m) in the western part; and from 23.7 °C to 34.8 °C in Lodwar (altitude of 506 m) in the Rift Valley and the drier north plain lands.

The mean annual rainfall over the country is approximately 680 mm. It varies from about 200 mm in the ASAL zones in counties such as Garissa, Isiolo, Mandera, Marsabit, Moyale, and Turkana, to 1,800 mm in the humid zones, in counties such as Nyeri, Meru, Nyandarua, and Mt. Elgon.

[6] National Water Master Plan 2030

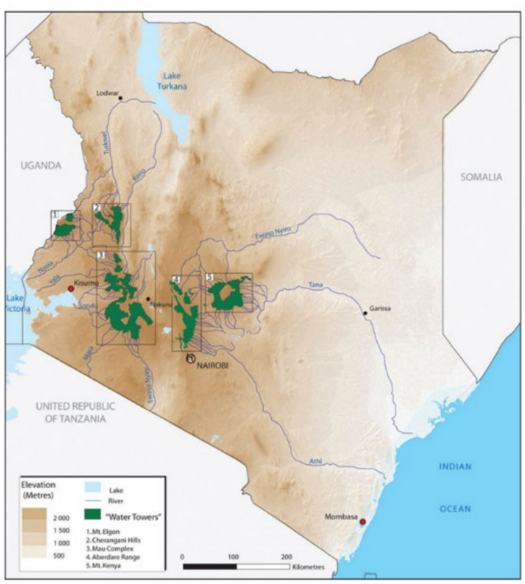
Humid zones, which receive more than 1,000 mm of annual rainfall, occupy less than 20% of the productive agricultural land and sustain approximately 50% of the country's population. Semi-humid zones receive 700-1,000 mm of rainfall annually and occupy between 30% and 35% of the country's land area, sustaining about 30% of the country's population. ASAL, which receive 200-700 mm of rainfall annually, cover over 80% of the country's land area.

1.1.4 Water Resources

Kenya has a total surface area of 581,309 km^2, of which water bodies cover only 2 percent of the area, thus limiting fresh water resources. The five water towers of Mount Kenya, the Aberdare Ranges, the Mau forest complex, Mount Elgon, and the Cherangani hills are the sources of water for irrigation, agriculture, industrial processes, and hydropower plants among many other uses[7]. There are six main catchment areas in the country, which are used as units for water resources management by the Water Resources Authority:

- Lake Victoria North Catchment Area (LVNCA), covering 3 percent of the country
- Lake Victoria South Catchment Area (LVSCA), covering 5 percent of the country
- Rift Valley Catchment Area (RVCA) which includes the inland lakes, covering 22.5 percent of the country
- Athi Catchment Area (ACA) stretching up to the coast, covering 11.5 percent of the country
- Tana Catchment Area (TCA), covering 21.7 percent of the country
- Ewaso Ng'iro North Catchment Area (ENNCA), covering 36.3 percent of the country

Figure 2: Kenya's Water Towers



Source: www.unep.org

[7] http://www.fao.org/nr/water/aquastat/countries_regions/Profile_segments/KEN-WR_eng.stm

The water distribution in the drainage basins is uneven with, for example, 282,600 m³/km² in Lake Victoria basin, or over 750 m³/year per capita and 21,300 m³/km² in the ACA, or 162 m³/year per capita[8].

Inland water bodies, mainly the nine large lakes, cover 11,230 km². Most of them are saline, with the exception of Lakes Victoria, Naivasha, and Baringo. The lakes Nakuru, Naivasha, Bogoria, Baringo, and Elmenteira, as well as Tana River Delta, have been declared Ramsar Sites of International Importance for the Conservation of Biodiversity, exceeding 265,000 ha[9] in total.

Internal renewable surface water resources are estimated at 20,200 million m³/year and renewable groundwater resources at around 3,500 million m³/year. However, 3,000 million m³/year is considered an overlap between surface water and groundwater, which gives a value of total internal renewable water resources (IRWR) of 20,700 million m³/year. External water resources are estimated at 10,000 million m³/year, which is the inflow from Lake Omo from Ethiopia into Lake Turkana. Surface water leaving the country is estimated at 8,900 million m³/year through Lake Victoria to Uganda (8,400 million m³/year) and through the Ewaso Ng'iro River, also called Lagh Dera, into Somalia (500 million m³/year). The dependency ratio was around 33 percent and the total renewable water resources were 30,700 million m³/year, or 692 m³/year per capita in 2014. This per capita value is projected to fall under the absolute water scarcity threshold of 500 m³/year by 2030 due to the rising population.

There are six hydrogeological formations which influence the distribution and availability of the groundwater resources: eastern quaternary sediment areas, bedrock areas, western quaternary areas, volcanic rock areas in the Rift Valley, volcanic areas outside the Rift Valley, and older sedimentary areas. The volcanic and quaternary geological formations are rich in groundwater. The country's safe yield of surface water has been assessed at 7,400 million m³ per year while that of groundwater is about 1,000 million m³ per year[10]. However, this figure needs to be reviewed in light of the new aquifers identified in Turkana country in 2013, and the five deep high capacity groundwater reserves accounting for about 250,000 million m³. Among these aquifers, the Lotikipi aquifer, located to the west of Lake Turkana, is estimated to have over 200,000 million m³ of water. The small Lodwar basin aquifer can also serve as a strategic reserve for Lodwar, the regional capital of Turkana county[11].

The total capacity of large and medium dams (> 15 m) is about 24,800 million m³. It is used entirely for hydropower and urban water supplies. In addition, around 4,100 small dams and water pans increase the storage capacity by an additional 184 million m³ and are available for all uses[12].

The latest severe drought in Kenya extended from 2007 to the end of 2009 and affected all sectors of the economy. The average annual rainfall is 630 mm, although the actual amount varies between less than 200 mm in northern Kenya and over 1,800 mm on the slopes of Mount Kenya[13]. Kenya is divided into

[8] WRMA Performance Report 2 (WRMA, 2011)
[9] The List of Wetlands of International Importance (RAMSAR, 2013)
[10] The National Water Master Plan 2030. Final Report – Volume I Executive Summary (WRMA, 2013)
[11] Strategic groundwater reserves found in Northern Kenya (UNESCO, 2013)
[12] Draft National Irrigation Policy (Ministry of Agriculture, Livestock and Fisheries, 2015)
[13] Aquastat Country Profile Kenya (2010)

five drainage basins. The Lake Victoria Basin Drainage area system in Western Kenya is part of the Nile River Basin. The closed Rift Valley Inland Drainage system includes a number of rivers and lakes, including large freshwater lakes such as Lake Turkana, Lake Baringo, and Lake Naivasha, rivers such as the Kerio River, as well as a number of salt lakes.

The Athi drainage system, the Tana drainage system, and the Ewaso Ng'iro North drainage system all flow toward the Indian Ocean. The water distribution in the basins is highly uneven with Tana the Lake Victoria Basin having a surplus, and the other three having deficits.

Nairobi receives its water resources from two drainage systems. The oldest sources of water are the Kikuyu Springs (used since 1906) and the Ruiru Dam (since 1938), which are both located in the Athi River Basin. The Sasumua Dam, the Ndakaini-Thika Dam (since 1996), and the Chania-B Dam supply Nairobi through interbasin transfers from the Tana River drainage area. About 20% of the supply comes from ground water resources which corresponds to around 60,000 to 70,000 m^3 per day[14]. Mombasa, Kenya's second largest city, serves its water demand through the Marere Water Works in the south-west, the Baricho Intake on the Lower Athi River, and from Mzima Springs on the Upper Athi River, through a 220 km pipeline to the city[15].

1.2 Background and Objective of Project Development

Climate change is globally acknowledged as one of the most significant development challenges facing humanity. There is increasing evidence that climate change is directly affecting the social, economic, and human development world over. Combating climate change, therefore, has become one of the key global development priorities. The effects of climate change and related disasters have the potential to adversely impact a majority of Kenyans given that about 75% of the population depends directly on land and natural resources for their livelihoods. In recent years, there has been increased attention to climate change due to its impacts on the lives of Kenyans. This has been mainly due to an increase in the intensity and frequency of extreme climatic events such as severe droughts and flooding. These extreme events have had negative socio-economic impacts on almost all sectors of Kenyan society such as health, agriculture, livestock, environment, hydropower generation, and tourism. The seriousness of the problem has made it imperative for policy makers to focus on mainstreaming climate change in development policies and strategies[16].

Kenya faces social, economic, and environmental stresses and constraints, which limit its ability to adapt to climate change problems. Kenya’s population is growing rapidly and is projected to reach 46.7 million in 2017. Over 60 percent of the country’s population is rural (29.06 million) and relies predominantly on the environment and natural resource sectors. Water security is a key issue given that Kenya’s people and economy are highly vulnerable to erratic climatic patterns and limited water availability[17]. In the past two

[14] Climate variability and water resources degradation in Kenya (2010)
[15] Nature's Benefits in Kenya, World Resources Institute (2010)
[16] Kenya National Human Development Report (2013) http://hdr.undp.org/en/content/climate-change-and-human-development.
[17] World Bank. Kenya Coastal Region Water Security and Climate Resilience Project. Project Appraisal Document (World Bank, 2013)

decades, from 1992–2012, Kenya was ranked first among African countries in terms of people affected by droughts (roughly 46 million people) and fifth in terms of those affected by floods (about 2.8 million people) during the same period.

Kenya has limited freshwater endowments and is classified as a chronically "water-scarce" country in absolute and relative terms. It faces the additional challenge of high inter-annual and intra-annual rainfall variability. According to the Joint Monitoring Programme for Water Supply and Sanitation (JMP), 63% of Kenyans (82% in urban areas and 57% in rural areas) had access to improved drinking water sources in 2015, and 22% of Kenyans (45% in urban areas and 14% in rural areas) are reported as having access to piped water through a house or yard connection. Furthermore, access to improved water sources in urban areas decreased from 92% in 1990 to 82% in 2015. On the contrary, while access in rural areas increased from 33% to 57% during the same period[18], the quality was poor when compared to water quality in urban areas. Overall, in order to increase water accessibility in both urban and rural areas, current infrastructure for water is quite unsatisfactory.

Hence, Kenya needs to adopt interventions to improve water resource monitoring, conservation, and storage measures as part of its climate change strategies. In the context of water management, the project will be implemented with a focus on the Upper Athi River Catchment Area (UARCA), one of the key water sources in Kenya. This is because the resources to be provided by the Green Climate Fund (GCF) do not fully cover the entire Athi River Catchment Area. Thus, the proposed project will be planned in such a way that every activity and input is focused on the UARCA, and the lessons learned and best practices produced by the project will be shared widely and implemented across other parts of the country. The project is anchored on the National Climate Change Plans and policies. It aims to further actions that are already included in the water sector's policies and plans.

1.3 Objectives and methodologies Used in the Feasibility Study

This feasibility study was commissioned as part of the preparations for a possible GCF project on "Enhancing the resilience of communities and ecosystems in the Upper Athi River Catchment Area, Kenya." The objectives of the study are as follows:

- To assess and evaluate the impact of climate change in UARCA from various standpoints such as hydrology, environment, humanity, and society
- To establish baseline data for the project that would go on to serving as a basis for the adoption of a comprehensive sustainable strategy
- To recommend an action plan with optimal technology and capacity enhancement programs as a solution for the implementation at both national and sub-national levels

The feasibility study has been conducted over a period of six months from March to August 2018. The methods used include data collection, literature review, field surveys, and consultations with key stakeholders along with a detailed evaluation of the prevailing efforts of adaptation to and mitigation of the

[18] WHO / UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation. 2017. WHO / UNICEF

impacts of climate change. Recent government policy, strategy, and plans on climate change, water resources management, and disaster management, among others were reviewed. A series of meetings were also held to consult with key stakeholders in Kenya in March, and from July to August 2018. These meetings were held with officials from Ministry of Water and Sanitation (MWS), the National Environment Management Authority (NEMA), the Water Resources Authority (WRA), and Kenya Meteorological Department (KMD), and a professor of University of Nairobi (UoN). Further, there were field missions to four county governments to meet key provincial officials from the region, and to interview a number of stakeholders, including several current Water Resource User Associations (WRUAs).

This study was prepared as part of a series of technical and socio-economic studies and financial feasibility reviews to inform the development of the project. The report begins by reviewing the policy framework for adaptation and resilience in Kenya, and then analyzes the vulnerability and risk mapping in UARCA to suggest potential project sites. Then, it examines the priority areas of water resources monitoring, water conservation, and storage measures in detail, focusing on the economic feasibility as well. It then summarizes a number of key findings and provides recommendations for consideration in further planning and provides additional relevant background materials in a series of annexes.

CHAPTER 2 : Climate Risk Profile of Kenya

2.1 Climate Change in Kenya: Impacts and Risks

2.1.1 The Impact of Climate Change in Kenya

The Intergovernmental Panel on Climate Change(IPCC) report (2014) [19] warns that Kenya could be seriously impacted by climate change due to global warming. Kenya is expected to face a rise in epidemics and severe food shortages in the future due to climate change. In addition, Mombasa County is estimated that economic losses will reach 90 billion Kenya shillings ($ 1.1 billion) by 2030 due to large-scale coastal flooding. Due to climate change, Kenya's water and food resources are becoming scarce. With limited resources, there is a concern that regional conflicts will grow and conflicts will intensify. Kenya’s rainy season has been progressively shortened in recent years, as a result of global warming. Food productivity has been on the decline as a result of severe drought. The country is also facing a shortage of water, which is affecting everyday life, as well as the livestock and the livestock-related industry. Climate change is expected to reduce Kenya's main food resource, namely corn and soybean, threatening food security, and thus increasingly affecting people who are already affected by poverty.

The production of corn is projected to fall to one-fifth its current amount, while soybean production will also see a decline by 68%. In 2030, due to food shortages, 55% of newborns are predicted to have developmental problems. In addition, fatal meningitis and malarial epidemics are expected to pave the way for greater poverty among the poor. In Mombasa, by 2030, between 170,700 and 266,300 inhabitants will be exposed to coastal flooding and flood risk, resulting in an estimated economic loss of between 58 billion and 90 billion Kenyan shillings.

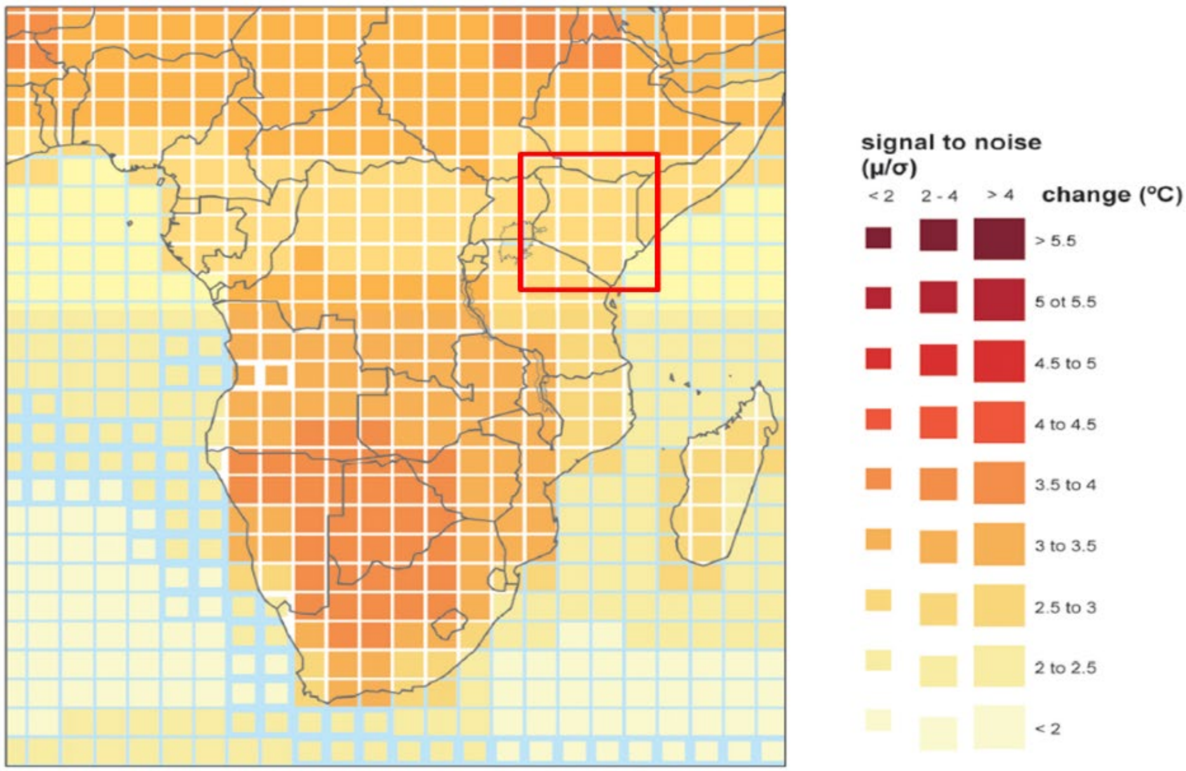
The Met Office Hadley Center for Climate Change[20] in the UK has produced a climate change scenario ensemble based on the HadCM3C climate model to analyze global climate change impacts by creating scenarios of increasing CO_2 emissions caused by human activity. These results are reflected the result of using the Coupled Model Intercomparison Project Phase 3 (CMIP3) model outputs and presently provide CMIP5 multi-model ensemble data to analyze the more comprehensive impacts on future climate change. The results of the CMIP3 ensemble forecasts for temperature and precipitation for the A1B emission scenarios for Africa and surrounding areas, including Kenya, are shown in Figures 3 and 4 below.

Figure 3 shows the forecast of the projected changes in average annual temperature by 2100, based on the change in the annual mean temperature between 1960 and 1990. The data presented in Figure 3 represent an average of the results arrived at by the 21 models that participated in CMIP3. Almost all models of the CMIP3 ensemble project address the temperature rise in Africa at large and Kenya in particular. The size of each pixel depends on the extent of the model ensemble, and indicates the consistency among the results projected. Based on temperature forecasts predicted by CMIP3, it appears that Kenya may face a

[19] Climate Change 2014: Mitigation of Climate Change, Summary for Policymakers and Technical Summary. https://www.ipcc.ch/pdf/assessment-report/ar5/wg3/WGIIIAR5_SPM_TS_Volume.pdf
[20] Climate: Observations, projections and impacts: Kenya http://eprints.nottingham.ac.uk/2040/16/Kenya.pdf

temperature increase of about 3 ℃ by 2100, and the ensemble prospects for each model appear to agree.

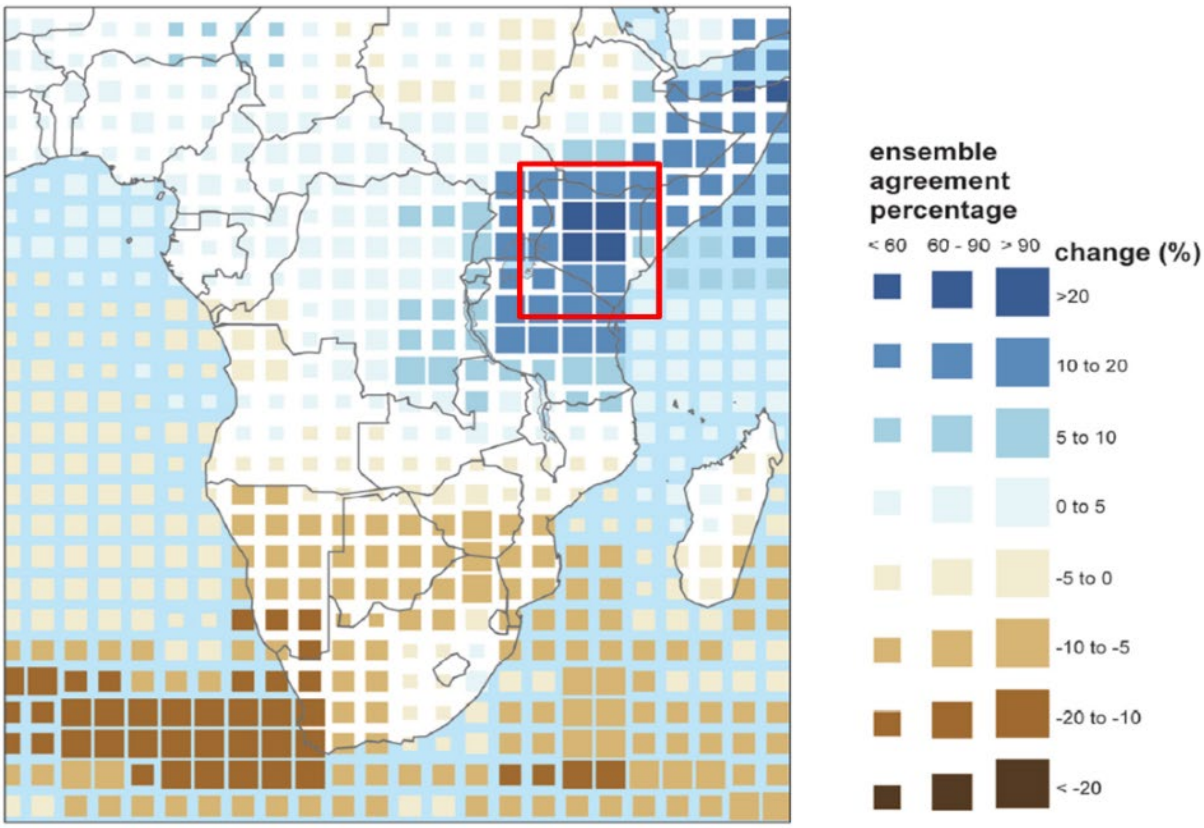
Figure 3: Percentage change in average annual temperature by 2100 averaged over 21 CMIP3 models based on the 1960-1990 baseline climate.



Source: Climate: Observations, projections and impacts: Kenya

Figure 4 shows the forecast of the projected average annual precipitation by 2100, based on change in the annual average precipitation between 1960 and 1990. Unlike the temperature change prediction, the climate model ensemble data can confirm the variance of precipitation. It shows the local variability of precipitation for the African region. Based on the results of the climate model, we can identify the decline in precipitation over the southern regions of Africa. We can find an increase in precipitation in the Middle Eastern Africa, around where Kenya is located. The results of most climate model ensembles are expected to show a strong increasing tendency in precipitation over Kenya, with an increase pattern of more than 20% in the future.

Figure 4: Percentage change in average annual precipitation by 2100 averaged over 21 CMIP3 models based on climate in the baseline period of 1960 to 1990.



Source: Climate: Observations, projections and impacts: Kenya

Therefore, according to the predictions of the Global Climate Models (GCMs), the frequency of severe droughts and the intensity of heat in Kenya are expected to increase. In addition, changes in arable areas, increased crop damage, reduced availability of food resources, an increase in the number of pests, and the emergence of new types of diseases can be expected. The increase in rainfall due to climate change is expected to increase the frequency and intensity of floods. and it is necessary to prepare for extreme spells of rain due to increased precipitation in the short term, and lengthy spells of dry seasons due to decreased precipitation in the long run as a result of climate change. In addition, measures against waterborne diseases such as malaria, cholera, and typhoid will be necessary. In conclusion, Kenya is vulnerable to the adverse impacts of climate change, manifesting in the form of both droughts and floods. It will soon become a matter of great urgency to implement appropriate countermeasures in vulnerable areas.

Kenya is one of the most water-scarce countries in Africa. Based on its current population growth, the availability of water is projected to fall to 350 cubic meters per person by 2020[21]. The Kenya National Water Management Plan (NWMP) 2030 suggests that the water demand is projected to increase by three times, from 1,145 million in 2010 tons to 4,586 million tons in 2030, due to population growth, and industrial and agricultural development. It is projected that the water demands for 2030 are expected to increase to about 281% against the available water resources. Maintaining a balance will require the appropriate and maximum utilization of water resources. However, water resources are unevenly distributed spatially and temporally in the catchment, with large areas suffering from water deficits. With the per capita water availability being less than half of the global standard, the catchment experiences water supply problems that worsen during droughts. This situation is expected to worsen further by 2030. The water deficits emphasize on the need for planning to maximize the utilization of water resources, such as maximum development of water resources, introduction of water demand management, and the limitation of water demands within the water supply capacity[22].

Table 1: Available Water Resources and Demand vs. Future Resources and Demand in the Athi Catchment Area (ACA), Kenya

Year	Water Demands (MCM/year)						
	Domestic	Industrial	Irrigation	Livestock	Wildlife	Fisheries	Total
2010	519	93	498	25	3	7	1,145
2030	941	153	3,418	59	3	12	4,586

Source: National Water Management Plan (NWMP), 2030

2.1.2 Climate-Related Policy and Regulations in Kenya

2.1.2.1 Government's Organization for Climate Change Adaptation

Kenya has developed several strategies and plans to respond to the unpredictable impacts of climate change over the last few years. The National Climate Change Response Strategy 2010 (NCCRS), the National Climate Change Action Plan (NCCAP) 2013, the National Adaptation Plan (NAP) 2015, the Intended Nationally Determined Contribution 2015 (INDC), and Vision 2030 have all aimed at formulating climate change related legislation, policies, and strategies. These plans have also aimed at the development of national blueprints through flagship programs and projects with aspects of adaptation and mitigation. Among these plans, the NCCAP, developed in 2013 through an extensive consultative process, is expected to inform national development and policy decisions in all sectors of the economy. As climate change planning is an intersectional and dynamic process, it is anticipated that the recommended actions will be tracked continuously. Further, the NCCAP will be revised and updated on a five-yearly cycle in line with national planning and budgetary processes.

Other legislative and regulatory instruments have also been formulated to address climate change. Some of these include the National Water Master Plan 2030, the National Policy for the Sustainable Development of Northern Kenya and other Arid Lands 2010, the NDMP 2012, the Environmental Management and

[21] World Resources Institute (WRI), Kenya Ministry of Environment and Natural Resources, Kenya Ministry of Planning and National Development, & International Livestock Research Institute. 2007. Nature's benefits in Kenya: An atlas of ecosystems and human well-being. Retrieved from http://pdf.wri.org.kenya_atlas_fulltext_150.pdf

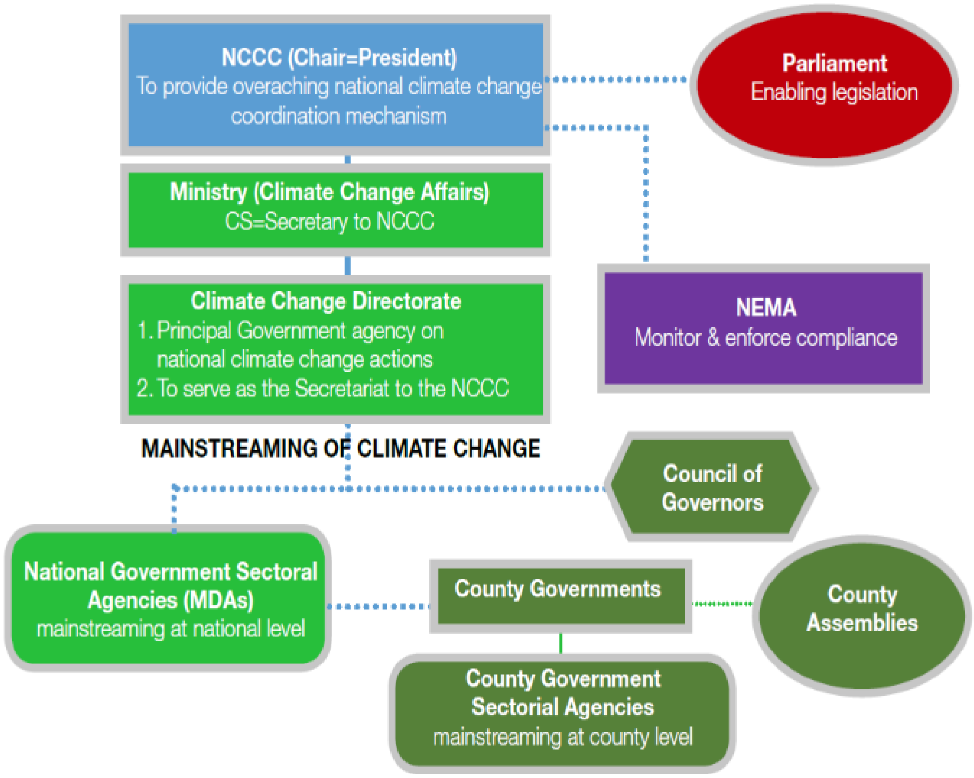
[22] National Water Master Plan, 2030

Coordination Act (EMCA, 1999), the Energy Policy and Act, the Agricultural Sector Development Strategy 2010-2020, the Kenya Forestry Master Plan 1995-2020, the Second National Environment Action Plan (NEAP, 2009-2013), and Threshold 21 (T21) Kenya. There are also a range of other instruments that have aimed at regulating water, energy, land use, forestry, agriculture, and food security policies.

In May 2016, the President assented to the Climate Change Act, which provides a framework for action that promotes low carbon, climate resilient development in Kenya. It is an important milestone in Kenya's path toward developing its economy while simultaneously reducing greenhouse gas emissions. The country has also validated its National Climate Change Framework Policy that complements and reinforces the actions called for in the new Climate Change Act, providing the environment for its implementation. Although Kenya is operationalizing these policies and plans by implementing climate change action in various areas, the country still experiences difficulties due to limited funding and lack of technical and institutional capacity.

The organizational structure relied on by the government in implementing its climate change adaptation policies is shown in Figure 5.

Figure 5: : Institutional coordination structures under the Climate Change Act 2016 [23]

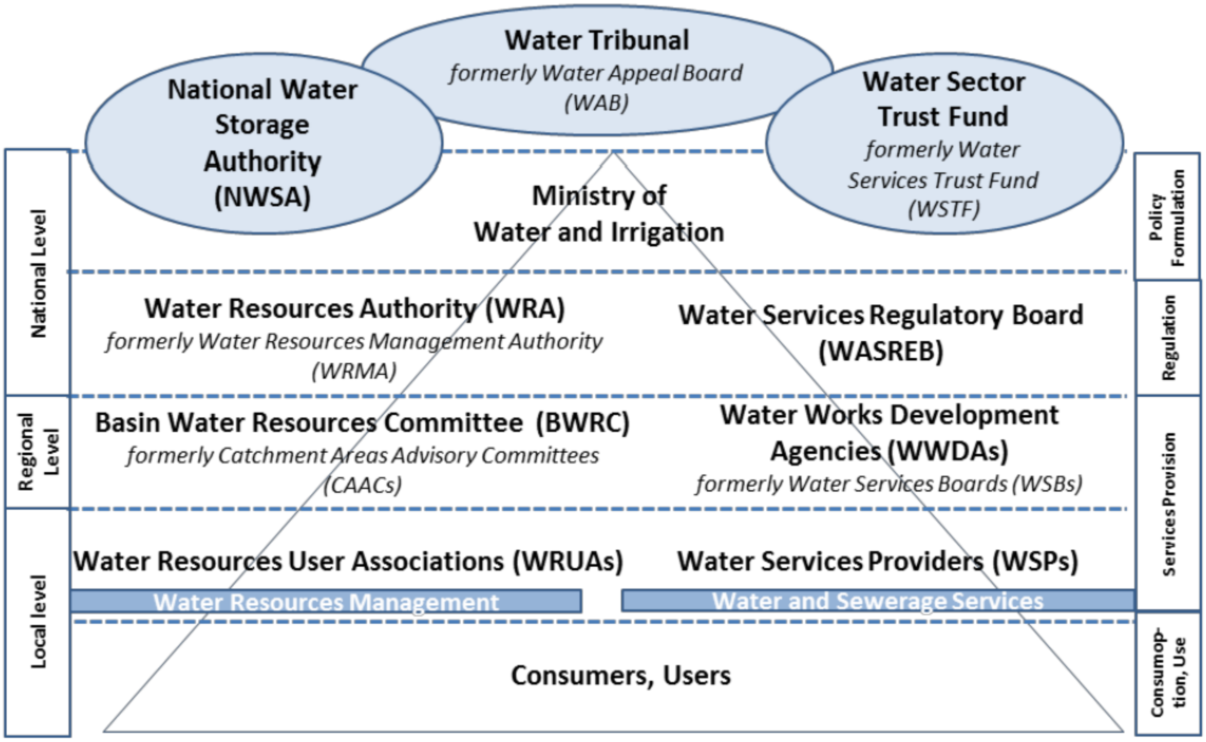


Source: Kenya National Adaptation Plan 2015-2030.

[23] Kenya National Adaptation Plan 2015-2030 - unfccc.
http://www4.unfccc.int/nap/Documents%20NAP/Kenya_NAP_Final.pdf

Figure 6 shows the roles and responsibilities of the management in the development and regulation of water resources and water services based on Kenya's governmental organization. The purpose of the 2016 Water Act is to align the water sector with the primary objectives of the Constitution. The Act recognizes that water-related functions are a shared responsibility between the national and county governments[24].

Figure 6: Roles and responsibilities under Kenya's 2014 Water Bill



Source: Understanding the Kenya 2016 Water Act

The implementation of the policy has implications for groundwater management as it relates to: 1) identifying the availability and vulnerability of groundwater resources; 2) developing the institutional, capacity, and financing arrangements for groundwater management; 3) supporting integrated water resources management; and 4) considerations for groundwater quality management.

The Water Act 2012 and Water Act 2016 aim at providing direct service delivery of water and sewerage services by creating an authority on behalf of country governments. The acts regulate the ownership and control of water and makes provision for the conservation of surface and groundwater as well as the supply of services in relation to water and sewerage. Additionally, there exists a draft National Water Harvesting and Storage Management Policy whose goal, in line with Vision 2030, is to facilitate the expansion of water

[24] Understanding the Kenya 2016 Water Act https://www.2030wrg.org/wp-content/uploads/2016/12/Understanding-the-Kenyan-Water-Act-2016.pdf

harvesting, storage and development of flood capacity sustainably to contribute toward the creation of wealth and employment, food security, and poverty reduction for national prosperity.

Table 2: Kenya's Climate Change Plans and Recommended Actions for the Water Sector

Plan and Policy	Recommended Actions for the Water Sector
National Climate Change Response Strategy (NCCRS) 2010	– Construction of dams and water pans – Protection of water towers, river banks, and water bodies – De-silting of riverbeds and dams – Municipal water recycling facilities – Building capacity for water quality improvement and awareness campaigns to promote water efficiency measures.
National Climate Change Action Plan (NCCAP) 2013	– Mainstreaming of Climate Change concerns into all water resource management plans and actions – Water conservation efforts including the reversal of degradation of the main water towers and rehabilitation and restoration of all water catchments – Increasing urban and rural domestic water supplies and urban sewage services to help combat water-borne diseases and their social and economic impacts – Enhance irrigation and drainage to increase agricultural production and address water requirements for livestock production – Carry out effective trans-boundary water resources management – Carry out water resources assessment, documentation and dissemination of necessary information to stakeholders
Intended Nationally Determined Contributions (INDC) and National Adaptation Plan (NAP) 2015	– Mainstreaming of climate change adaptation in the water sector by implementing the National Water Master Plan (2014)

2.1.2.2 Kenya Vision 2030 and Water Resources in the Athi Catchment Area (ACA)

Kenya has recognized the growing threat of climate-induced risks to its short-term and long-term development prospects. Thus, the Government of Kenya formulated several legislative and regulatory instruments, including the National Water Master Plan 2030, which incorporated climate change into planning for the water sector.

Kenya Vision 2030 (2008-2030) [25] is the country's long-term national planning strategy. It represents a development blueprint for the country, which aims at transforming Kenya into "a newly- industrializing, middle-income country providing a high quality life to all its citizens in a clean and secure environment"

[25] Ministry of water and sanitation: Review of national water quality management stratagem (Concept Note)

by 2030. Table 3 summarizes the policies and vision of the Kenyan government in adapting its water sector to the impacts of climate change.

Table 3: Climate Change Adaptation in the Kenyan Water Sector

WATER AND SANITATION	
Action	Mainstreaming of climate change adaptation in the water sector.
Summary	The impacts of climate change lead to increasing scarcity of water especially in the ASAL region, meaning that Kenya requires adequate water management strategies that take into account the sector's vulnerability to climate change. The water sector needs to identify current and future vulnerabilities and develop strategies and plans to manage water sources, basins, water supply and wastewater. Large-scale irrigation projects need to be planned appropriately as adaptation measures.
Examples of ongoing projects/initiatives	Implementation of the National Water Master Plan (2014), the Kenya Water Security and Climate Resilience Project, Adaptation to Climate Change in Arid and Semi-Arid Lands (KACCAL), the Adaptation Consortium, the Western Kenya Community Driven and Flood Mitigation Project, Capacity Development for Effective Flood Management Project, and Water Infrastructure Solutions from Ecosystem Services Underpinning Climate Resilient Policies and Programs.
Gaps	Awareness, capacity building, financing
Short-term sub-actions	• Enhance the capacity of institutions and bodies responsible for water and sanitation to deal with the impacts of climate change in the water sector. • Promote awareness on the impacts of climate change in the water sector, including promoting public awareness on water conservation (recycling and waste water management) and efficient water use. • Mainstream disaster risk reduction measures in planning and service delivery in the water sector, particularly in vulnerable and high risk regions. • Promote the use of efficient irrigation systems.
Medium-term sub-actions	• Enhance collaboration in trans-boundary water resource management. • Strengthen water resource monitoring and assessment for early warning and planning. • Promote technologies that enhance water resource efficiency.
Long-term sub-actions	• Implement the National Water Master Plan 2030.
Budget	US$ 5,075,489,183
Responsibility	The Ministry responsible for water and sanitation, MDAs, County Governments, Research Institutions and Academia, Civil Society, and the Private Sector.

Source: Enhanced climate resilience toward the attainment of Vision 2030 and beyond

Implementation of Strategy

The project will be implemented in three different phases:

- Short-term: $10 million
- Medium-term: $300 million
- Long- term: $500 million

Short-term measures (2018-2020)

- Review of the National Water Quality Management Strategy
- Source funds to implement the strategy
- Short-term trainings at all levels (professional and sub-professional)
- Procure emergency water testing equipment
- Recruit new critical technical staff
- Develop Water Quality Management (WQM) tools, such as manuals
- Set up institutional framework for WQM
- Set up WQM Committees/Task Forces/Working Groups
- Define WQM institutional responsibilities

Medium-term measures (2018-2023)

- B.Sc, M.Sc. training in WQM
- New recruitment of technical staff
- Procure emergency equipment/water quality test kits
- Establish the National Water Quality Monitoring and Reporting Guidelines
- Prepare catchments-based WQM plans
- Initiate enforcement of quality guidelines
- Establish a water quality monitoring/assessment program
- Enforce water pollution control measures
- Source funds to support WQM
- Initiate research on water quality and other related matters

Long-term measures (2018-2030)

- Establishment of a National Water Testing Laboratory to serve as a center of excellence and a referral water quality laboratory for the entire water sector
- Upgrading or improving existing water quality testing facilities
- Long-term training of water quality personnel (B.Sc, M.Sc, Ph.D)
- Recruitments of new technical staff for effective succession management (most of the current staff are due for retire in the next five years)
- Advanced trainings on instrumentation
- Enforcement of Water Quality Monitoring and Reporting Guidelines
- Introduction and use of biological water quality indicators
- Introduction and use of new and innovative WQM tools, such as environmental isotopes
- Enforcement of water pollution control measures
- Making operational national water quality monitoring and assessment programs (from 2018)
- Carry out research on WQM

2.2 Climate Change Impact Assessment in the Upper Athi Catchment Area

2.2.1 Historical Data and Climate Change Scenarios

2.2.2.1 Historical Data

Climate change poses a real threat to development prospects and livelihoods. Kenya's average temperatures are rising, rainfall patterns are changing, and the incidence and intensity of extreme weather events such as droughts and floods are increasing. Droughts and floods have devastating consequences on the economy, environment, and society, resulting in food insecurity, malnutrition, damage to infrastructure, and loss of life. Researchers have estimated the cost of droughts and floods in Kenya at about 2.6 percent of the GDP each year[26]. The adaptation analysis explains that exact processes that affect Kenya's climate are not fully understood and predicting future climate trends remains difficult. Temperatures in Kenya will continue to increase, and the frequency of hot days and nights will rise, with cold days and nights becoming rare. Precipitation is expected to increase in many areas, with the largest growth in rainfall occurring in the highland districts and the coastal region. The northeast is expected to become significantly drier[27].

Kenya has varying air temperatures, ranging from the coldest weather in the snow-capped Mt. Kenya (below 0 °C) to the hottest weather in the arid and semi-arid areas in the north and northeast (above 40 °C). In particular, the average daily temperature in Nairobi is 13.6–25.2 °C while that of the drier north plain is 23.7–34.8 °C. Since 1960, Kenya's mean annual temperature has increased by 1.0 °C, at an average rate of 0.21 °C per decade. The rate of increase has been most rapid in March-May (0.29 °C per decade) and slowest in June-September (0.19 °C per decade).

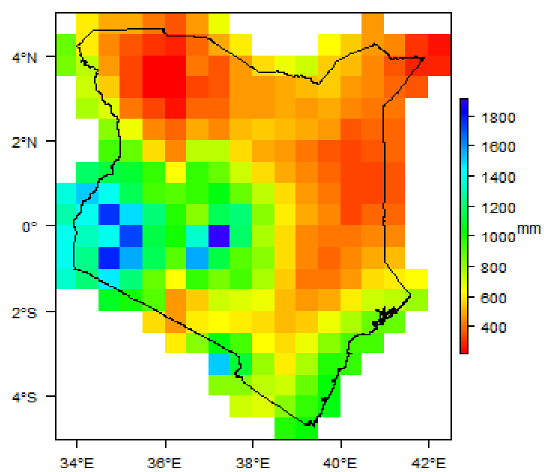
As agriculture is the most important economic activity in Kenya, representing more than 26% of its GDP and engaging 75% of its national population, the mean annual rainfall is highly important in Kenya. Kenya has climatic and ecological extremes with altitudes varying from sea level to over 5,000 m in the highlands. The mean annual rainfall is approximately 680 mm, showing a range of 200–1,800 mm. The humid zones house more than 20% productive agricultural land and approximately 50% of the country's population, where the mean annual rainfall is more than 1,000 mm. The semi-humid zones receive 700–1,000 mm of rainfall annually, and these zones hold about 30% of the country's population. The others are classified as arid zones, whose mean annual rainfall shows a range of 200–700 mm.

Figure 7 presents the spatio-temporal variability of annual and monthly precipitation (rainfall) and temperature for the period 1961 to 2010. These maps and graphs were developed based on the CRU TS 3.21 dataset produced by the Climatic Research Unit at the University of East Anglia, UK[28].

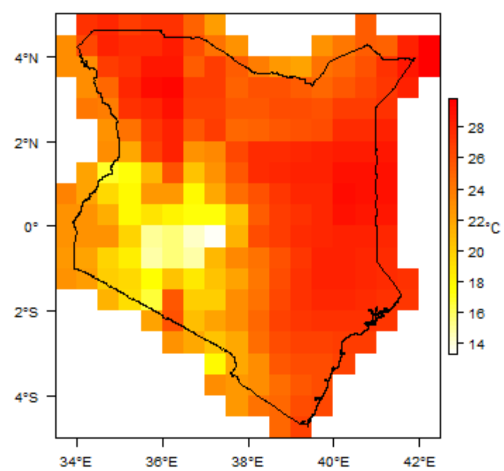
[26] Downing, C. Preston, F., Parusheva, D., Horrocks, L., Edberg, O., Samazzi, F., Washington, R., Muteti, M., Watkiss, P. and Nyangena, W. 2008. Kenya: Climate Screening and Information Exchange. Final report. Report to Department for International Development. Oxfordshire: AEA. page 30.
[27] https://www.ecn.nl/publications/PdfFetch.aspx?nr=ECN-B--12-016
[28] Hydrogeology of Kenya
http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Kenya

Figure 7: Spatio-Temporal variability of annual and monthly rainfall and temperature in Kenya

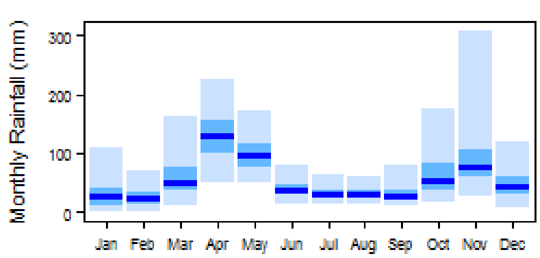
(a) Annual Rainfall



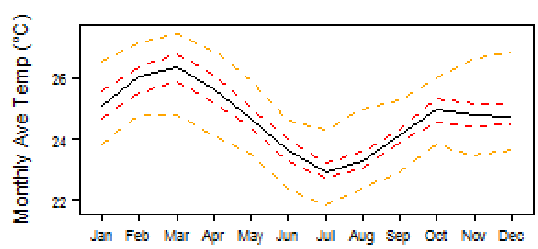
(b) Annual Temperature



(c) Monthly Rainfall



(d) Montly Temperature



Source: http://earthwise.bgs.ac.uk/index.php/Hydrogeology_of_Kenya

2.2.1.2 Climate Change Scenario Data

Climate change scenarios may show different results depending on the downscaling and bias correction method used, even within the same target area. Therefore, standardized research for the production of climate change scenario data is needed. In addition, it is necessary to analyze climate change scenarios using the results of various GCMs rather than of only a single GCM model. It is necessary to mention the uncertainties inherent in the climate model as well.

Table 4 presents a list of the Coupled Model Intercomparison Project Phase 5 (CMIP5) 26 GCMs and their spatial resolution of grid matrix and modeling group. The projection of uncertainty in precipitation and temperature as a result of climate change are calculated using CMIP5 26-GCMs during the historical and future periods in the Upper Athi Catchment Area in Kenya.

Table 4: List of CMIP5 26-GCMs and Modeling Groups used

No.	Model Name	Resolution	Modeling Group
1	ACCESS1-0	0.25°(25×25km)	Commonwealth Scientific and Industrial Research Organization and Bureau of Meteorology, Australia
2	BCC-CSM1-1	0.25°(25×25km)	Beijing Climate Center, China Meteorological Administration
3	BCC-CSM1-1-m	0.25°(25×25km)	
4	BNU-ESM	0.25°(25×25km)	College of Global Change and Earth System Science, Beijing Normal University
5	CanESM2	0.25°(25×25km)	Canadian Center for Climate Modeling and Analysis
6	CCSM4	0.25°(25×25km)	National Center for Atmospheric Research
7	CESM1-BGC	0.25°(25×25km)	Community Earth System Model Contributors
8	CMCC-CM	0.750°×0.748°	Centro Euro-Mediterraneo per I Cambiamenti Climatici
9	CNRM-CM5	0.25°(25×25km)	Centre National de Recherches Météorologiques/Centre Européen de Researche et Formation Avancée en Calcul Sceintifique
10	CSIRO-MK3-6-0	0.25°(25×25km)	Commonwealth Scientific and Industrial Research Organization, Queensland Climate Change Centre of Excellence
11	FGOALS-g2	2.813°×1.659°	Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Chinese Academy of Sciences, and Center for Earth System Science, Tsinghua University
12	FGOALS-s2	2.813°×1.659°	
13	GFDL-CM3	0.25°(25×25km)	NOAA Geophysical Fluid Dynamics Laboratory
14	GFDL-ESM2G	0.25°(25×25km)	
15	GFDL-ESM2M	0.25°(25×25km)	
16	HadGEM2-AO	1.875°×1.250°	Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto National de Pesquisas Espacials)
17	INMCM4	0.25°(25×25km)	Institute for Numerical Mathematics
18	IPSL-CM5A-LR	0.25°(25×25km)	Institut Pierre-Simon Laplace
19	IPSL-CM5A-MR	0.25°(25×25km)	
20	IPSL-CM5B-LR	3.750°×1.895°	
21	MIROC-ESM	0.25°(25×25km)	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
22	MIROC-ESM-CHEM	0.25°(25×25km)	
23	MIROC5	0.25°(25×25km)	
24	MPI-ESM-LR	0.25°(25×25km)	Max-Planck-Institute für Meteorologie (Max Planck Institute for Meteorology)
25	MPI-ESM-MR	0.25°(25×25km)	
26	MRI-CGCM3	0.25°(25×25km)	Meteorological Research Institute

2.2.2 Downscaling and Bias Correction Methods

2.2.2.1 Downscaling

In this feasibility study, the R-CMIP5 package developed by Cho (2013) [29] was used for the extraction of the detailed data on Kenya climate change scenarios. The procedure followed in GCMs data processing by R-CMIP5 is presented below:

- Automatic extraction of CMIP5 GCMs data provided by Earth System Grid Federation[30].
- Performing the NetCDF Operator (NCO) function and clipping data using Shell script to extract the NetCDF grid corresponding to the target area based on the user's input of latitude and longitude coordinates
- Extracting time series data from point-to-point text format using observation point coordinates on the grid in NetCDF format in CMIP5 GCMs data
- Production of downscaled and bias corrected climate change scenarios data by branch by using qmap package of R program

2.2.2.2 Bias Correction

Gridded data produced from climate models have low spatial resolution and the target areas are spatial averages. In many cases, the region to be analyzed includes the ocean, and it is difficult to reproduce actual phenomena (Yoon and Cho, 2015[31]). In addition, to trust future projections produced by climate models, the past and present climate must also be reproduced. Statistical downscaling is necessary to refine the target area from the data produced by climate model scenarios. Generally, while downscaling, the systematic errors in GCMs are corrected by comparing the results of the simulated climate model with those of the same period during the observation period in a process called bias correction. Once the reproducibility of the simulated results of the climate change scenario data of GCMs is verified, the reliability of future scenarios can be assured.

In this study, we used the Quantile Mapping (QM) method to correct the systematic errors between the simulation and observation during the historical observation period. Cannon et al. (2015) proposed the equation for the general decimation method can be expressed as the follows:

$$\hat{x}_{m,p}(t) = F_{o,h}^{-1}\{F_{m,h}[x_{m,p}(t)]\} \quad (1)$$

[29] Cho, J. P. (2013) Climate Change Impacts on Agricultural Reservoirs with Consideration of Uncertainty, *APCC Research Report 2013-05*, pp. 1-136.
[30] ESGF, http://pcmdi9.llnl.gov/esgf-web-fe/
[31] Yoon, S. K., and J. P., Cho. (2015) The uncertainty of extreme rainfall in the near future and its frequency analysis over the Korean Peninsula using CMIP5 GCMs, *J. Korea Water Resour. Assoc*., Vol. 48, No. 10, pp. 817-830.

here, $x_{m,p}(t)$ represents the value before bias correction at future time t, and $\hat{x}_{m,p}(t)$ represents the value after bias correction at future time t. Further, $F_{m,h}$ represents cumulative probability density function of simulated data through GCMs during the historical period, and $F_{o,h}^{-1}$ represents the inverse function of the cumulative probability density function of observed data during the historical period. p indicates projection, h indicates the historical period, m means the GCMs model, and o means observation.

In general, for the case of precipitation, the Gumbel distribution can be applied as a parametric method for bias correction, applying a rate of change for the baseline and future periods, and using a method that reflects trends in future data. The bias correction for precipitation can be expressed as follows:

$$\hat{x}_{m,p}(t) = F_{o,h}^{-1}\left\{F_{m,h}\left[\frac{\bar{x}_{m,h}\, x_{m,p}(t)}{\bar{x}_{m,h}(t)}\right]\right\}\frac{\bar{x}_{m,p}(t)}{\bar{x}_{m,h}} \tag{2}$$

where $\bar{x}_{m,h}$ and $\bar{x}_{m,p}$ are the mean of historical and future periods respectively, as simulated by the GCM model.

2.2.3 Impacts of Climate Change on the Upper Athi River Catchment Area

Table 5 presents a list of rain gauge stations provided by the WRA. The mean value of available stations was calculated by county, and the precipitation data of each county was constructed.

Table 5: Available Automatic Rain Gauge Site for 8 Counties

County	Sta. ID	Site Name
Kiambu	9036244	KIENI FOREST STATION
	9137123	MANGU HIGH SCHOOL
	9136014	KAMUNDU ESTATE KIAMBU
Nairobi	9136130	NAIROBI WILSON AIRPORT
	9136158	NAIROBI WATER DEVELOPMENT DEPARTMENT
Machakos	837	MACHAKOS WATER YARD
	9137010	MACHAKOS DISTRICT OFFICE
	9137028	MACHAKOS MATILIKU
	9137028	MACHAKOS MATILIKU
	9137098	MACHAKOS DAM
Makueni	9237002	KIBWEZI DWA PLANTATION LTD.
	9137056	MAKUENI UNOA HILL
	9137069	MAKUENI ATHI CAMP

	9137075	MAKUENI KAMPI YA MAWE
Kajiado	9136185	KAJIADO MASAI RURAL TR. CENTRE
	9136039	KAJIADO DISTRICT OFFICE
	9236002	KAJIADO NAMANGA DISTRICT
	9237007	KAJIADO MASHURU DISPENSARY
Kwale	9439001	KWALE AGRICULTURAL DEPARTMENT
	9439028	KWALE NDAVAYA
Mombasa	9439002	MOMBASA OLD OBSERVATORY
	9439021	MOMBASA PORT REITZ AIRPORT
	9439041	MOMBASA PLAYING FEILDS
Kilifi	9240029	FUNDISHA PRIMARY SCHOOL
	9339020	BARICHO WATER WORKS

Figure 8 shows the observed rainfall characteristics for eight counties in the Athi River basin. Data on precipitation in the eight Athi River Basins were extracted and analyzed from the data available during 1959-2016. The highest normal annual precipitation was observed in Kiambu, while the lowest was observed in Kajiado. The normal annual precipitation of Kwale, Mombasa County, which is located in the lower stream of the Athi River was also observed largely.

Figure 8: Normal Annual Precipitation in Eight Counties of the Athi River Basin

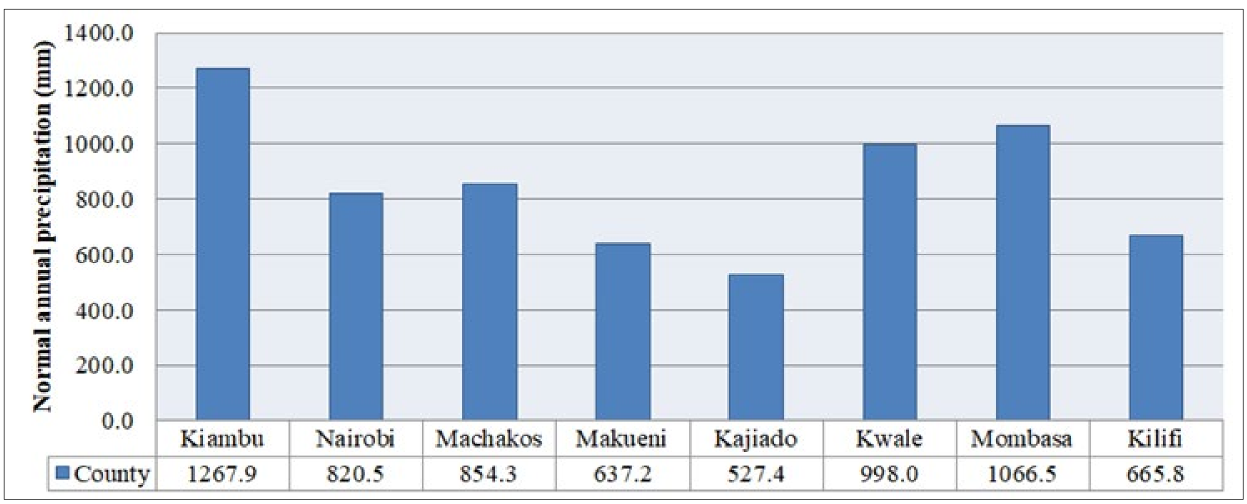


Figure 9 shows the monthly precipitation characteristics of the Athi River basin. In most counties, precipitation tends to be concentrated in April-May and November-December. June-September was analyzed to be the dry season in most counties, except for Kiambu, Kwale, and Mombasa.

Figure 9: Average monthly precipitation of the eight counties in the Athi River Basin

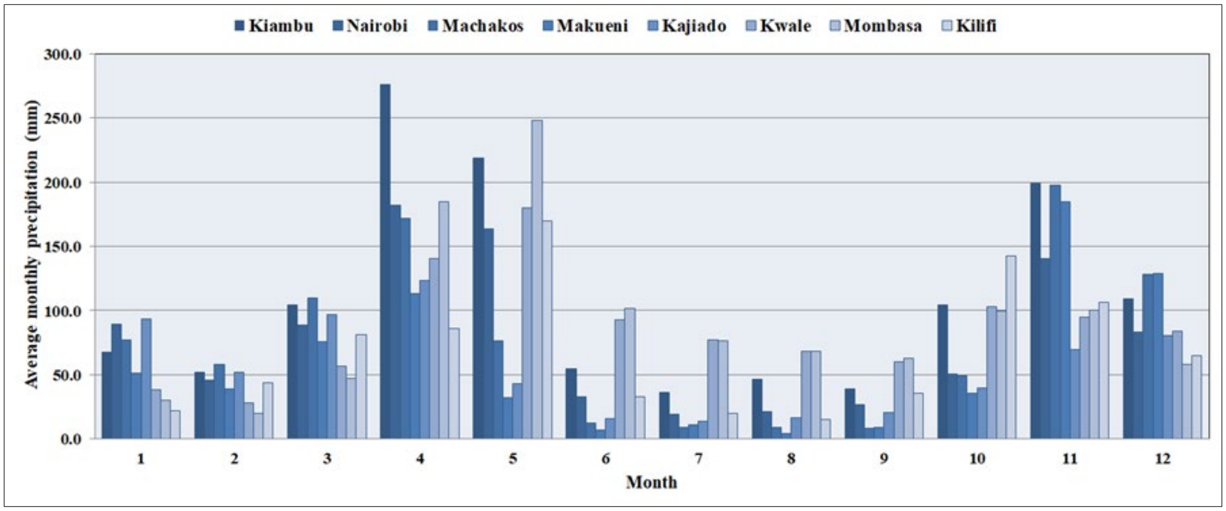
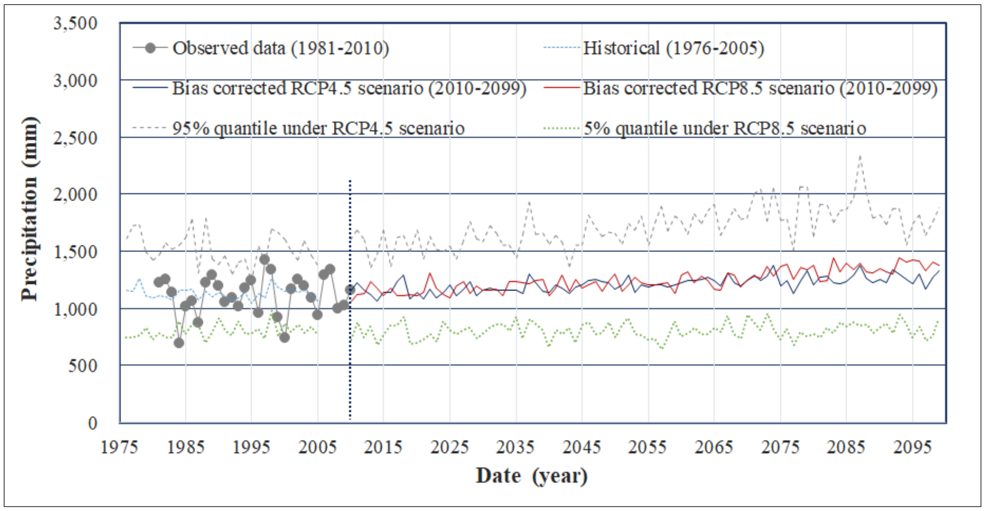


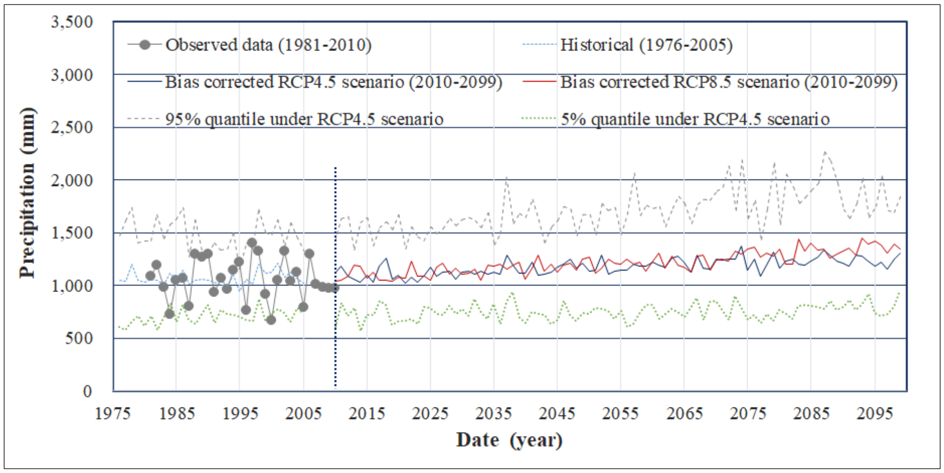
Figure 10 shows the future precipitation of the four counties in the Athi River basin. The overall range is shown by displaying 95% percentile and 5% percentile. Fluctuations in future precipitation are considerably large. Precipitation is the highest in Nyandarua and Kiambu. The analysis of 26 GCM results shows an overall increasing trend.

Figure 10: Future Annual Precipitation in Four Counties

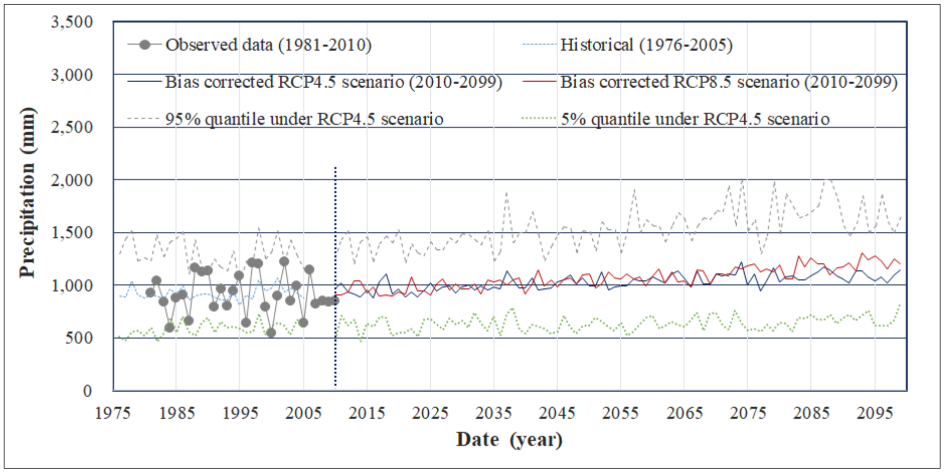
(a) Nyandarua County



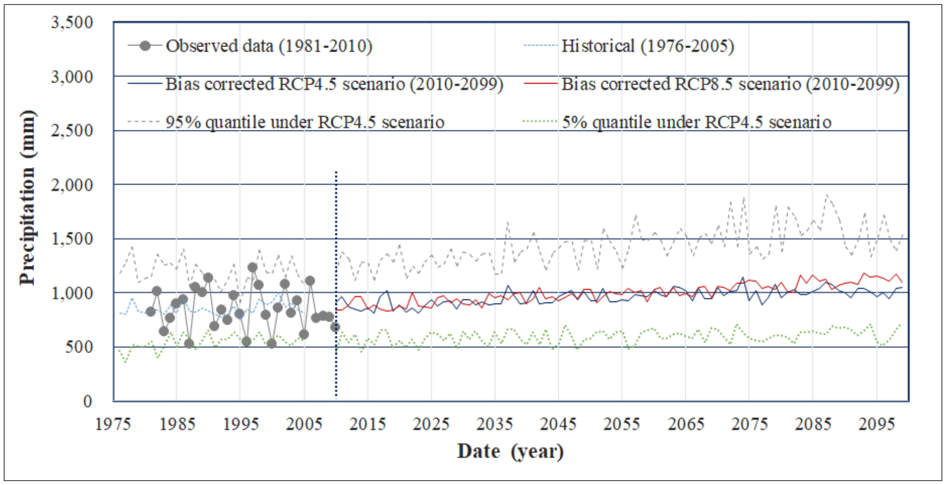
(b) Kiambu County



(c) Nairobi County



(d) Machakos County



2.3 Vulnerability and Risk Mapping in the Upper Athi Catchment Area

2.3.1 Conceptual Framework for Risk Mapping

2.3.1.1 Definition of Disasters Risk

The definition of risk varies according to its application in research. The basis of understanding the term "risk" lies in a commonsense interpretation of the concept, in that risk associated with a particular hazard lies in the consequences of the hazard and increases with both the probability and severity of the hazard. The definition of risk and its vulnerability is based on the "district disaster system theory," which takes into account hazard, exposure, and vulnerability. Hence, risk is expressed by the following equation (Parry et al., 2007[32]):

$$\text{Risk} = \text{Hazard} + \text{Exposure} + \text{Vulnerability} \quad (3)$$

where hazard is the premise, vulnerability is the base, and risk is the consequence. Crichton (1999) [33] has been defined risk as the probability of a loss, and this depends on three elements: hazard, vulnerability, and exposure. If any of these elements increases or decreases, risk will increase or decrease accordingly.

In view of increasing natural disasters, relevant organizations and experts around the world have conducted detailed studies of disaster risks. The United Nations Development Programme (UNDP) has established the Disaster Risk Index (DRI), which is a country-level disaster risk assessment index with a global scale that emphasizes the relationship between national development and disaster risks (UNDP 2004[34]). Vulnerability can be defined as physical, social, economic, and environmental factors or processes, which have significant impacts on communities (UNISDR, 2012[35]).

Flood and drought disasters risk are considered a function of hazard (trigger and conditions, etc.), exposure (locations, capability, and environments), and vulnerability (susceptibility to damage and loss). Thus, this feasibility study derived the Integrated Risk Index (IRI) model by incorporating the physical hazard and socio-economic vulnerability to conduct a climate risk assessment in Kenya in the form of the following functions:

$$\text{Integrated Risk Index (IRI)} = f\,(H_i, E_j, V_k) \quad (4)$$

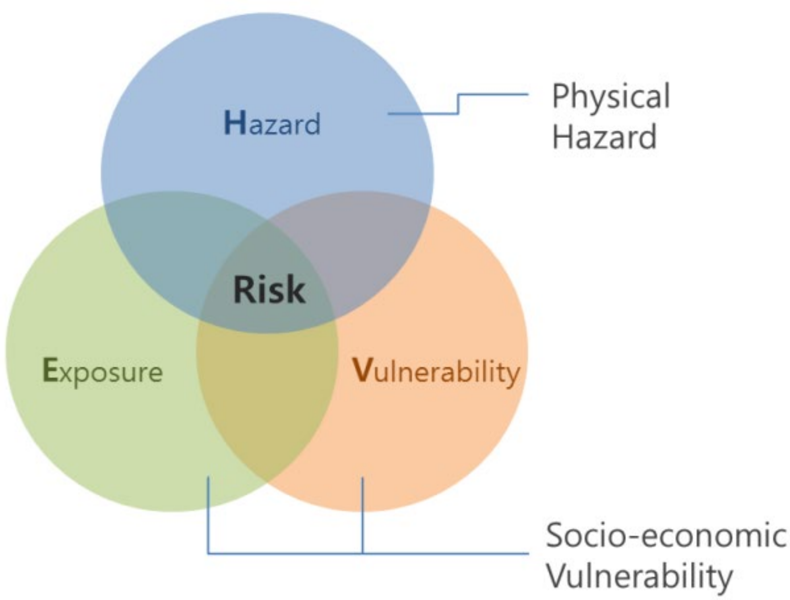
[32] Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCC. Vol. 4. Cambridge University Press, 2007.
[33] Crichton, D. (1999). The Risk Triangle. *Natural Disaster Management, Tudor Rose, London,* pp. 102–103.
[34] UNDP (United Nations Development Programme). 2004. Reducing Disaster Risk: A Challenge for Development. New York: UNDP.
[35] UNISDR (Glossary of the UN International Strategy for Disaster Reduction). (2012). URL: http://www.unisdr.org/eng/library/lib-terminology-eng%20home.htm.

$$IRI = \sum_{i=1}^{l}(h_i \times H_i) + \sum_{j=1}^{m}(e_j \times E_j) + \sum_{k=1}^{n}(v_k \times V_k) \tag{5}$$

here, H_i represents the hazardous hydrological index, while eE_j and V_k represent the socio-economic index incorporating the vulnerability criterion. h_i, e_j, and v_k indicate weighting factors for hazard, exposure, and vulnerability, respectively.

The IRI involves the normalization and application of weighting factors to variable indicators. IRI can be calculated using multi-criteria decision-making methods such as Delphi-Analytic Hierarchy Process (AHP) analysis. Figure 11 shows a conceptual diagram of flood and drought disasters risk assessment in Kenya, which incorporated physical hazards and socio-economic vulnerability under climate change.

Figure 11: Conceptual diagram of risk assessment in Kenya



2.3.1.2 Conceptual framework

Tables 6 and 7 show a 4-column indicator system, which comprises goals, components, determinants, and indicators. This system was established for the assessment of the Integrated Flood Risk Index (IFRI) and the Integrated Drought Risk Index (IDRI) in the Upper Athi Catchment Area in Kenya. The assessment indicators are selected systematically by following the approach outlined in previous studies (Rossi et al., 1994[36]; Fedeski and Gwilliam, 2007[37]; Ni et al. 2010[38]; Wang et al. 2011[39]). The goal is to estimate the above indices and to separate the three components of hazard, exposure, and vulnerability.

The hazard component was divided into three determinants: trigger, condition, and response. The exposure component was divided into two determinants: capability (for drought), location (for flood) and environment. Socio-economic vulnerability was divided into two determinants: susceptibility and resilience. There are a number of indicators of considerations for each component; major and available indicators in each component are selected and their weighting factors are applied using Delphi-AHP analysis and some statistical approach.

Table 6: Conceptual Framework for Flood Disaster Risk Assessment in Kenya

Goal	Components	Determinants	Indicators
Integrated Flood Risk Index (IFRI)	Hazard	Trigger	• Day maximum precipitation; (H_1) • Number of days over 50mm/day; (H_2) • Hourly rainfall over 30mm/d; (H_3) • Rainy season precipitation (March to April, October to November); (H_4) • Annual maximum runoff; (H_5) • Annual maximum flood level; (H_6)
		Condition	• Slope of watershed; (H_7) • Cove Number (CN); (H_8) • Land cover condition; (H_9)
		Response	• Historical flood events; (H_{10}) • Historical flood damage amount; (H_{11})
	Exposure	Capability	• Lowland area; (E_1) • Number of low-lying households; (E_2) • Impermeable area ratio; (E_3) • Flood mitigation and early warning system; (E_4) • Flood Education system; (E_5)
		Environment	• Road length and road area; (E_6)

36 Rossi, G., N. Harmancioglu, and V. Yevjevich. (1994). Coping with Floods. *Kluwer Academic Publishers*, Dordrecht/Boston/London.

37 Fedeski, M., and J. Gwilliam. (2007). Urban Sustainability in the Presence of Flood and Geological Hazards: The Development of a GIS-based Vulnerability and Risk Assessment Methodology. *Landscape and Urban Planning,* Vol. 83, No. 1, pp. 50–61.

38 Ni, J., L. Sun, T. Li, Z. Huang, and A. G. L. Borthwick. (2010). Assessment of Flooding Impacts in Terms of Sustainability in Mainland China. *Journal of Environmental Management,* Vol. 91, No. 10, pp. 1930–1942.

39 Wang, Y., Z. Li, Z. Tang, and G. Zeng. (2011). A GIS-Based Spatial Multi-Criteria Approach for Flood Risk Assessment in the Dongting Lake Region, Hunan, Central China. *Water Resources Management,* Vol. 25, No. 13, pp. 3465–3484.

			• Number of rainfall observation stations; (E_7) • Number of water level observation points; (E_8) • Flood control dam and reservoir capacity; (E_9)
	Vulnerability	Susceptibility	• Population Density (# of people/km^2); (V_1) • Number of people over 60 and under 12 in age; (V_2) • Size of female population; (V_3) • Number of livestock; (V_4) • Incidence of waterborne diseases (cholera, typhoid, parasite, diarrhea, etc.); (V_5)
		Resilience	• Ratio of river dike area; (V_6) • Number of hospitals and public health centers; (V_7) • Number of schools and public institutions; (V_8) • Number of public officials for drought management; (V_9) • Gross Regional Domestic Products (GRDP); (V_{10}) • Financial self-reliance; (V_{11})

Table 7: Conceptual Framework for Drought Disaster Risk Assessment in Kenya

Goal	Components	Determinants	Indicators
Integrated Drought Risk Index (IDRI)	Hazard	Trigger	• Average annual precipitation; (H_1) • Dry season (June to September, December to February) Precipitation; (H_2) • Number of dry days; (H_3) • Number of consecutive rainless days; (H_4) • Long-term outflow (7-Day Low Flow); (H_5) • Underground water flow (Base flow); (H_6)
		Condition	• Cove Number (CN); (H_7) • Land cover condition; (H_8) • Soil texture and structure; (H_9)
		Response	• Historical drought events; (H_{10}) • Historical drought damage amount; (H_{11})
	Exposure	Capability	• Reservoir water storage (per unit area); (E_1)

			• Number of Sand Dams; (E_2) • Number of Water Pans; (E_3) • Number of wells (public, village, and NGOs); (E_4) • Number of groundwater observation points; (E_5) • Drought mitigation and early warning system; (E_6)
		Environment	• Ratio of agricultural land area; (E_7) • Percentage of irrigation area; (E_8) • Pump operation rate (village intake pump) ; (E_9) • Water supply penetration rate; (E_{10}) • Agricultural water, domestic water, industrial water consumption; (E_{11}) • River water, groundwater usage; (E_{12})
	Vulnerability	Susceptibility	• Population Density (# of people/km^2); (V_1) • Number of people over 60 and under 12 in age; (V_2) • Size of female population; (V_3) • Number of livestock; (V_4) • Incidence of waterborne diseases (cholera, typhoid, parasite, diarrhea, etc.); (V_5) • Agriculture Productivity (corn, wheat, cassava, beans, etc.); (V_6)
		Resilience	• Number of hospitals and public health centers; (V_7) • Number of schools and public institutions; (V_8) • Number of public officials for drought management; (V_9) • Gross Regional Domestic Products (GRDP); (V_{10}) • Financial self-reliance; (V_{11})

2.3.2 Flood and Drought Risks in the Upper Athi River Catchment Area

2.3.2.1 Method of Flood and Drought Risk Assessment

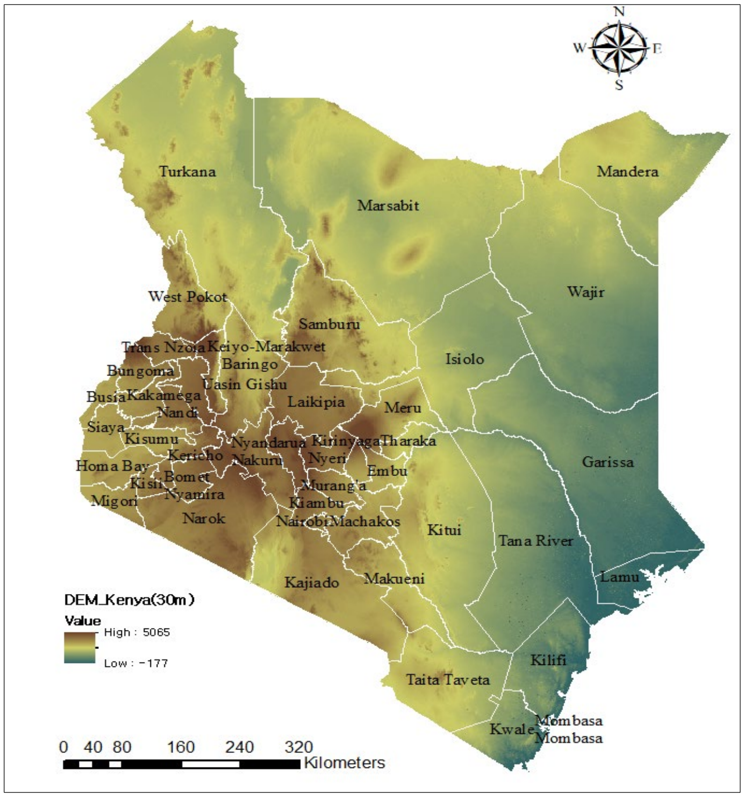
In this section, we analyze the precipitation data of the Athi River basin to assess the effects of climate change on the Athi River basin and conduct a flood and drought risk assessment on the four upstream counties. To analyze the impact of climate change in the Athi River basin, we need data on weather, climate, and topography, as well as social and economic data. Table 8 shows the data collected for climate change impact analysis. We used observed rainfall data provided by the WRA. As a result of performing quality control on observed data, AgMERRA reanalysis data was replaced with observed data because there were many missing values and outliers in the former. The Digital Evaluation Model (DEM) was constructed using 30 m grid size data provided by ASTER[40] Global. Figure 12 shows the DEM of Kenya.

Table 8: List of Data Collection

Data list	Source
Reanalysis data	AgMERRA (https://data.giss.nasa.gov/impacts/agmipcf)
DEM	ASTER Global DEM: 30 x 30m resolution(https://earthexplorer.usgs.gov)
Watershed	Global River Basin (Africa) (http://www.waterbase.org/download_data.html)
River	https://hydrosheds.cr.usgs.gov
Administration map	http://mapeastafrica.com/countries/east-africa-shapefiles/kenya-shapefiles
Land use	https://earthexplorer.usgs.gov http://glcf.umd.edu/data https://landcover.usgs.gov/glc

Figure 12: Digital Elevation Model (DEM) of Kenya

[40] Advanced Spaceborne Thermal Emission and Reflection Radiometer



We used GCM data provided by APEC Climate Center (APCC) to conduct risk analysis for future climate. A total of 26 GCMs were downscaled into Kenya to produce precipitation, maximum and minimum temperature data. The APCC Integrated Modeling Solution (AIMS) was used as the downscaling platform, while the Simple Quantile Mapping (SQM) method was applied in the downscaling process.

The assessment of flood and drought risk as a result of climate change was conducted by selecting and integrating indicators for hazards, exposure, and vulnerability. We constructed a function addressing issues of hazards, exposures, and vulnerability, and selected indices corresponding to each item to analyze the integrated risk. Figure 13 shows the flow of the risk analysis process. Table 9 summarizes the climate hazard indicators, namely flood and drought risk assessment. The index was developed by a joint CCl/CLIVAR/JCOMM Expert Team on Climate Change Detection and Indices (ETCCDI). In Table 9, green refers to the drought indicator while blue refers to the flood indicator. Table 10 shows the runoff hazard indicators for flood and drought. Table 11 shows the exposure and vulnerability indicators for flood and drought.

Figure 13: Procedure of Flood and Drought Risk Assessment

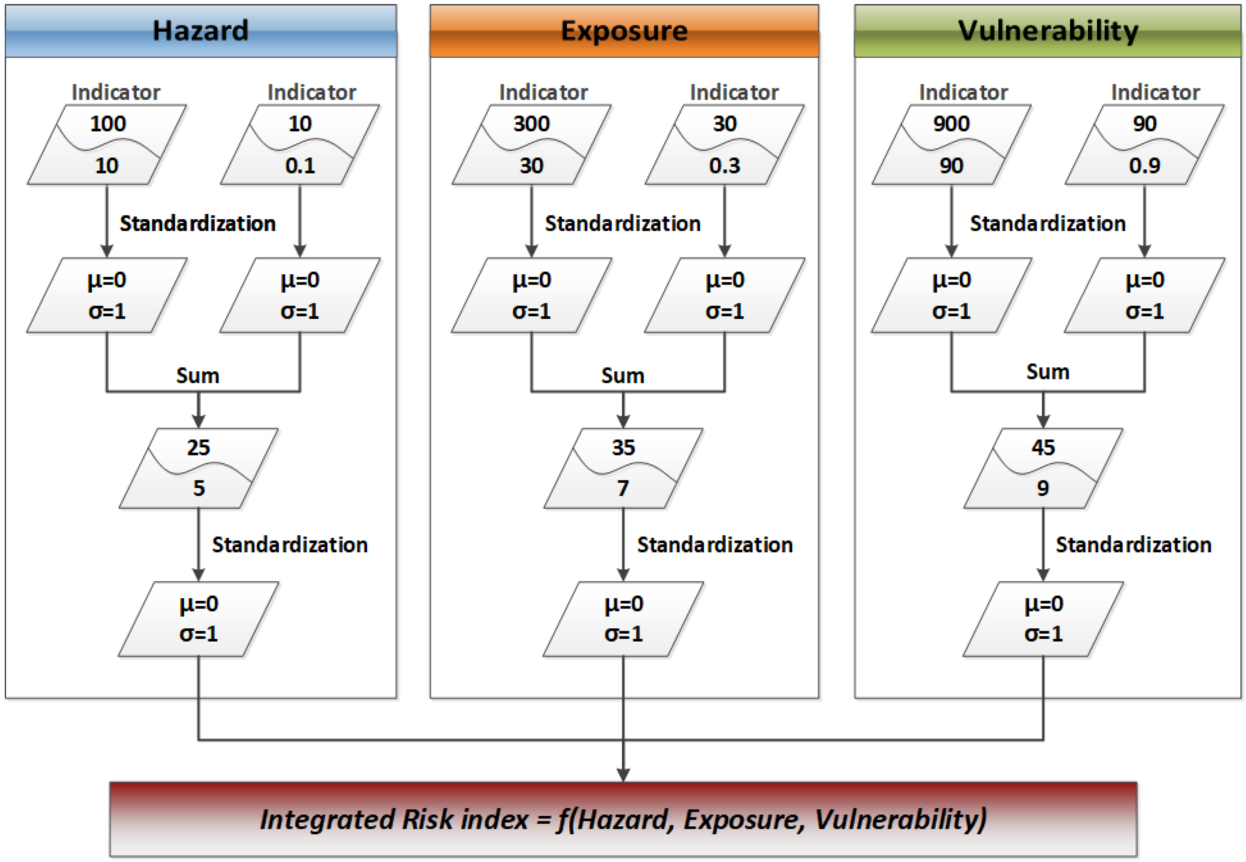

Hazard
Indicator
100
10
Indicator
10
0.1
Standardization
μ=0
σ=1
μ=0
σ=1
Sum
25
5
Standardization
μ=0
σ=1
Exposure
Indicator
300
30
Indicator
30
0.3
Standardization
μ=0
σ=1
μ=0
σ=1
Sum
35
7
Standardization
μ=0
σ=1
Vulnerability
Indicator
900
90
Indicator
90
0.9
Standardization
μ=0
σ=1
μ=0
σ=1
Sum
45
9
Standardization
μ=0
σ=1
Integrated Risk index = f(Hazard, Exposure, Vulnerability)

Table 9: Climate Hazard Indicators for Flood (blue) and Drought (orange) Risk

ID	Indicator	Variable	Description	Unit
1	SU	TMAX	Annual count of days when TMAX >25°C	Days
2	ID		Annual count of days when TMAX <0°C	Days
3	TXn		Annual minimum value of TMAX	°C
4	TXx		Annual maximum value of TMAX	°C
5	TX10p		Percentage of days when TMAX <10th percentile	%
6	TX90p		Percentage of days when TMAX >90th percentile	%
7	WSDI		Annual count of days with at least 6 consecutive days when TMAX >90th percentile	Days
8	FD	TMIN	Annual count of days when TMIN <0°C	Days
9	TR		Annual count of days when TMIN >20°C	Days
10	TNn		Annual minimum value of TMIN	°C
11	TNx		Annual maximum value of TMIN	°C
12	TN10p		Percentage of days when TMIN <10th percentile	%
13	TN90p		Percentage of days when TMIN >90th percentile	%
14	CSDI		Annual count of days with at least 6 consecutive days when TMIN <10th percentile	Days
15	DTR	TMAX &TMIN	Annual mean difference between daily maximum temperature TMAX and TMIN	°C
16	CDD	PRCP	Maximum number of consecutive days with daily PRCP <1mm	Days
17	CWD		Maximum number of consecutive days with daily PRCP ≥ 1mm	Days
18	R50mm		Annual count of days when PRCP≥ 50mm	Days
19	PRCPTOT		Annual total PRCP in wet days (daily PRCP ≥ 1mm)	mm
20	Rx1day		Annual maximum 1-day precipitation	mm
21	Rx5day		Annual maximum 5-day precipitation (PRCP)	mm
22	R95pTOT		Annual total PRCP when daily PRCP >95 percentile	mm
23	R99pTOT		Annual total PRCP when daily PRCP >99 percentile	mm
24	SDII		Simple precipitation intensity index. Annual precipitation divided by the number of wet days	mm/day
25	PRCPMAX		Annual maximum daily precipitation	mm

Table 10: Runoff Hazard Indicators for Flood (blue) and Drought (orange) Risk

ID	Indicator	Variable	Description	Unit
1	Qmax	Runoff	Annual maximum daily runoff	m^3/s
2	Q5		Annual upper 5% percentile daily runoff	
3	Q25		Annual lower 25% percentile of daily runoff	

Table 11: Exposure and Vulnerability Indicators for Flood Risk Assessment

Exposure	Basins, Forests, and Parks	Forests in county (km^2)
	Population Density	Population density (people/km^2)
	Total Child Mortality Rate	Total number of children under 5 years (in thousands)
	General Sex Ratio	Total female population (in thousands)
	The Population Over 64 Years	Number of people over 64 years (in thousands)
	Households Owning Livestock	Number of households owning livestock (in thousands)
Vulnerability	Accessibility and Transport	Average travel time to nearest city (min) *Average of all 1x1-km squares in county
	Access to Safe Water Sources	Percentage of households without access to safe water
	Access to Improved Sanitation	Percentage of Hhs without access to improved sanitation

2.3.2.1 Results of Drought and Flood Risk Assessment

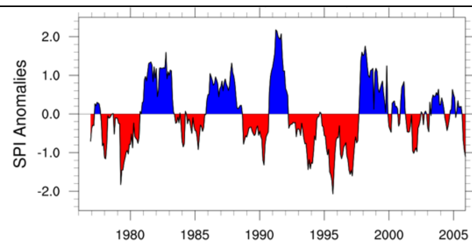
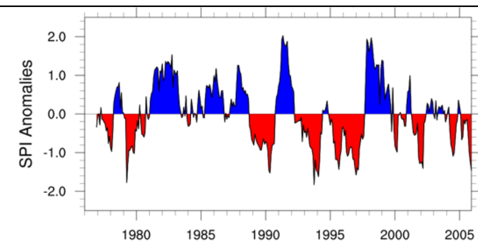
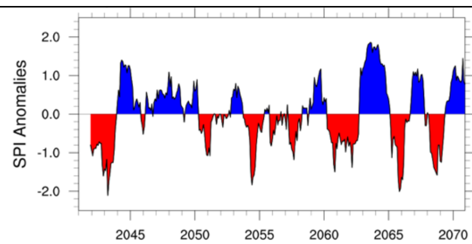
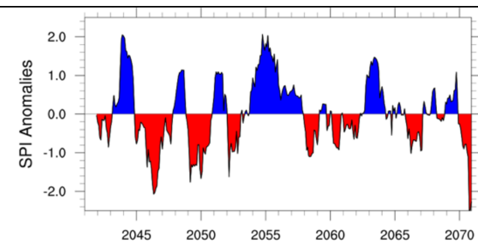
Drought

Increased temperatures and variability in rainfall are likely to exacerbate prevailing conditions and may have a significant impact on the availability of water in the future, and thereby, cause droughts. The prolonged drought of 2008-2011 highlighted some of the devastating and pervasive socio-economic consequences of climate change. Crop production losses from reduced yields of food and cash crops amounted to KSh69 billion and KSh52 billion, respectively. The livestock sector experienced the worst impact, since it lost approximately KSh699 billion, with KSh56 billion being incurred on veterinary care, water, feed, and a decline in production decline, and KSh643 billion as losses due to animal deaths.

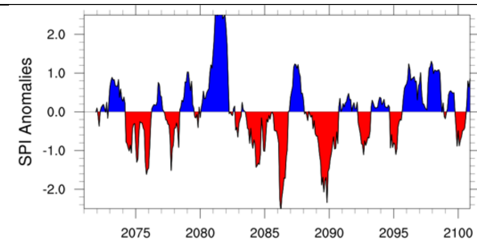
Drought risk assessment was conducted by estimating the IRI, comprising hazard, exposure, and vulnerability indices. Anthropogenic and environmental indicators were also used in this assessment.

The degree of dryness and wetness of rainfall changes are examined through analysis of 12-month Standardized Precipitation Index (World Meteorological Organization, WMO, 2012) for individual 30-year present climate (1976-2005) and three future climate periods (near, mid, and far-future climates) under RCP4.5 and RCP8.5 scenarios over the Athi River basin. The Standardized Precipitation Index (SPI) is constructed by fitting a probability distribution to a long record of precipitation and transforming it to a normal distribution with zero mean. A 12-month SPI reflects long-term precipitation patterns. Distinctive wet and dry signals in 12-month SPI usually are tied with streamflow's, reservoir levels, and even groundwater level at longer time scales (WMO 2012). According to WMO (2012), SPI values between -1.5 to -1.99 indicate "severe" dryness (wetness) while values less than -2.0 (greater than 2.0) indicate "extremely" dry (wet) climate. It is indicated further that a drought event occurs any time when the SPI is continuously negative and reaches an intensity of -1.0 or less.

Figure 3 shows SPI time series averaged over the Athi River Basin for current (1976-2005) climate and mid (2041-2070) and far (2071-2100) future climates under the RCP4.5 and RCP8.5 scenarios. Analysis of catchment-averaged SPIs provides informative summary of precipitation differences between epochs and scenarios, and helps in identifying the timing and duration of excessive dryness (reds) and wetness (blues) for individual scenarios and epochs. In addition to the response of climate to scenario forcing, temporal SPI variations for any epochs/periods depict basin-wide interannual variability of rainfall. Overall, longer and/or more frequent drier events are projected in the far-future climate under the RCP 8.5 scenario.

Period	RCP 4.5	RCP 8.5
Present climate (1976-2005)		
Mid-future (2041-2070)		

<table>
<tr>
<td>Far-future

](2071-2100)</td>
<td>
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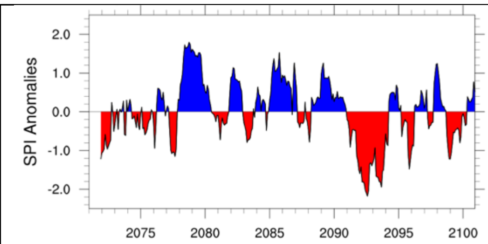
<td>
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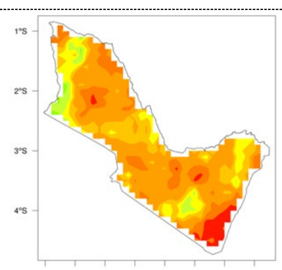
</table>

Figure 3: *Twelve-month Standardized Precipitation Index (SPI) over the Athi River Basin for present (1976-2005; top), mid (2041-2070; middle) and far (2071-2100; bottom) future climate periods under RCP4.5 (left) and RCP8.5 (right) scenarios.*

Area-average SPI may make comparison between events difficult because of the cancelling out of opposite signals across the Athi River Basin. The spatial variation and intensity of events can be readily identified by comparing the number of years exceeding a given SPI threshold at each grid point. Differences in frequency of occurrences between projected and present climates (future minus present) are used to assess future changes in *severe* and *extreme* droughts.

Figure 4 shows projected changes of *severe* droughts (SPI between -1.5 to -1.99) for near, mid, and far-future periods relative to the present climate (1976-2005) under the RCP4.5 and RCP8.5 scenarios over the Athi River Basin. For the present baseline climate, the percentage of *severe* droughts is higher for 4-model ensemble mean (RCP8.5) compared to the 3-model average for RCP4.5 in the Upper Athi river basin (bottom-right), while more frequent *severe* droughts are projected in the coastal areas under the RCP4.5 scenario. Although spatially mixed signals are indicated, *severely* dry climates are projected to intensify in the mid- to far-future periods under both scenarios.

<table>
<tr><td colspan="4">Projected changes of SEVERE droughts relative to 1976-2005</td></tr>
<tr><td></td><td>RCP 4.5</td><td>RCP 8.5</td><td></td></tr>
<tr>
<td>Frequency (%) of extreme dryness/droughts for the present climate

(1976-2005)</td>
<td>
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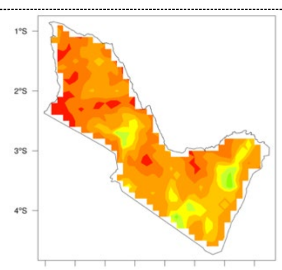
<td>
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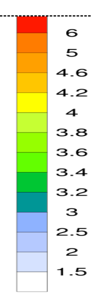
<td>
</td>
</tr>
<tr><td>Period</td><td colspan="3">Change from present climate</td></tr>
</table>

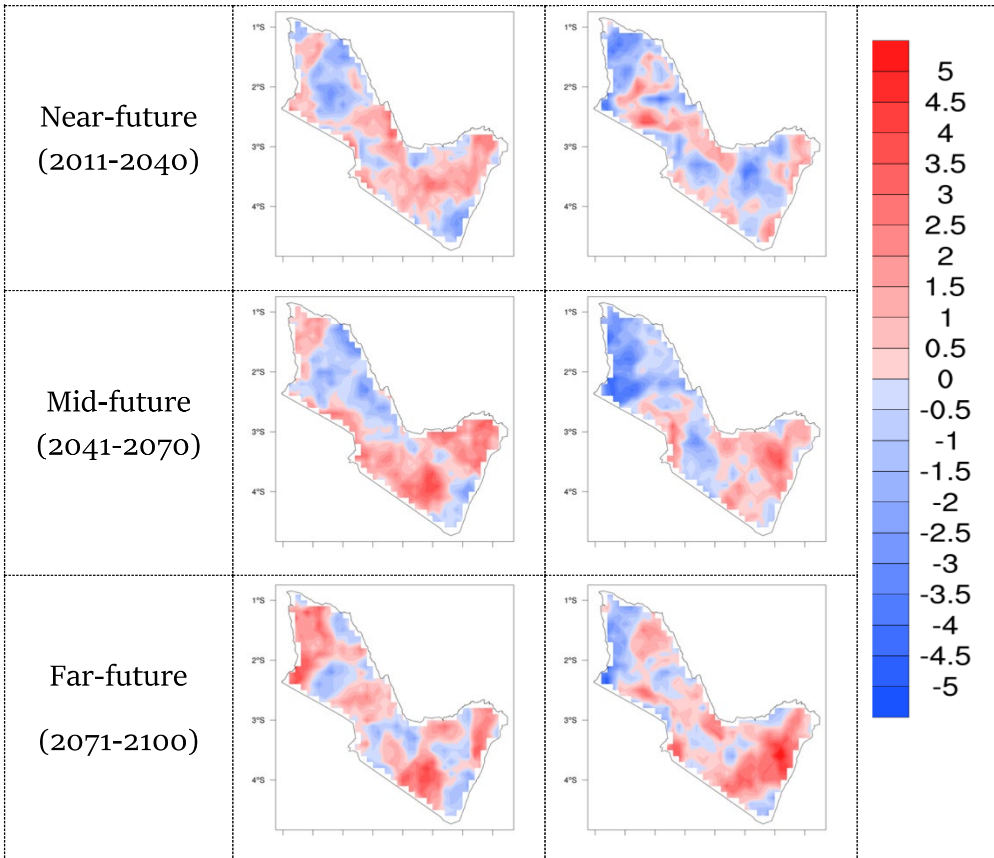


Figure 4: Frequency of ***severe*** droughts for present climate (1975-2005; top) and projected changes in ***severe*** droughts for near (2011-2040; second row), mid (1941-2070; third row) and far (2070-2100; bottom row) future periods relative to the current climate under RCP 4.5 (left) and RCP 8.5 (right) scenarios.

The frequency of ***extreme*** droughts (SPI less than -2.0) for the present-day climate and projected changes for near, mid, and far future climates under the RCP4.5 and RCP8.5 scenarios over the Athi River Basin are shown in **Figure** 5. Although the frequencies of ***extreme*** drought occurrences for the baseline climate are much lower than the corresponding values for ***severe*** drought events because of the rarity of ***extreme*** events, projected changes in ***extreme*** droughts have spatially more consistent and widespread signals under both RCP 4.5 and RCP 8.5 scenarios. Accordingly, ***extreme*** droughts are projected to increase for the three future periods under both scenarios across much of the Upper Athi River Basin. Compared to ***severe*** droughts, the frequency of more ***intense*** droughts is projected to be substantially higher for the ***extreme*** drought indicator in the Upper Athi River Basin. On the other hand, the extent and frequency of severe droughts are higher than that for extreme category in the coastal regions for mid- to far future projected climates under both scenarios.

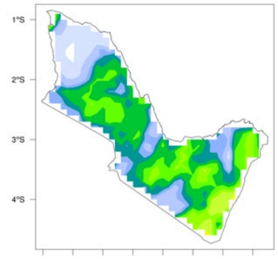
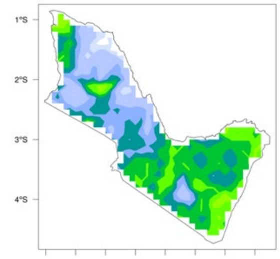
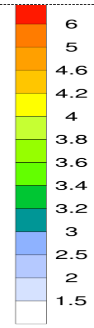
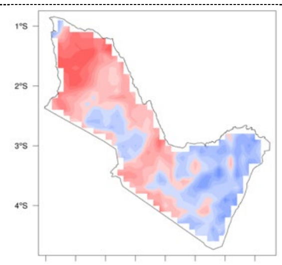
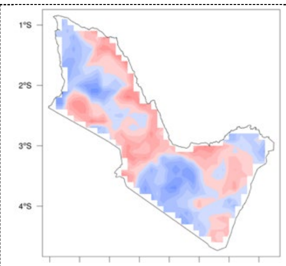
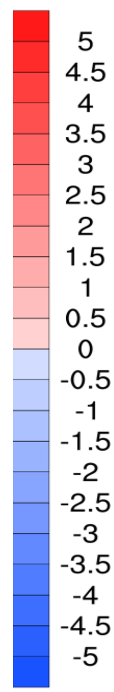
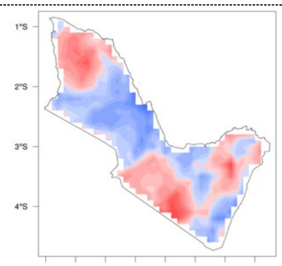
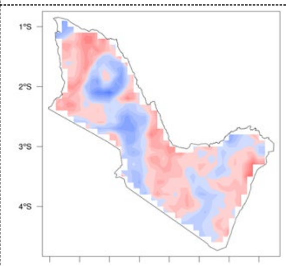
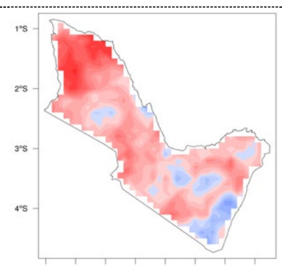
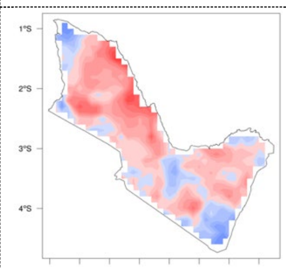
Projected changes of EXTREME droughts relative to 1976-2005			
	RCP 4.5	**RCP 8.5**	
Frequency (%) of extreme dryness/droughts for the present climate (1976-2005)			
Period	**Change from present climate**		
Near-future (2011-2040)			
Mid-future (2041-2070)			
Far-future (2071-2100)			

Figure 5: Frequency of ***extreme*** droughts for present climate (1975-2005; top) and projected changes in ***extreme*** droughts for near (2011-2040; second row), mid (1941-2070; third row)

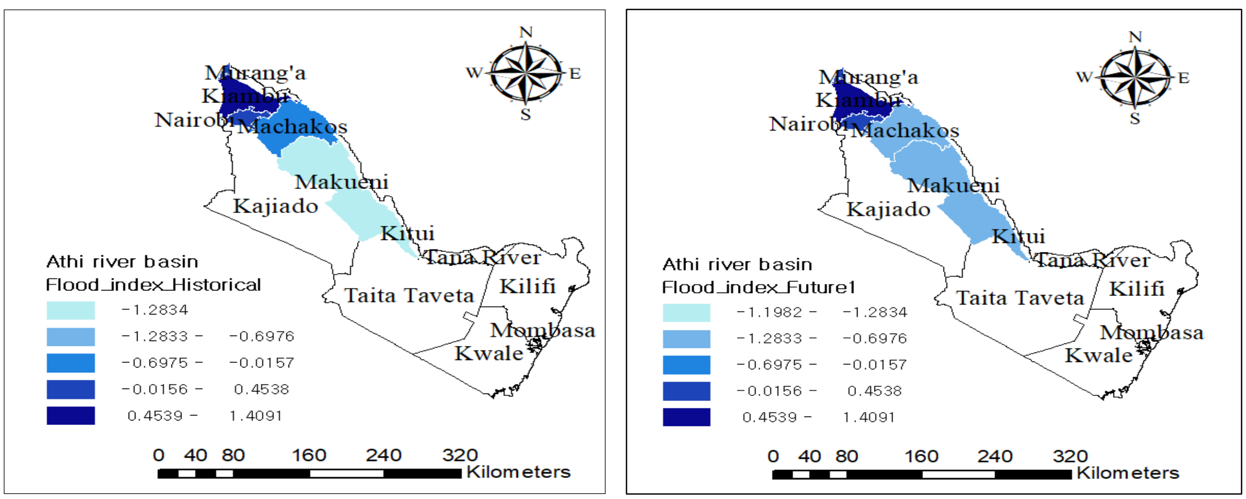
and far (2070-2100; bottom row) future periods relative to the current climate baseline under RCP 4.5 (left) and RCP 8.5 (right) scenarios.

Floods

Kenya has experienced severe flooding as a result of irregular seasonal rainfall, which has been inconsistent since 1960. Major flooding took place in 1997-98, as a result of the El Niño effect. These floods were estimated to have caused damage to the equivalent of at least 11 percent of the GDP, including damage to transport infrastructure worth KSh62 billion (USD 777 million) and to water supply infrastructure worth KSh3.6 billion (USD 45 million). While floods are generally associated with higher damages on public infrastructure assets, the burden of droughts falls more heavily on people, communities and the private sector.

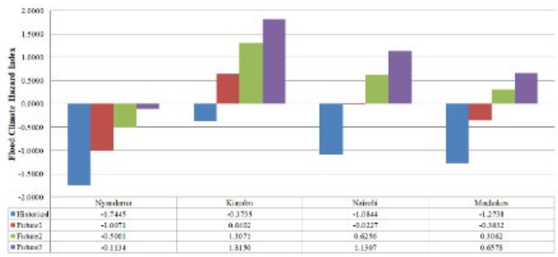
Bearing in mind Kenya's vulnerability to floods, a flood risk assessment was conducted on the lines of the drought risk assessment. It appears that the flood risk is likely to rise in the future, especially in Kiambu and Machakos.

Figure 14: Historical flood risk index (left: 1976 – 2005) and estimated flood risk index (right: 2011-2040)

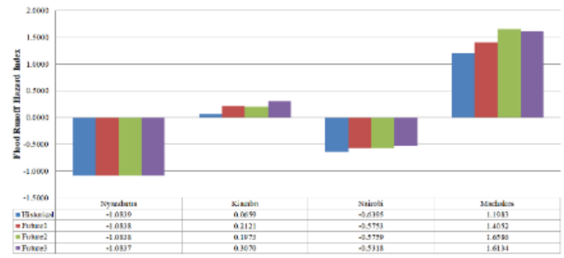


Figures 16 and 17 show the climate hazard, runoff hazard, exposure, and vulnerability indices for flood and drought risk assessment in Nairobi, Kiambu, Machakos, and Nyandarua. Except for the runoff hazard index, all other indices show a tendency to increase in the future.

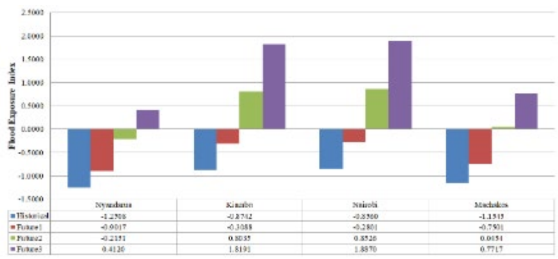
Figure 15: Flood climate Hazard, Runoff Hazard, Exposure, and Vulnerability Indices Of Four Counties Under the RCP4.5 Scenario



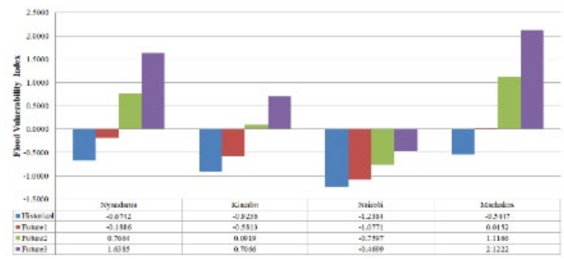
(a) Climate hazard index



(b) Runoff hazard index

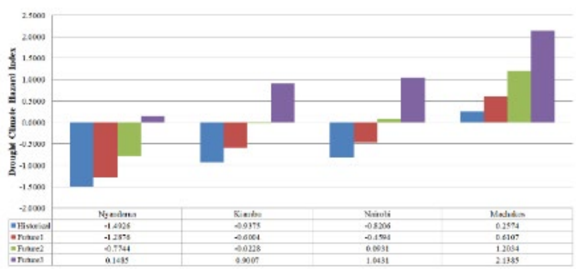


(c) Exposure index

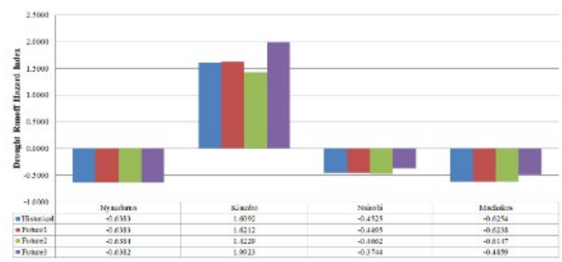


(d) Vulnerability index

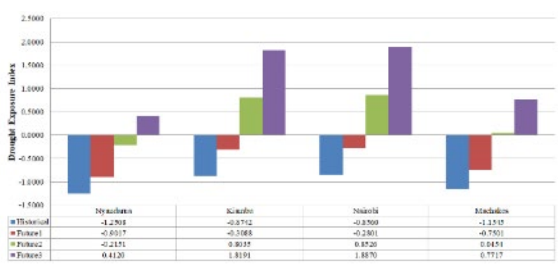
Figure 16: Drought Climate Hazard, Runoff Hazard, Exposure, and Vulnerability Indices of Four Counties Under the RCP4.5 Scenario



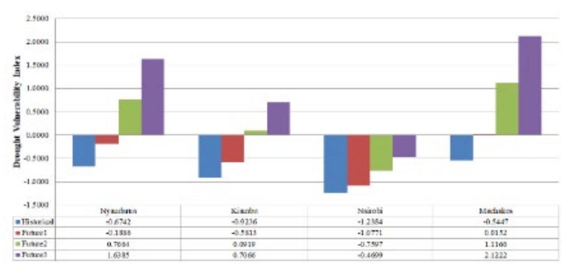
(a) Climate hazard index



(b) Runoff hazard index



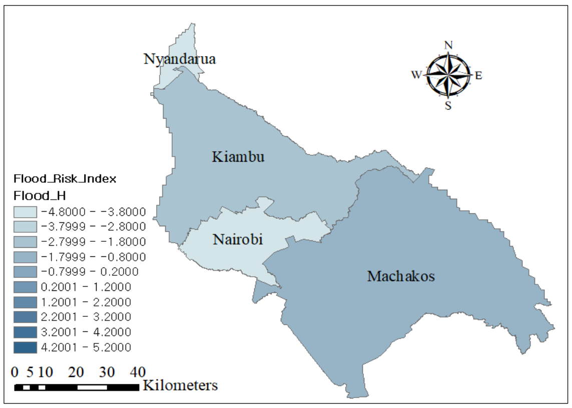
(c) Exposure index



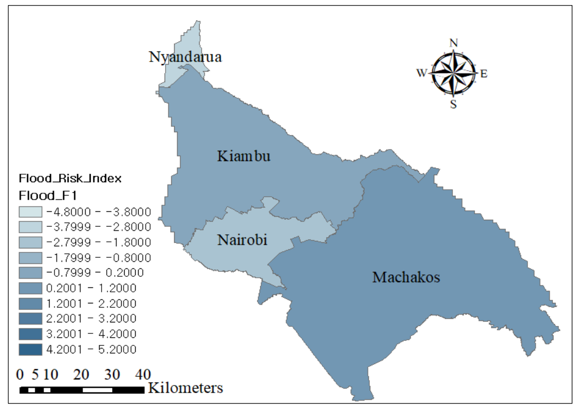
(d) Vulnerability index

Figures 18 to 20 depict the results of the flood and drought risk assessments conducted in the four counties during the four periods. In the historical period, Machakos was most vulnerable to floods. The flood risk levels of Kiambu and Machakos increase significantly in the future. This result is because Kiambu had the largest values in both the climate hazard and exposure indices and Machakos had the largest values in both the runoff hazard and vulnerability indices. In the historical period, Kiambu was most vulnerable to drought. Moreover, the drought risk levels of Kiambu and Machakos increase significantly in the future period.

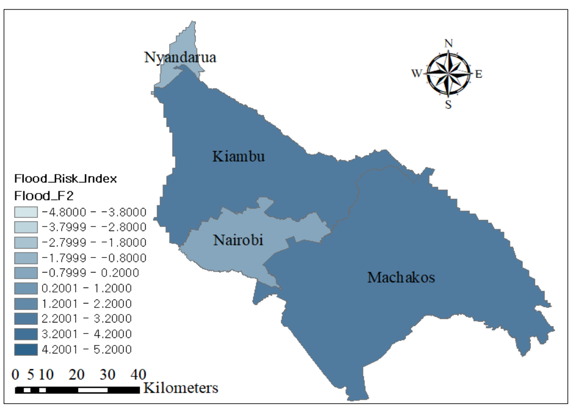
Figure 17: Flood risk index of four counties under the RCP4.5 scenario



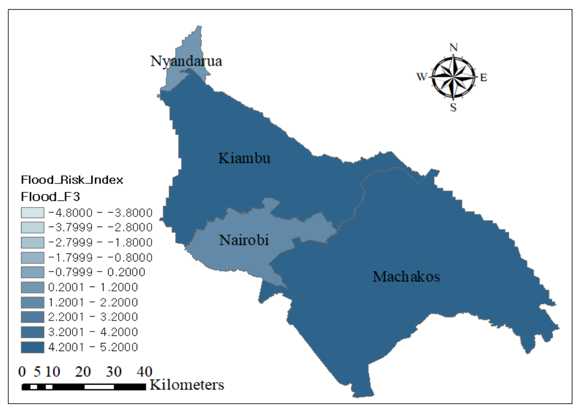
(a) Historical period (1975-2005)



(b) Future1 period (2011-2040)

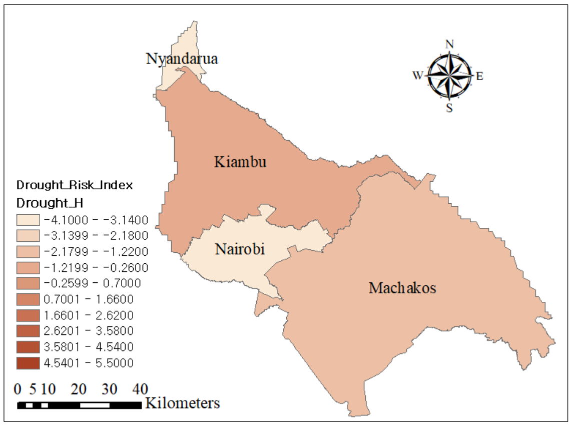


(c) Future2 period (2041-2070)

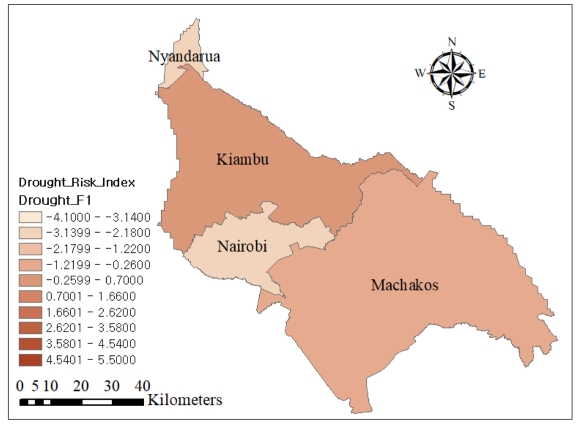


(d) Future3 period (2071-2099)

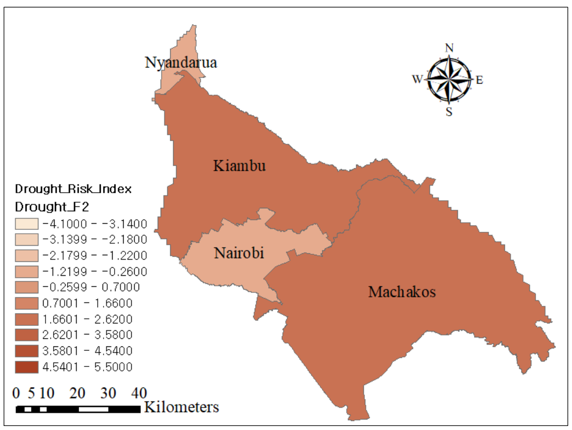
Figure 18: Drought risk index of four counties under the RCP4.5 scenario



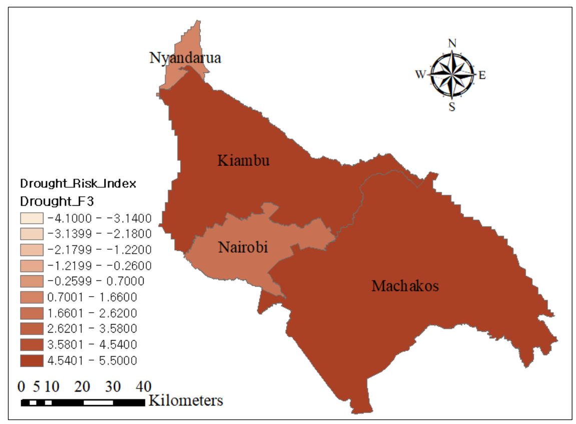
(a) Historical period (1975-2005)



(b) Future1 period (2011-2040)



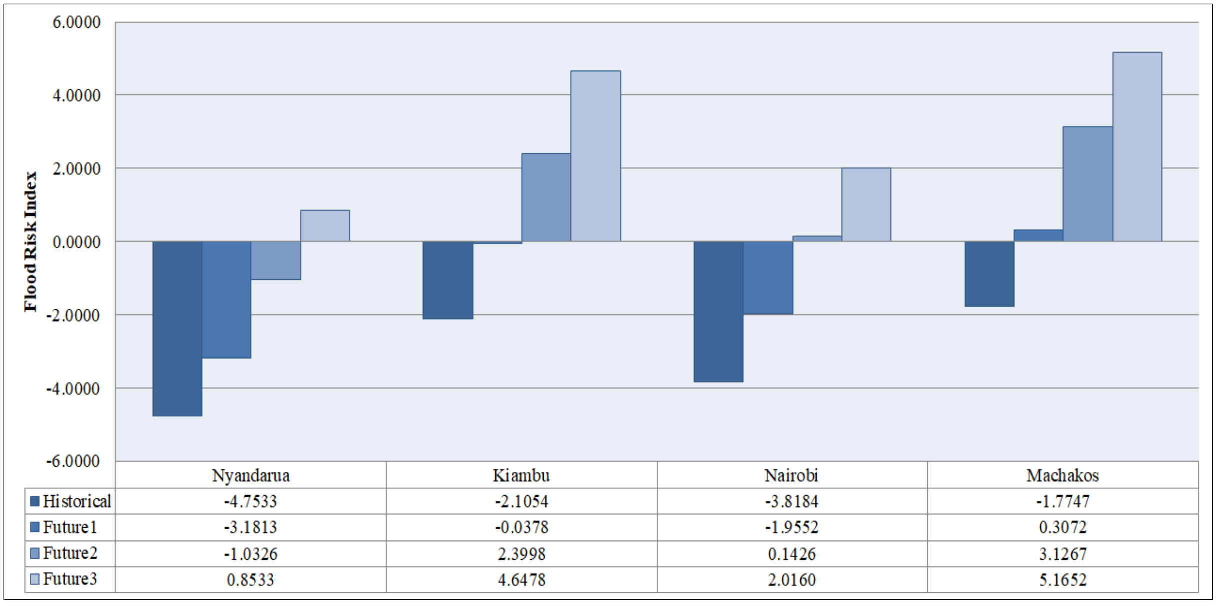
(c) Future2 period (2041-2070)



(d) Future3 period (2071-2099)

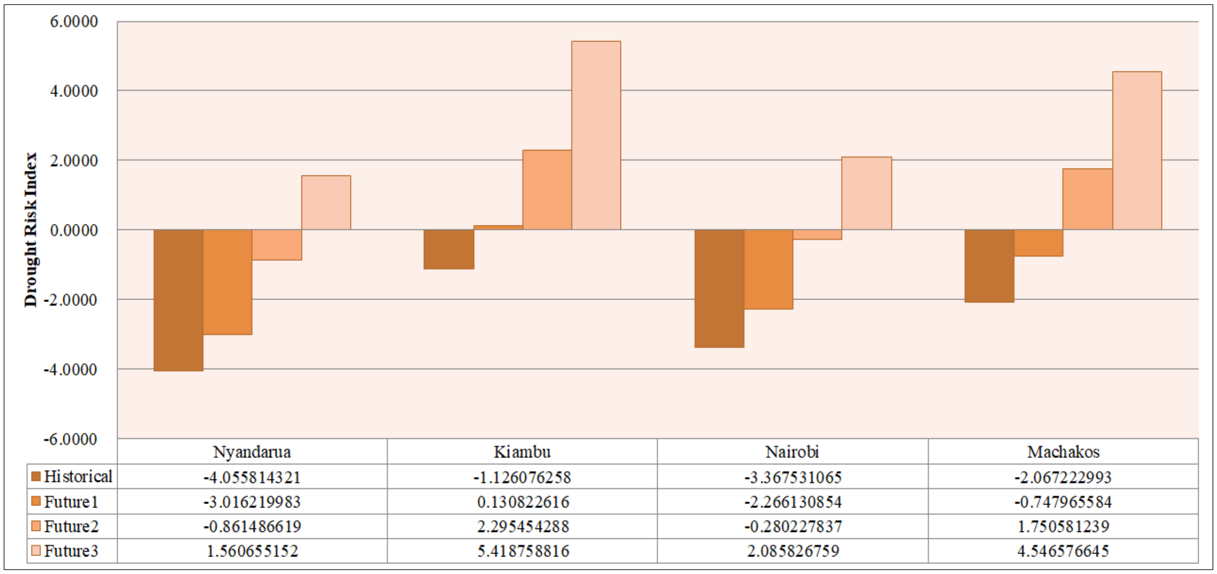
Figure 19: Flood and drought risk index of four counties under RCP4.5 scenario

(a) Flood risk index



	Nyandarua	Kiambu	Nairobi	Machakos
Historical	-4.7533	-2.1054	-3.8184	-1.7747
Future1	-3.1813	-0.0378	-1.9552	0.3072
Future2	-1.0326	2.3998	0.1426	3.1267
Future3	0.8533	4.6478	2.0160	5.1652

(b) Drought risk index



	Nyandarua	Kiambu	Nairobi	Machakos
Historical	-4.055814321	-1.126076258	-3.367531065	-2.067222993
Future1	-3.016219983	0.130822616	-2.266130854	-0.747965584
Future2	-0.861486619	2.295454288	-0.280227837	1.750581239
Future3	1.560655152	5.418758816	2.085826759	4.546576645

2.4 Prioritization of and Suggestions for Potential Project Sites Based on Risk Mapping

While the impacts of climate change are global, it is predicted that Kenya will suffer more as a result of poverty and the lack of capacity to respond to climate change. Scientists often warn that climate change will exacerbate existing threats to food, health, and economic security in African countries. Among the African countries, Kenya is considered among the most vulnerable to floods and droughts due to rising temperatures and variability of precipitation as a result of climate change. The proposed project is to be located in Southern Kenya and will cover the Athi River Catchment Area which is spread across 68,900 km^2 and has a population of approximately 9.79 million[41]. Along the Athi River Catchment Area, there are 12 counties, namely Nairobi, Makueni, Taita Taveta, Kwale, Mombasa, Kiambu, Machakos, Kajiado, Kilifi, Kitui, and Nyandarua.

Historically, drought risk was the highest in Kiambu, Machakos, Nairobi, and Nyandarua, in that order. It showed the same priority in the future. Historically, drought risk was the highest in Kiambu, Machakos, Nairobi, and Nyandarua, in that order. The same trend appeared likely to continue in the future.

In order to ensure the effectiveness and efficiency of the proposed project within the proposed budget, this project will focus on the four counties. Those counties have been selected as the core project sites for enhancement of the Athi River Catchment Area through the consultative meeting with relevant government entities for this project, NEMA, WRA, MWS and county governments.

(1) **Nairobi**: Poor drainage infrastructure has resulted in frequent floods in Nairobi. The upstream region of the Athi River suffers great damage when compared to the downstream region. Irregularity of water supply due to climate change has threatened the sustainability of Nairobi and has also caused waterborne diseases. Given the high population density in this city (> 3 millions), appropriate measures need to be implemented urgently.

(2) **Kiambu**: The Upper Athi River passes through Kiambu. The geographical location of this region largely affects the quantity and quality of the water resources that feed into the Upper Athi River. Any failure in improving the quality and quantity of water in this region can result in the deterioration of the quality and quantity of water in the Lower Athi River. Although this town is surrounded by hilly farmlands, rapid urbanization within limited land space is expected to disturb the water system. There is a need for risk management in order to Kiambu's vulnerability to droughts and floods.

(3) **Machakos**: Machakos is surrounded by hilly terrains and farmlands. The location of this city is substantially important in monitoring the quality and quantity of water in the Athi River. As risks of drought and flood are expected to increase in this area in the future, establishing a system to monitor the quality and quantity of the water is necessary. Further, it is also necessary to install water tanks that can store water for use during dry periods.

[41] http://www.wrma.or.ke/index.php/wrma-regional-offices/athi/catchment-status.html

(4) **Nyandarua**: The watershed of Nyandarua is highly crucial because it is a major water body in Kenya. The flows of the Athi and Tana Rivers are affected by this area. Unfortunately, the Abadara forest, which used to provide water resources of a high quality, has been destroyed by illegal harvesting and deforestation. Consequently, the quality and quantity of water from this forest has also deteriorated. It is necessary to spread awareness on the negative effects of such activities among villagers to mitigate the damage caused.

CHAPTER 3 : Policy and Institutional Frameworks related to climate-resilient development

3.1 National Development Policy and Plan

3.1.1 National Water Policy

The National Water Policy is mainly guided by the Sessional Paper No. 1 of 1999 named the National Policy on Water Resources Management and Development (NPWRMD) and The Constitution of Kenya 2010. Before the year 2000, the national water sector was characterized by the over centralized planning and state control of water resources and water services management. The outcome was inefficient management, low investment and poor service delivery. The Sessional Paper No. 1 of 1999 separated policy and regulation, water resources management and water services management. The Sessional Paper No. 1 of 1999 was therefore operationalized by the Water Act 2002 to create appropriate institutional framework. The Water Act 2002 set out main principles and mandates of institutions for the regulation and management of water resources and water services in the country. On water resources, the Water Resources Management Rules 2007 provides detailed implementing rules of the Water Act with respect to Water Resources.

It is noted that the National Water Policy 1999 is currently in the process of revision to align with the new Constitution of Kenya.

3.1.2 The Constitution of Kenya 2010

In 2010, the country enacted a new Constitution-the Constitution of Kenya 2010 (CoK2010) which created two levels of government. The high level National government and local level 47 No semi-autonomous devolved units -counties. Some functions of national government have been devolved to the county government. The main thrust of the CoK 2010 on Water resources emphasizes on the sovereignty of the people, fundamental human rights, ownership and control of water resources as part of land vested on the national government, sustainable development and environmental conservation. The CoK 2010 entitles every person to have access to sufficient, affordable water and sanitation of acceptable quality for personal and domestic use. The CoK 2010 necessitated that Water Act 2002 be revised to accommodate the general devolution governance framework. The revision of Water Act 2002 culminated into Water Act 2016 to reflect devolution and streamline the functions of some key institutions created by the Water Act 2002.

3.1.3 The Water Act 2016

Water Act 2016 is a revision of previous Water Act 2002 to align the water sector with the CoK 2010 primary objective of devolution. It recognizes the shared responsibility between the national government and county government on water related functions. It also gives priority to use of abstracted water for domestic purposes over other socio-economic uses such as industrialization and irrigation. Based on the act, the institutional set up of the water sector is given in Figure 21.

Figure 20: Water Sector Institutional Structure

National Water Harvesting and Storage Authority

Water Sector Trust Fund

Water Tribunal

Kenya Water Institute

National Level	**MWS**		**Policy formulation**
	WRA	**WASREB**	**Regulation**
Regional Level	**BWRC**	**Water Works Development Agencies**	**Service Provision**
Local Level	**Water Resource Users Association (WRUA)**	**Water Service Providers**	
	Users	**Consumers**	**Consumption , Use**
	Water Resource Management	**Water and Sewerage Services**	

3.1.4 The National Water Master Plan 2030 (NWMP 2030)

The National Water Master Plan 2030 has been prepared between 2010 and 2014 to provide a road map for implementation of water policies to meet socio-economic demand of Vision 2030, tenets of the Constitution of Kenya 2010 and Water Act 2002. The NWMP 2030 was prepared by Water Resources Authority (WRA) formerly Water Resources Management Authority (WRMA) through the technical and financial support by Japan International Cooperation Agency (JICA), based on the Integrated Water Resource Management (IWRM). The Plan focuses on the basin- approach to water resource development and management, dividing the Country into 6 catchments: Lake Victoria North, Lake Victoria South, Rift Valley, Athi, Tana and Ewaso Ngiro Catchments.

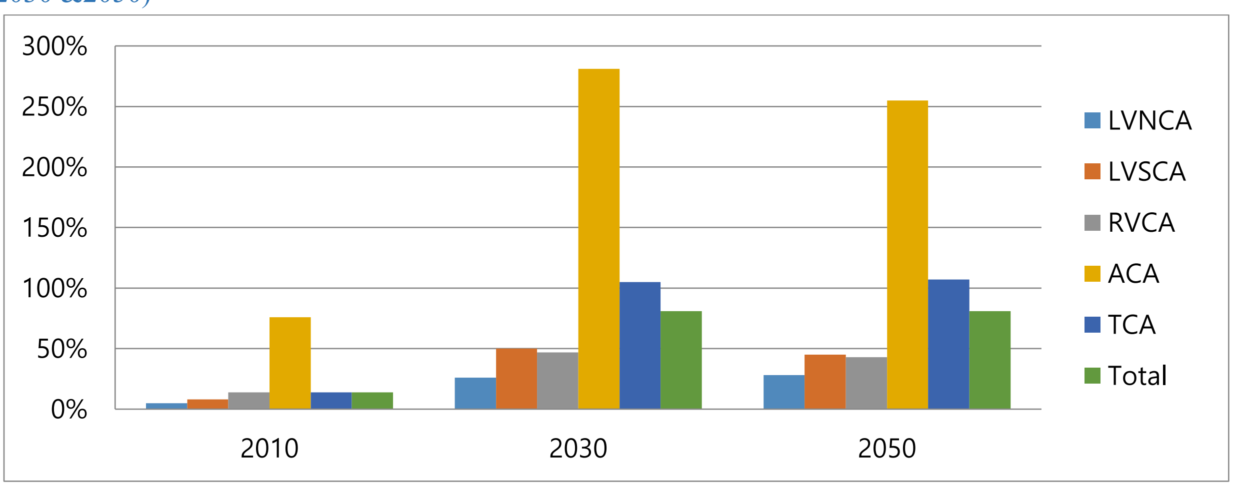
The catchments form the basis of WRA administrative structure for planning, regulation of development and management of water resources in the country. The NWMP 2030 plan comprises specific development plans for; water supply, sanitation, irrigation, hydropower and water resources. The management plans include; water resources, flood and, drought disasters and environmental. The Plan has outlined the requisite institutional strengthening measures to ensure its timely implementation and sustainability of the water resource development and management programs. The Plan has highlighted the Climate Change risks and proposed general measures for a countrywide adaptation.

The national ratio of water demand to available water resources in 2010 is 14%. If the Plan is implemented, then ratio will stabilize at 81% through 2030 up to 2050. Comparing the 6 catchments, Athi Catchment is the most water stressed. The socio-economic demand for water is high due to high rate of urbanization i.e. Nairobi and Mombasa cities located within the catchment, hence depending on inter-basin transfer from the neighboring Catchments. The percentage of water demand to the available water resources by catchment area (see Figure 22) depicts and predicts 76%, 280% and 255% water deficit in 2010, 2030 and 2050 for the Athi Catchment. Nationally, the per capita water availability for ACA is low at 464 m^3 per year compared to the global recommended amount of 1,000 m^3 per year.

3.1.5 National Disaster Management Policy (NDMP)

The National Disaster Management Policy, March 2009, was developed by the Ministry State for Special Programs now incorporated in the Ministry of Devolution and Planning. The policy remarks that Kenya's disaster profile is pre-dominantly nature-based; droughts, fire, floods, terrorism, technological accidents, diseases and epidemics that disrupt people's livelihoods, destroy the infrastructure, divert planned use of resources, interrupt economic activities and retard development. The objective of the policy is set to institutionalize mechanisms for addressing disasters. It was formulated due to common disaster events, the successive Reports of the Inter-governmental Panel Climate Change (IPCC), the Climate Change Conference held in Nairobi (Nairobi , Nov. 2006), and a comprehensive environmental reconnaissance survey emphasizing the central role of Climate Change in any sustainable planned and integrated National Strategy for Disaster Management[42].

Figure 21: Projected % Water demand against available Water Resources by Catchment Area (Yr 2010, 2030 &2050) [43]



[42] National Disaster Management Policy
[43] National Water Master Plan, Vision 2030

The policy outlines the following key principles for effective and efficient disaster management:

- The primacy of coordination, collaboration and communication
- Lesson learning and knowledge management
- Multidisciplinary and multi-sectoral approach
- Increasing partnerships and role of communities in Disaster prevention and management
- Factoring of climate into disaster risk reduction
- Research and dissemination of information
- Regional and International perspectives
- Strengthening of Capacities for Disaster Management

The Policy has established the following code of conduct;

Disaster response interventions based on facts and verifiable information:

- Humanitarian imperative
- Aid is given regardless of ethnicity, political or religious affiliation or geographical considerations
- Respect for culture and customs
- Disaster assistance to reduce future vulnerabilities to disaster as well as meeting basic needs
- Stakeholders to reinforce the capacity of local communities to manage the full Disaster Cycle

Involvement of beneficiaries in Disaster Management Programs:

- Mainstreaming Women and Children Issues
- Mainstreaming the Concerns of the Challenged and Elderly
- Environmental Concerns

The Institutional framework of the policy aims to establish National Disaster Risk Management Authority (NADMA) to coordinate various government and non-governmental entities involved in Disaster risk reduction and management.

Implementation of the NDMP:

The Disaster Risk Management Act, 2018 was enacted in March 2018 to operationalize the institutional framework for the NDMP. Consequently, NADMA has been established and commenced its operation.

3.1.6 WRUA Development Cycle (WDC)

WRUAs represent the interests of the water users in a sub-catchment and are important in promoting compliance to the water laws. The WDC framework defines the arrangements between WRA and the Water Sector Trust Fund (WSTF) regarding funding of water resource management activities through the WRUAs. It highlights the need for stakeholder participation and collaboration with WRUAs in water resource management (WDC, 2015). However, WDC has been lately revised to expand the opportunity for funding framework to accommodate other financiers, attract resources by leveraging on Public Private Partnership (PPP) and also include Climate Change adaptation frameworks.

3.2 Key Institutions in Water Sector

3.2.1 Ministry of Water and Sanitation (MWS)

The MWS is responsible for policy formulation, provision oversight in the water sector, coordination, monitoring, financial administration of the sector budget and general sector supervision.

3.2.2 Water Resources Management Institutions

3.2.2.1 Water Resources Authority (WRA)

Water Resources Authority (formerly Water Resources Management Authority (WRMA), is mandated newly under the Water Act 2016 to protect, conserve, control and regulate use of water resources through the establishment of a national water resource strategy composed specific basin wide strategies. It is also responsible for: formulation and enforcement of standards, procedures and regulation for the management and use of water resources; policy development; planning and issuing of water abstraction permits; and setting and collecting permits and water use fees.

3.2.2.2 Basin Water Resource Committee (BWRC)

Catchment Areas Advisory Committees (CAAC), which previously played a regulatory function at the regional level under Water Act 2016, have been replaced with BWRCs in the Water Act 2016. BWRCs will comprise members drawn from stakeholders within the basin and aimed to achieve wide stakeholder participation in the management of water resources at the basin level. The BWRCs will retain the same regional functions as the former CAACs, which is to: manage catchments, facilitate establishment of Water Resource User Associations and play an advisory role to the WRA. Each county government in the basin will have a representative in the BWRC whose water resources rest within the county government's geographical jurisdiction.

3.2.2.3 Water Resource User Associations (WRUAs)

Water Act 2016 provides for establishment of WRUAs similar to the Water Act 2002. WRUAs are community based associations for collective management of water resources and resolution of conflicts concerning the use of water resources. Under Water Act 2016, WRUAs have been strengthened; BWRC may contract WRUAs as agents to perform certain duties in water resource management.

3.2.2.4 National Water Harvesting and Storage Authority (NWHSA)

The NWHSA is responsible for development and management of national public water works for water resource management and flood control. The NWHSA is yet to be established.

3.2.3 Water Supply and Sewerage Services Institutions

3.2.3.1 Water Services Regulatory Board (WASREB)

The constitutionally guaranteed right to water and the need to protect consumers provides a strong basis for the national regulation and monitoring of water and sewerage services. This is critical to protect the interests and rights of consumers from exploitation and to set minimum national standards. As such, the functions of WASREB have been maintained in the 2016 act. WASREB holds the mandate to approve tariffs, monitor and enforce water services standards and issue licenses to water service providers.

3.2.3.2 Water Works Development Agencies (WWDAs)

The 2016 Water act defines national public water works as water works whose water resource is: cross county in nature, financed out of the national government share of national revenue and intended to serve a function of the national government. These may include assets such as water storage and water works for the bulk distribution of water services. Furthermore, it specifies that development and management of national public works will be undertaken by the WWDAs whilst county public works will be a responsibility of the respective county. The 2016 Water Act provides for handing over of national public works upon commissioning from WWDAs to the county government, joint committee or authority of the county governments if the water works' assets exclusively rest geographically within their jurisdiction.

The national government has the responsibility of supporting county governments to perform their respective duties. As such, upon commissioning of cross county assets, in a case where several county governments collectively want to transfer these assets from WWDA, the Act makes provision for establishment of an authority of county governments or a joint committee. Transfer of the ownership and management of these assets from the WWDA can then be done to the authority of the county governments or joint committee.

WWDAs are responsible for the: (i) development, maintenance and management of national public works; (ii) operation of the national public waterworks and provision of water services as a water service provider, until the responsibility for the operation and management of the waterworks is handed over to the county government, joint committee or CCA; (iii) provision of technical services and capacity building to county governments and water service providers within its region.

3.2.3.3 Water Services Providers (WSPs)

WSPs are private companies owned by Local Authorities designated under Water Act 2012 and Water 2016 to provide direct service delivery of water and sewerage services on behalf of the County government. WSPs are responsible for provision of water services within the area specified in their licenses and development of county assets. Currently, WSBs sign service level agreements with WSPs and the regulator issues licenses to WSB. Under the new Water Act 2016, WSPs are licensed and licensed by WASREB.

3.3 Implementation Institutional Framework

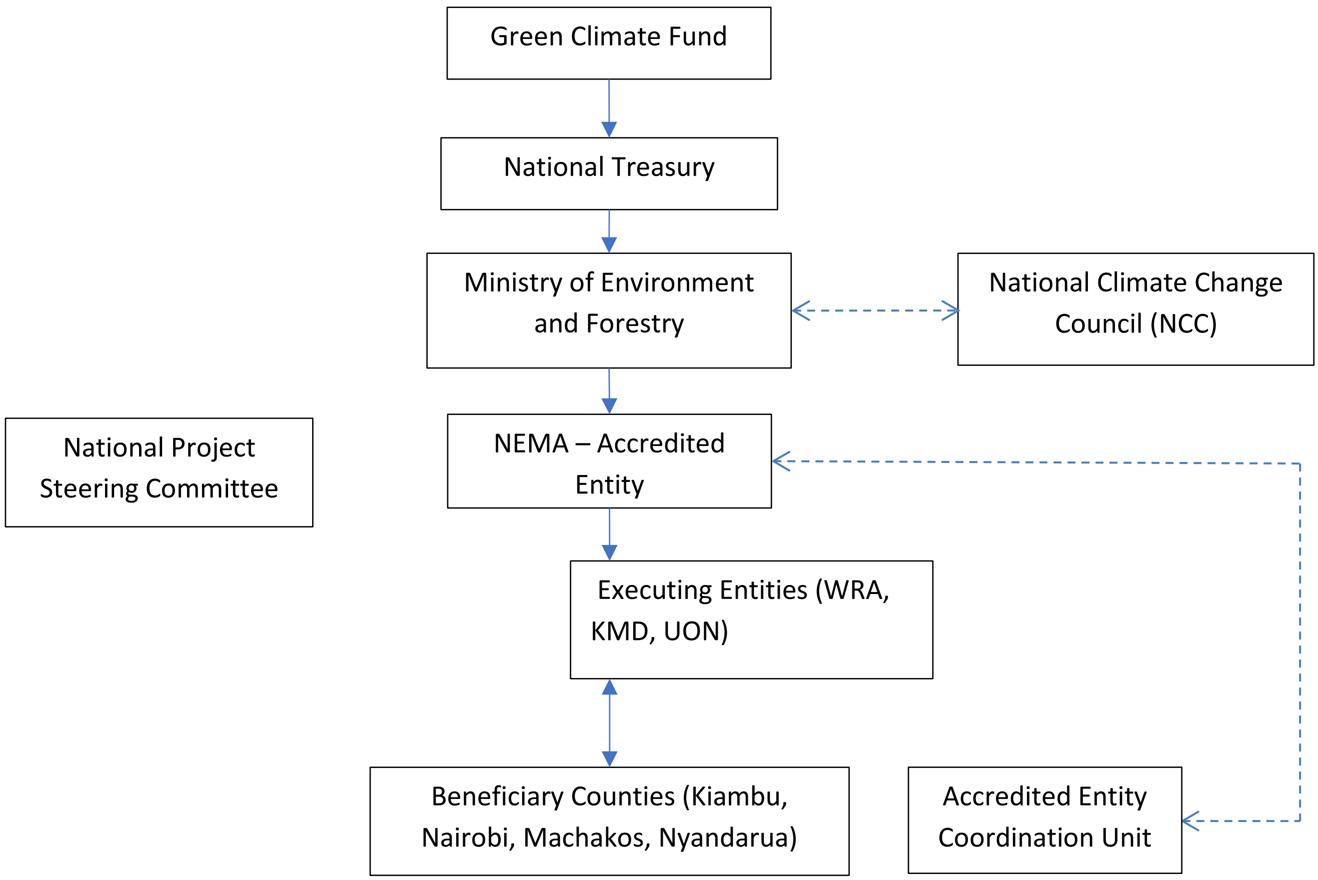
3.3.1 Role of National Government in the project

The project implementation arrangement is defined by legal mandate, technical capacity and guidance from the stakeholders consulted. The figure 23 below illustrates the institutional arrangements for the GCF project implementation.

3.3.1.1 National Treasury

The National Treasury is the National Designated Authority (NDA) by GCF. It represents the official government on all matters. The NT shall be responsible for all financial negotiation and execution of grant agreement with GCF. NT shall submit disbursement requests to GCF and then transmit to NEMA through the relevant channels. Also the National Treasury shall ensure that PSC meets quarterly to review the progress and provide necessary guidance and direction to NEMA.

Figure 22: Project Coordination Unit Structure



3.3.1.2 Ministry of Water and Sanitation

The Ministry of Water and Sanitation (MWS) is shall provide policy direction and oversight roles on water resources, water conservation and storage measures planned. WRA is under the MWS. The Principal Secretary of the MWS shall be a member of the PSC. Given that the GCF project is water related, capacity building for the selected staff of the Ministry has been considered and proposed.

3.3.1.3 Ministry of Environment and Forestry

The Ministry of Environment and Forestry (MEF) is responsible for policy direction and general oversight on all matters environment. The Kenya Meteorological Department (KMD) is actually part if the MEF. In addition, NEMA is a state agency under MEF. For these reasons, MEF has been designated both as an implementing and a coordinating Ministry under the GCF project. The PS of the MEF shall be a member of the PSC. The capacity building measures will be limited to KMD.

3.3.1.4 Project Steering Committee (PSC)

It is proposed to establish Project Steering Committee (PSC). The committee shall include the Permanent Secretaries from the National Treasury (who shall chair the session), Ministry of Water and Sanitation, Ministry of Environment and Forestry and Ministry of Devolution and Planning. If necessary, the PSC can co-opt PS from any other relevant ministry. The PSC shall provide policy direction to the GCF project and guide on inter-ministerial issues related to the project. The PSC should meet quarterly to review the progress of the program and guide NEMA accordingly. The PSC shall be established as soon as the funding Proposal is approved by GCF.

3.3.2 County Government

The administrative structure of the Kenya government has devolved power and functions to the county governments. Water resources and soil conservation functions of the National government have been devolved to the county government. Also, County governments are essentially key stakeholders on any project implemented within any county. In this project, the CGs of Nyandarua, CG of Kiambu, CG of Nairobi and CG of Machakos will be key stakeholders on the project.

3.3.3 State Agencies and Department

The follow State Agencies and Department shall perform the following roles in the project;

3.3.3.1 National Environment Management Authority (NEMA)

The NEMA is the Accredited Entity which is the applicant in the project. Consequently, it bears the greatest responsibility for successful implementation of the GCF project. NEMA will therefore perform the following roles;

- Project Management: NEMA shall be responsible for overall project planning, execution, coordination, monitoring, and evaluation and reporting. To achieve this, it will guide implementing entities to prepare Quarterly Work plans, which it will consolidate and submit to the relevant authorities.
- Reporting: NEMA shall prepare all the necessary reports required by GCF. It will prepare, submit and present quarterly progress reports to PSC for information and guidance. Similarly, NEMA will present quarterly progress report with a bias on Climate Change Component of the Project to the National Climate Change Council. All the reports shall be copied to the Implementing entities i.e WRA and KMD.
- Budget and Auditing: NEMA shall be responsible for the overall project budgeting based on the agreed work plans prepared by the implementing entities. The implementing entities shall prepare semi-annual mini-budgets accompanied by work plans for the components of the project. NEMA shall review and consolidate the budgets to inform disbursements request to GCF and budget

application to the National Treasury through the specific line Ministries, i.e. MEF (for KMD and NEMA) and MWS (for WRA). The budget plans and request shall be prepared for GCF funding and separate for Government of Kenya Counterpart Contribution for the project. NEMA shall coordinate with the Director General of Kenya National Audit office to arrange and facilitate project specific audit for the Project according to the agreed Grant Funding requirement.

There is need to strengthen Project Management unit to be established at NEMA by hiring/seconding a dedicated Project Management Team to ensure that the project is efficiently and effectively managed to achieve the goal and objectives.

3.3.3.2 Water Resources Authority (WRA)

The objective of the project is to enhance water resource management for adaptation to climate change impacts. In this regard, WRA is appropriate to implement the project as part of its core mandate. The specific components to be implemented by WRA are:

- Component 1: Water Resource Monitoring
- Component 2; Water Conservation Measures by WRUAs
- Component 3: Capacity Building Measures to WRA and WRUA

WRA has demonstrated a strong framework on preparedness for project implementation. The WRA headquarter is suitable to plan and execute both procurement and financial management functions of the project. On the other hand, the WRA Regional Office for Athi (in Machakos) demonstrated capacity to coordinate, monitor and guide WRUA activities within Kiambu, Nairobi and Machakos County. In addition, WRA has strong Sub-catchment offices in Kiambu, Nairobi and Machakos which will play key roles in project implementation at the grass-root/county level. However, implementation of activities by WRA in Nyandarua County needs to be specifically decided by WRA and inform NEMA accordingly.

WRA will therefore have to appoint a Project Implementation Unit, dedicated for project planning, supervision and coordination at the grass-root/county level.

3.3.3.3 Kenya Meteorological Department (KMD)

The KMD is responsible for implementation of the part of component 1- meteorological data and information system. This will entail planning, procuring and implementation of automatic weather stations within the upper Athi catchment.

There is need to strengthen Project Implementation unit to be established at KMD by seconding a dedicated Project Implementation Officer to ensure that the project is implemented within requisite efficiency, cost, quality and timelines.

3.3.4 Local entities

Local entities entails community groups and associations that either will use, manage or maintain conservation facilities to be implemented under the project. In this case, the role of WRUAs and Water Pan Management Committee are to be noted as elaborated hereafter.

3.3.4.1 WRUAs

Water Resource Users Association (WRUA) is a formally registered group of community members at the sub-basin level for a collaborative management of water resources. The membership is voluntary and mainly comprises water users, riparian land owners and interested groups within a sub-catchment designated by WRA. Best practices of IWRM and Constitution of Kenya 2010 emphasizes public involvement, participation and collaboration with local communities on management of water resources. By virtue of locality and dependency on the water resources, WRUAs are both beneficiary to the properly managed water resources as well as victims to cyclic and erratic climate change induced water resource related vagaries such as droughts, floods, pollution, human and wildlife water related conflicts.

The Water Act 2016, section 29 (1) & (2) prescribes the establishment and function of WRUAs at the sub-basin level. WRUAs are envisioned to facilitate collaborative management of water resources and aide related conflict resolutions. At the grass-root level, WRUAs are the agents of the WRA at the community level. In addition, WRUA can be appointed by BWRC as agency to perform water resources conservation activities.

CHAPTER 4 : Enhanced Technical Capacity for Integrated Water Resources Management

4.1 Establishment of A Water Resources Monitoring System for Data Acquisition

4.1.1 Background

Kenya faces enormous challenges in the management of its limited water resources. These challenges are associated with data collection and information generation on water resources, water scarcity and variability, water pollution, enforcement of water laws, catchment degradation, and the impact of climate change. The magnitude of the issues and challenges and the severity of the water crisis that Kenya faces cut across most sectors of the economy. This makes water resources management a high priority[44].

The National Water Resources Management Strategy (NWRMS), 2012, the National Water Master Plan (NWMP), 2030, the National Water Quality Management Strategy (NWQMS), 2012, and the Catchment Management Strategy (CMS), 2015 all prioritize water resources monitoring as a key factor in water resources management. Water resources management in Kenya is primarily guided by the National Water Resources Management Strategy (NWRMS). Its strategic objectives are as follows:

- **Strengthening monitoring networks to enhance data collection and to improve the information management system**
- Improving the use of water resources management tools for effective water resources planning and allocation
- Strengthening stakeholder collaboration to enhance water storage and to address the impacts of climate change
- Building staff capacity and improving the work environment

The NWMP 2030 aims to create a framework for water resources development and management consistent with the country's social and economic development activities. The plan provides information on how water will be managed and developed to meet Kenya's development needs, as envisaged in Vision 2030 as follows:

- Water supply development plan
- Water resources development plan
- **Water resources management plan**
- Institutional strengthening plan for water resources management

The water resources management plan for ACA in NWMP 2030 addresses five major components, namely monitoring, evaluation, water permit issuance, water permit control, and watershed conservation. The monitoring strategies are described for five monitoring items namely: i) surface water level, ii) surface

[44] Catchment Management Strategy for Athi Catchment Area, 2015-2022 (WRMA, 2015)

water quality, iii) groundwater level, iv) groundwater quality, and v) rainfall. Based on the strategy, NWMP 2030 suggested that the installation of 26 stations for the surface water level, 24 stations for the surface water quality, 24 stations for the groundwater level and quality, and 38 stations for rainfall are necessary.

The NWQMS 2012-2016 was prepared in response to the degradation in water quality, with the aim of enhancing social and economic development. The NWQMS addressed issues of institutional framework, key strategic actions, status and challenges, strategic responses, and implementation framework among others, through guiding principles on integrated water resources management, WQM options, performance monitoring, and enforcement. The goals of NWQMS are:

- Improved water quality by reducing pollution from point and non-point sources
- **Enhanced water quality monitoring programs, water quality data management, and information management and sharing**
- Harmonized WQM guidelines recognizing differences in institutional, social, and natural conditions

The CMS 2014-2022 was formulated by the WRA within the fundamental principles of the IWRM[45]. The main elements of the strategies under the scope of the CMS for catchment management are as follows:

- Water balance and demand management
- Water allocation and use management
- Flood and drought management
- Climate change adaptation
- **Monitoring and information management**

4.1.2 Current Needs, Gaps, and Barriers

Section 13 of the Water Act 2016 describes that the WRA has the mandate to collect, analyze, and disseminate information on water resources. The NWRMS outlines the objectives and strategies that address the major issues and challenges facing the country. It recognizes that integrated water resources management must be elevated and recognized as a national priority, which underpins Kenya's social and economic development, and requires substantial monetary and labor investment[46].

WRA focuses on the development of the IWRM system to maximize efficiency, equity, and sustainability of available water resources allocation. It does so by managing the entire watershed as a single "organism" to cope with floods and droughts due to climate change. For effective water resources management, it is necessary to utilize real-time measurement, storage, and distribution of hydrological and meteorological data. For this purpose, a remote monitoring system is essential. In addition, it is necessary to gather scattered

[45] Integrated Water Resources Management (IWRM) is a concept that indicates that water resources should be integrated and managed by the river basin unit by taking into consideration surface water and groundwater, water quantity and quality, and various uses of water resources for the conservation of water resources and protection of river environments.
[46] Athi Catchment Management Strategy for Athi Catchment Area (WRMA, 2015)

information in one place and provide customized information on water resources based on institutional characteristics easily and quickly.

Monitoring of water resources requires regular and systematic recording of measurements from a network of surface water and groundwater stations, meteorological monitoring stations, and pollution surveillance. However, due to limited financial resources, human resources, and equipment, the data and information on surface water and groundwater specifically focusing on areas of i) quantity, ii) abstraction, iii) water permits, and iv) water quality are not sufficiently generated. Further, the data and information obtained were not properly stored in the database[47].

According to the Hydro-meteorological Data Profile Report published by the WRA in 2017, there are 203 points that operate as Regular Gauging Stations (RGSs) carrying out surface water level monitoring in the ACA (see Figure 24). The report also indicates that there are 71 points in the upper ACA, which form the target area of this project.

Among the RGSs in the upper ACA, the telemetry system, that is the remote monitoring system for real-time measurement has been installed only at two stations, namely at 3BA29 and 3DA02, as seen in Figure 23. The 3BA29 station is equipped with a rainfall and water level sensor. However, it is now only possible to measure the water level at this RGS. The 3DA02 station is not in operation due to poor maintenance. The CMS (2014-2022) indicates that the surface water monitoring network in the ACA has been rationalized and 31 river gauging stations have been targeted for monitoring, as against the 26 stations proposed in the NWMP 2030. Ten of these are located in the Upper Athi Catchment Area along with two of the abovementioned telemetry stations.

Table 12 presents the status of the telemetry stations as of 2017 for water quality monitoring of the surface water by the WRA. There are six stations with telemetry systems in the Upper Athi Catchment Area. Three of these stations, namely 3BC08, 3BB11, and 3BD05, have been operated so far. However, the other stations are no longer running. In the case of past measured data, the missing value ratio is more than 50% , and there is insufficiency data for any statistical analysis.

Table 12: The Status of Telemetry Stations for Surface Water Monitoring

No	Name of Station	Station ID	County	Location	
				Latitude	Longitude
1	Ruiru River in Ruiru Town	3BC08	Kiambu	-1.145715	36.96437
2	Ndarugu River before the confluence with the Athi River	3CB05	Kiambu	-1.129973	37.161001
3	Athi River at Wamunyu	3DB01	Machakos	-1.41431	37.646793
4	Maruba dam	3EA02	Machakos	-1.52029	37.246809
5	Kiu River in the Kahawa Barracks in Githurai	3BB11	Kiambu	-1.19667	36.92013
6	Thiririka	3BD05	KIambu	-1.154558	37.040815

Source: Hydro-meteorological Data Profile Report (WRA, 2017)

[47] NWMP 2030, Sectoral Report(H) Water Resources Management (2013)

Figure 23: The status of RGSs in the Upper Athi Catchment Area

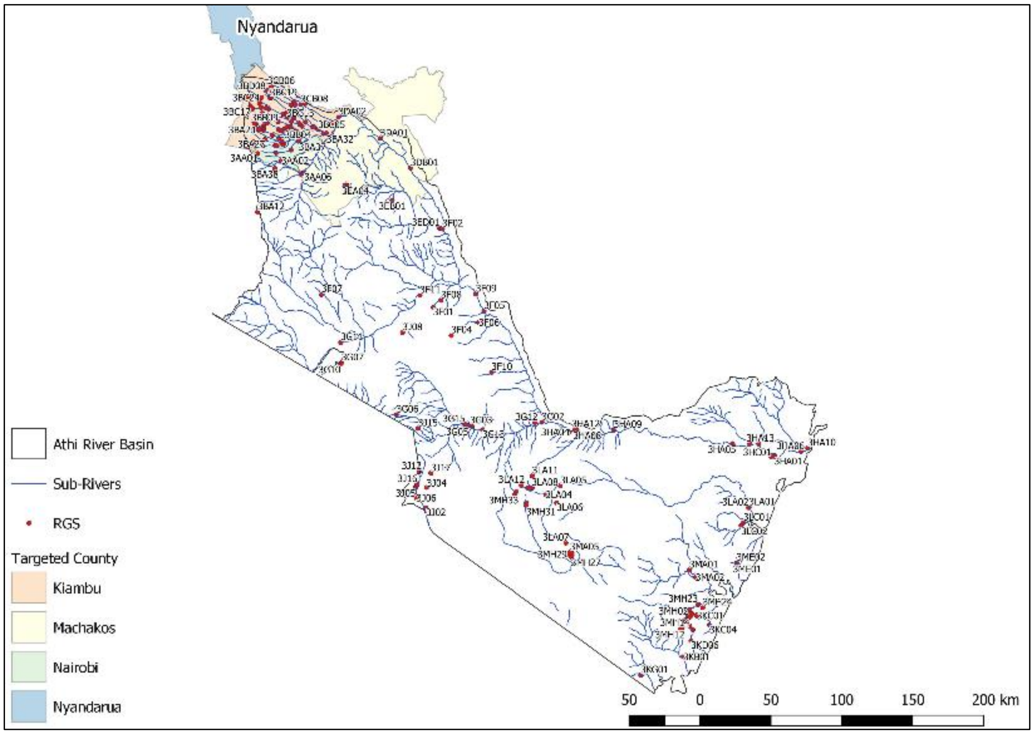
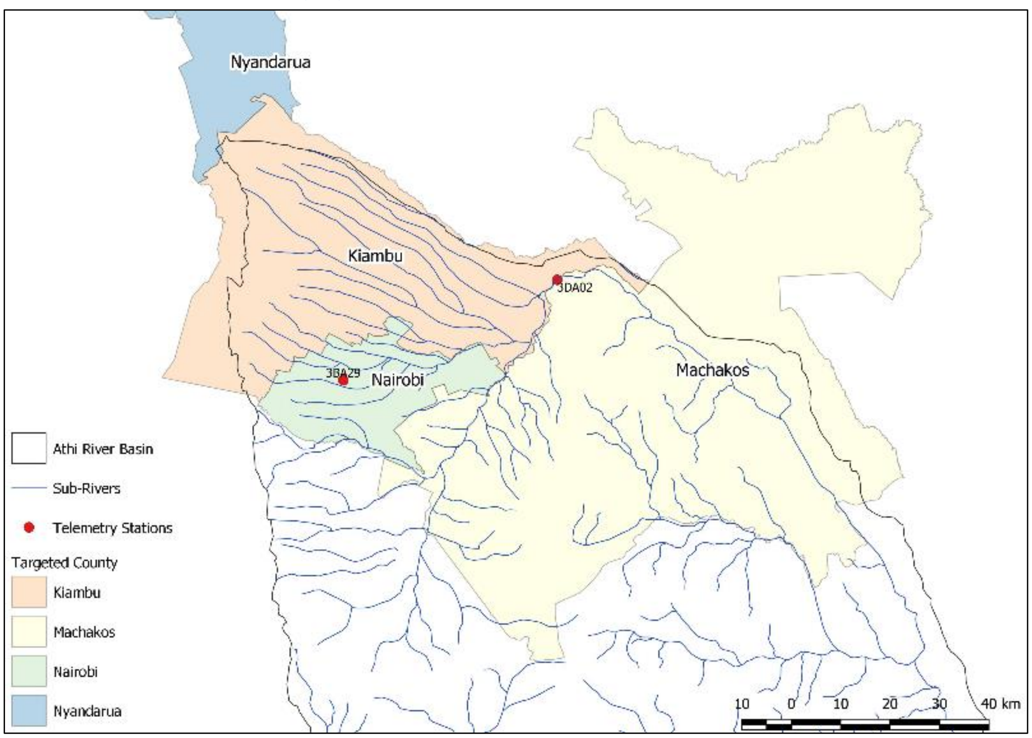


Figure 24: The location of telemetry systems in the 3BA29 and 3DA02 stations



Six telemetry stations monitor groundwater for water quality (see Table 13). Among them, only the Kiambu District Hospital and the MaKi Milan station are in operation, while the other four stations have not been operated so far.

Table 13: The Status of Telemetry Stations for Groundwater Monitoring

No	Name of Station	County	Location	
			Latitude	Longitude
1	Kiambu District Hospital	Kiambu	-1.168240	36.831400
2	Vinya Wa Kanyuuku	Machakos	Unknown	Unknown
3	MAKI MILAN	Kiambu	Unknown	Unknown
4	Limuru DO's Office	Kiambu	-1.109771	36.639548
5	Eastern flour Mills	Machakos	-1.502364	37.258573
6	Bishop Kioko Hospital	Machakos	-1.516558	37.264969

Source: Hydro-meteorological Data Profile Report (WRA, 2017)

The rainfall station network has been used for rainfall measurement by CMS 2014-2022, targeting 50 stations for monitoring as against the 38 stations proposed in the NWMP 2030. According to the telemetry system status data provided by the WRA, there are six telemetry stations involved in rainfall gauging of which five are running.

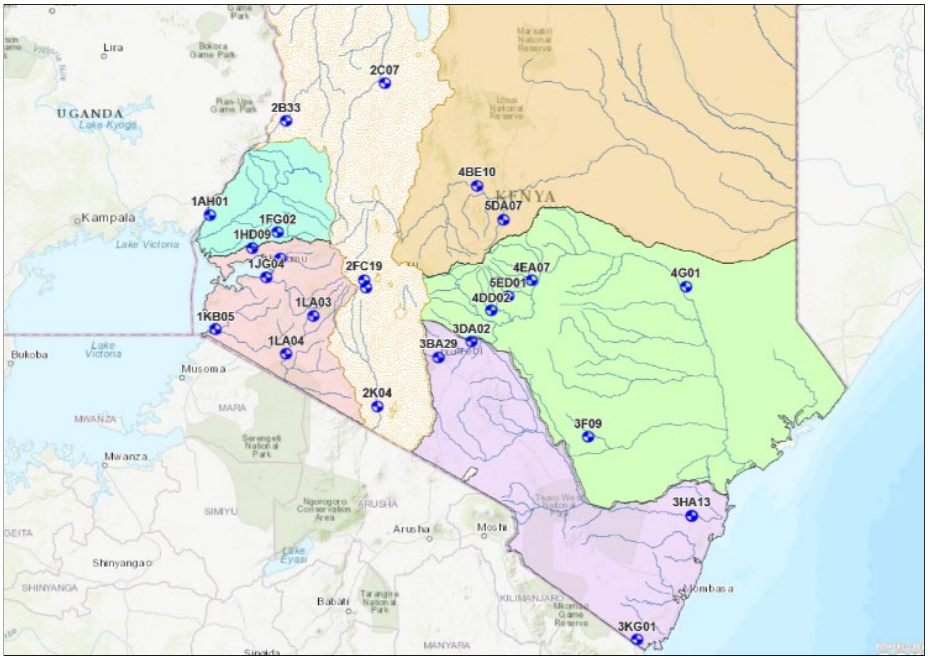
It is necessary to modernize the facilities used for water level and water quality monitoring of surface water and groundwater as well as rainfall measurement. It is necessary to install and utilize telemetry systems to achieve integrated water resources management, which is the final goal of the monitoring and information management in CMS 2014-2022. In addition, it is necessary to continuously strengthen the capacity of the WRA staff involved in data collection and analysis of water resources.

4.1.3 Surface Water Monitoring Stations

4.1.3.1 Current Situation

As mentioned in 4.1.2, the WRA has been monitoring 71 sites for water level and water quality in Nairobi, Nyandarua, Kiambu, and Machakos in the Upper Athi Catchment Area. It monitors 203 sites in all in the entire Athi Catchment Area. Further, the telemetric system is being operated in 24 stations across Kenya, including two of the four stations in the Athi Catchment Area located within the project site, as shown in Figure 26. Databases on water level, rainfall, temperature, relative humidity, power sources, and telecommunication networks have also been built. The system has been monitored online through the water resources information system of WRA.

Figure 25: Status of the telemetry system for surface water monitoring by the WRA



Source: http://wra-kenya.maps.arcgis.com

As part of the system configuration, a pressure water level sensor, a rainfall gauge, and a temperature/humidity sensor are installed at the site to be monitored. A battery is used to generate power. The telecommunication network is configured to transmit the data measured every three hours via the General Packet Radio Services (GPRS)/Global System for Mobile Communications (GSM) network. This data is to be monitored through a website by a team at the headquarters of the WRA in Nairobi.

However, due to the use of battery power, there were missing values based on the charging period and temporary stoppage of work during particular phases such as battery collection, recharging, and reinstallation. Further, the installed facilities underwent a loss of function due to deterioration of equipment. There was also the possibility of theft due to outdoor exposure. A consultation with a system engineer confirmed the necessity for the establishment of a flood and drought alarm system and for the system operating parts to be secured.

4.1.3.2 Field Survey

In order to assess the feasibility of the sites chosen for the installation of new telemetric monitoring systems as proposed by the WRA based on the national water resources management plan, field surveys were conducted in Nairobi, Nyandarua, Kiambu, and Machakos between July 3 and July 17, 2018.

The survey team visited the stations targeted with the guidance of the headquarters and the person in charge of each region of the WRA. They collected comments and feedback on the proposed installation of the water resource monitoring system from stakeholders.

During the consultations with the Nairobi County Section official on July 4, 2018, the survey team was able to understand the need for water resources monitoring, and in particular, the requirements for the flood warning and alarm systems. A major flood occurred at the Athi River Kamulu RGS 3BA02 which is the flood monitoring station for the Nairobi sub-region, the Nairobi River Museum Hill RGS 3BA29, and the Mbagathi RGS 3AA04 at the end of March 2018 as shown in Figure 27.

Figure 26: Flooding at the RGS 3BA02 and Joska (March 2018)

Source: Flood monitoring in Nairobi Sub Regional Office (WRA, 2018)

The survey team consulted with WRA officers in Nyandarua County on July 6, 2018 on the installation of rain gauges. Nyandarua County is located at the top of the Athi Catchment Area and serves as a water tower for many watersheds in Kenya. Thus, this consultation was necessary. In Kiambu, 23 sites were surveyed and a meeting with field experts was held. In Ruiru Dam, the survey team found that there was a need to strengthen water resources monitoring by installing comprehensive monitoring sensors to evaluate the water level, water quality, and rainfall. In Machakos, two monitoring sites were surveyed including the Athi River and the Maruba River upon the request of the Regional Office of the Upper Athi Catchment Area.

Figure 27: Ruiru Dam (left) and the Athi River (3DB1) (left)

Consultations and field surveys were conducted at 34 surface water monitoring sites across the four counties of Nairobi, Nyandarua, Kiambu, and Machakos. Twenty-eight stations were found relatively well connected for GPRS/GSM use, and 23 stations except five rainfall stations were selected as targets of surface water monitoring including water quality monitoring. However, since the telecommunications environment in the future may vary depending on the telecommunication conditions around the monitoring stations and the telecommunication network situation of each of the mobile telecommunication companies, it is necessary to investigate the details in the construction phase.

The main findings of the survey in each region and target point are presented in Table 14. The location and specification of the selected surface water monitoring stations are shown in Table 15 and Figure 29.

Table 14: Number of Surveyed and Selected Surface Water Monitoring Stations

County	Survey	Selection			
		Total	Water Level	Water Level & Water Quality	Rainfall
Total	34	28	3	20	5
Nairobi	7	6	2	2	2
Nyandarua	2	-	-	-	-
Kiambu	23	20	1	16	3
Machakos	2	2	-	2	-

Figure 28: Location of selected surface water monitoring stations (23 stations)

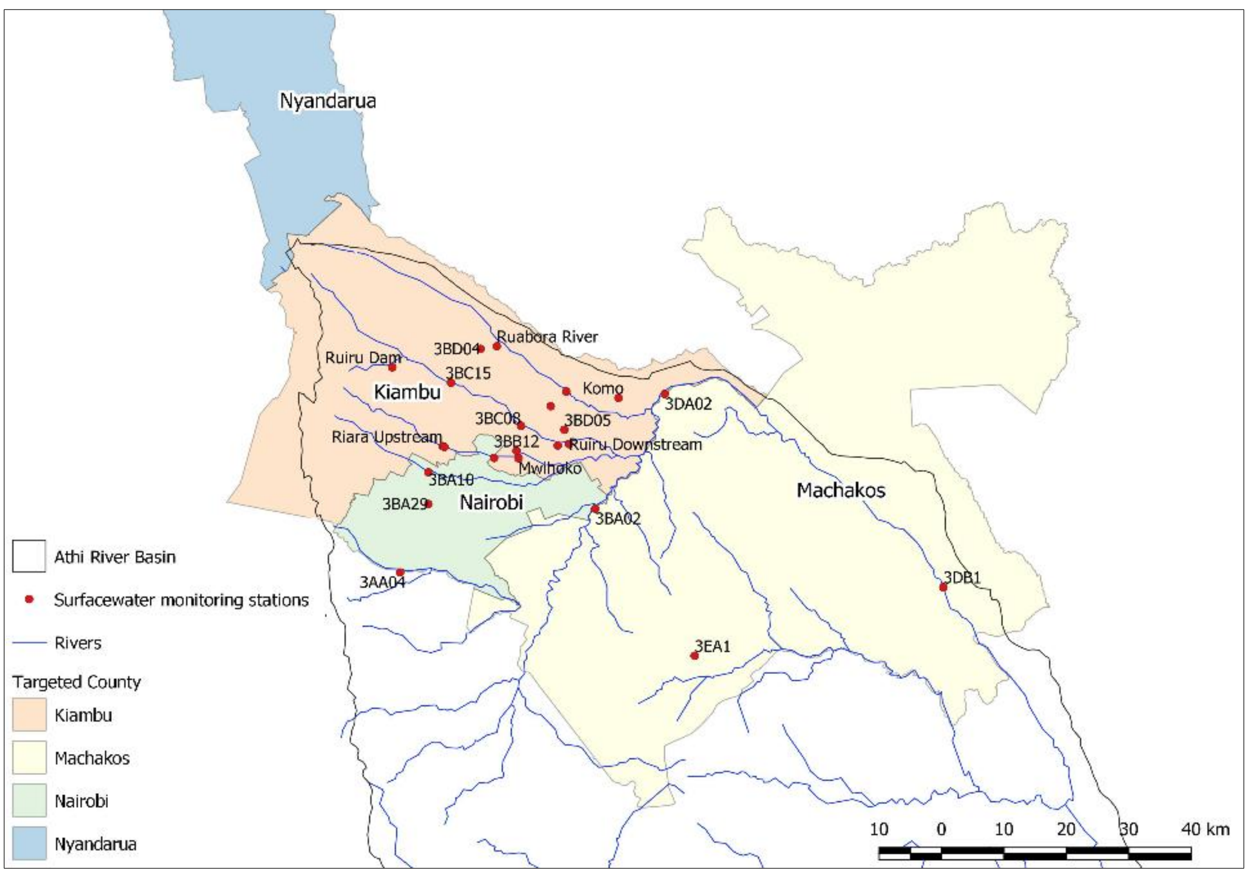


Table 15: Specification of Selected Surface Water Monitoring Stations

No.	Name of Station	Name of River	Coordinates		Applied Sensors			
			Latitude	Longitude	Water Level	Water Level & Water Quality	ADCP	Rainfall
Nairobi County								
1	3AA04	Mbagathi	-1.38889	36.76863		o		
2	3BA10	Ruiruaka	-1.22257	36.81430	o			
3	3BA02	Athi	-1.28337	37.08420	o			
4	3BA29	Nairobi	-1.27528	36.81416		o		
Kiambu County								
5	3BB12	Kamiti	-1.18738	36.95704		o		
6	3BB11	Kiu	-1.19889	36.92062		o		
7	3BC08	Ruiru	-1.14533	36.96418		o		
8	3BD05	Thiririka	-1.15226	37.03416	o			
9	3DA02	Munyu	-1.09275	37.19690		o	o	
10	Ruiru Dam	Ruiru	-1.04829	36.75605		o		o
11	3BC15	Gatamaiyu	-1.07394	36.85125		o		
12	New Station	Ruabora	-1.01326	36.92512		o		
13	Mwihoko	Kiu	-1.19945	36.96007		o		
14	Thika road Bridge 3CB	Ndarugu	-1.08862	37.03739		o		
15	Thika Super highway	Thiririka	-1.11311	37.01229		o		
16	3BD04	Thiririka	-1.01777	36.89883		o		
17	Riara Upstream	Riara	-1.17935	36.83772		o		
18	Riara Downstream	Riara	-1.18065	36.84048		o		
19	Ruiru Upstream	Ruiru	-1.17838	37.02372		o		
20	Ruiru Downstream	Ruiru	-1.17595	37.04167		o		
21	New Komo Station	Komo	-1.09925	37.12205		o		
Machakos County								
22	3DB1	Wamunyu	-1.41420	37.64706		o		
23	3EA1	Maruba	-1.52773	37.24449		o		

4.1.3.3 System Installation Plan

(a) Central Station

The water resources monitoring system in the Upper Athi Catchment Area should be established as an integrated water resources information system including information on surface water, groundwater, and rainfall.

It is necessary to provide integrated water resources information in the upper ACA to the database server, the web-server, and the system administrator. To this end, separate space must be created in the headquarters of the WRA to establish the integrated water resources management information system. There is a need to link weather data and information from the KMD to enable early flood warnings in floodplain areas.

It is also needed to incorporate and install various kinds of software such as operation software (OS), database management software (DBMS), mobile applications, and utility programs such as MS-Office and Vaccine for computer server operations. It is recommended that an Uninterruptible Power Supply system (UPS) be installed to secure power supply in the event of power outages. A mobile application was developed separately to improve system utilization on mobile devices.

(b) Monitoring Station

Each selected site will be equipped with water level and water quality sensors as main tools of measurement. The water level sensor an each site should be capable of measuring the ultrasonic or pressure type to evaluate the condition of the site, the economic efficiency of the system, and the security measures available on the site, among other things. The water quality monitoring system should have a multi-parameters sensor that can measure not only temperature, but also PH and EC. It must be capable of measuring the water level. The existing commercial power supply is the most stable to operate the monitoring system at the site. However, the installation of the power distribution line at the monitoring site makes the system more economical. After consulting with the stakeholders, such as the field manager on the site, the use of a stable small solar PV power source that is relatively inexpensive is recommended.

Remote Terminal Units (RTUs), GSM/GPRS Modems, and the solar PV systems with solar battery are necessary for the storage and transmission of the data measured in the field into the server. Furthermore, the installation of housing, fences, and surveillance camera is recommended to prevent theft. Further, surveillance cameras can help the supervisor monitor and measure the surface water level and provide information on the site.

(c) Data Protection Equipment

In order to secure the reliability of the RTU and the data measured, as well as to protect the system, it is necessary to install noise filters and surge protective devices (SPDs). SPDs should be installed especially for the protection of analogue signals such as water level and water quality, and all systems must be grounded at each point.

(d) Operation and Maintenance (O&M) of Tools and Spare Parts

To ensure stable system operation and maintenance, a certain number of spare parts and tools will be secured. These spare parts and tools include:

- CPU of RTUs, SPDs, and batteries
- GPS/GPRS Modems
- Water level and water quality sensors
- Multi-testers and tool sets

(e) Operation and Maintenance (O&M) and Capacity Building

After the project is completed, system managers should be deployed for the efficient O&M of the system. Sufficient on-site and factory trainings should be provided along with manuals. Each course should include theories, principles, O&M processes, and troubleshooting for the systems and equipment installed.

After completion of the warranty period for the monitoring system, the O&M contract shall be concluded with the contractor within the budget allowance so that continuous system maintenance such as inspection, maintenance and repair can be performed.

4.1.3.4 Project Cost

Most of the equipment for building the surface water monitoring system is to be purchased and installed locally to maintain the efficiency of the O&M of the system. The cost of the materials including the installation labor cost (which has been verified on site) is calculated as seen in Table 16.

Table 16: Estimated Budget for Surface Water Monitoring System

Description	Item	Type	Unit	Qty	Unit Cost (USD)	Total Cost (USD)	Remarks
a) Office equipment							
Office equipment	Server and Monitor	HDD 1TB, LED 61cm	No.	1	5,700	5,700	
	Printer and Laptop	A3, Laser	L/S	1	1,300	1,300	
	DID monitor and PC	LED 138cm x 2	L/S	1	9,000	9,000	
	Software	OS, DBMS, Mobile	L/S	1	17,000	17,000	
	Gigabit N/S	24P, System Rack	No.	1	250	250	
	UPS and Battery	Case, 1Ph, 3kVA	No.	1	3,800	3,800	
Training	O&M	System Operators	L/S	1	2,000	2,000	
Publicity	Media and IEC material	Posters, Brochures	L/S	1	20,000	20,000	
Sub Total						52,050	

b) Surface water monitoring							
Installation of monitoring station	Multi-parameter monitoring station	Data logger, GPRS modem, sensors (Water Level)	L/S	3	14,850	44,550	Inc.labour
	Acoustic doppler current profiler	ADCP and Accessories	No.	1	29,700	29,700	
	Solar PV panel (30W)	Inclusive battery (70 Ah)	L/S	23	1,600	36,800	
	Survey cross section	For the installation of equipment	L/S	23	790	18,170	
	Construction cost	Logger house, staff gauge, fence, stilling well	L/S	23	2,390	54,970	
	Branding	Branding and commissioning	No.	23	380	8,740	
Flood warning	Flood warning system (Solar 120W)	Battery, speaker, amp, and control (PC and mobile phone)	No.	1	18,000	18,000	
O&M	Tools and spare parts	Office and sites	L/S	1	15,000	15,000	
	Annual maintenance cost	Calibration of the equipment, services as necessary	Site	3	2,000	6,000	
Sub Total						231,930	
c) Water quality monitoring stations and laboratory equipment							
Water quality station	Installation of telemetric water quality stations	Procurement, supply, delivery and installation with accessories	No.	20	4,950	99,000	
	Procure the water quality field equipment	Water quality multiple parameter meter	No.	20	3,465	69,300	
Equipment of laboratories	Procure laboratory chemicals, reagents, and glassware	Operation of the laboratories analyses	L/S	1	49,500	49,500	Assorted
	Procure atomic absorption spectrophotometer	Heavy metal analysis (AAS)	No.	1	207,900	207,900	
	Procure oxitops	BOD effluent analysis	No.	2	24,750	49,500	
	Procure Chemical Oxygen Demand(COD) digester	COD effluent analysis	No.	2	22,770	45,540	
	Procure incubators	Bacteriological analysis	No.	2	14,850	29,700	
	Procure sediment analysis kit	Sediment analysis	No.	7	1,980	13,860	
	Procure High-performance liquid chromatography (HPLC)	Pesticide analysis	No.	1	108,900	108,900	
O&M	Calibration of equipment, repair of equipment	Replacement of equipment, overheads	L/S	1	29,700	29,700	
Sub Total						702,900	
Grand Total					**(a+b+c)**	**986,880**	

4.1.4 Groundwater Monitoring Stations

4.1.4.1 Background

Water resources consist of surface water and groundwater. Groundwater is a major source of water supply for drinking, irrigation, and livestock in many countries, especially in arid and semi-arid regions. It is also a vital element of groundwater-dependent ecosystems such as wetlands. Regular and systematic monitoring of groundwater resources is necessary for its effective management to support the water needs of the environment and citizens[48].

The purpose of a groundwater monitoring system is to monitor the quantity and quality of groundwater. Periodic water level measurements at various locations are essential for assessing the quantity of groundwater. Similarly, water quality monitoring is performed to assess the magnitude of contamination or the rate of contaminant migration in groundwater.

The system is scientifically designed to continuously monitor the groundwater condition, and the acquired data accumulate at regular time intervals and at the same location. In addition, through the management software, the data analysis, evaluation, reporting and other processes are carried out.

4.1.4.2 Current Situation

Kenya's groundwater monitoring system distinguishes between water level monitoring and water quality monitoring. Like the Kebete Treatment Station, there is a monitoring well but there is no sensor, RTU, or other equipment. The manager has checked the water level of the monitoring well manually in the field. For water quality monitoring, the manager has taken water sample from the well to measure the required water quality parameter in the lab (see Figure 31).

Like Kiambu Sub-county Hospital station, Kenya uses the existing well as a monitoring. In this case, water level monitoring is difficult, but water quality monitoring is relatively easy (see Figure 33). As described above, the groundwater monitoring system of Kenya is very ineffective because the manager acquires the data directly on site and manages the data in the office.

[48] Guideline on: Groundwater monitoring for general reference purposes by international groundwater resources assessment center (2008).

4.1.4.3 Field Survey

The evaluation of groundwater issues and the implementation of management solutions require hydrogeological data that are in part "baseline" and in part "time-variant" in character (see Table 17)-the collection of the "time-variant component" is what is usually considered "groundwater monitoring"[49].

Table 17: Types of Data Required for Groundwater Management

TYPE OF DATA	BASELINE DATA (from archives)	TIME-VARIANT DATA (from field stations)
Groundwater Occurrence and Aquifer Properties	• water well records (hydrogeological logs, instantaneous groundwater levels and quality) • well and aquifer pumping tests	• groundwater level monitoring • groundwater quality monitoring
Groundwater Use	• water well pump installations • water-use inventories • population registers and forecasts • energy consumption for irrigation	• water well abstraction monitoring (direct or indirect) • well groundwater level variations
Supporting Information	• climatic data • land-use inventories • geological maps/sections	• riverflow gauging • meteorological observations • satellite land-use surveys

Monitoring networks and systems are classified into three main groups (Table 18), and are specifically designed and operated to:

- Detect general changes in groundwater flow and trends in groundwater quality, and gaps in scientific understanding of the groundwater resource base (Primary Systems)
- Assess and control the impact of specific risks to groundwater (Secondary and Tertiary Systems)

The effectiveness of groundwater monitoring can be considerably increased by careful attention to network design, system implementation and data interpretation (see Table 19).

[49] Sustainable Groundwater management concepts & tools by World Bank (2006)

Table 18: Classification of groundwater monitoring systems by function

SYSTEM	BASIC FUNCTION	WELL LOCATIONS
Primary (Reference Monitoring)	evaluation of general groundwater behavior: • trends resulting from land-use change and climatic variation • processes such as recharge, flow and diffuse contamination	• in uniform areas with respect to hydrogeology and land use
Secondary (Protection Monitoring)	protection against potential impacts of following: • strategic groundwater resource • wellfields/springheads for public water supply • urban infrastructure from land subsidence • archaeological sites against rising water table • groundwater-dependent ecosystems	• around areas/ facilities/ features requiring protection
Tertiary (Pollution Containment)	early warning of groundwater impacts from: • intensive agricultural land use • industrial sites • solid waste landfills • land reclamation areas • quarries and mines	• immediately down- and up-hydraulic gradient from hazard

Table 19: Basic success rules for groundwater monitoring systems

NETWORK DESIGN	• objectives must be defined and program adapted accordingly • groundwater flow system must be understood • sampling locations and monitoring parameters must be selected by objectives
SYSTEM IMPLEMENTATION	• appropriately-constructed observation and abstraction wells must be used • field equipment and laboratory facilities must be appropriate to objectives • a complete operational protocol and data handling system must be established • groundwater and surface water monitoring should be integrated where applicable
DATA INTERPRETATION	• data quality must be regularly checked through internal and external controls • decision makers should be provided with interpreted management-relevant datasets • program should be periodically evaluated and reviewed

Considering the above prerequisites, we have discussed groundwater monitoring station and project tasks with WRA Headquarters and WRA Regional Specialists such as Nairobi, Kiambu and Machacos.

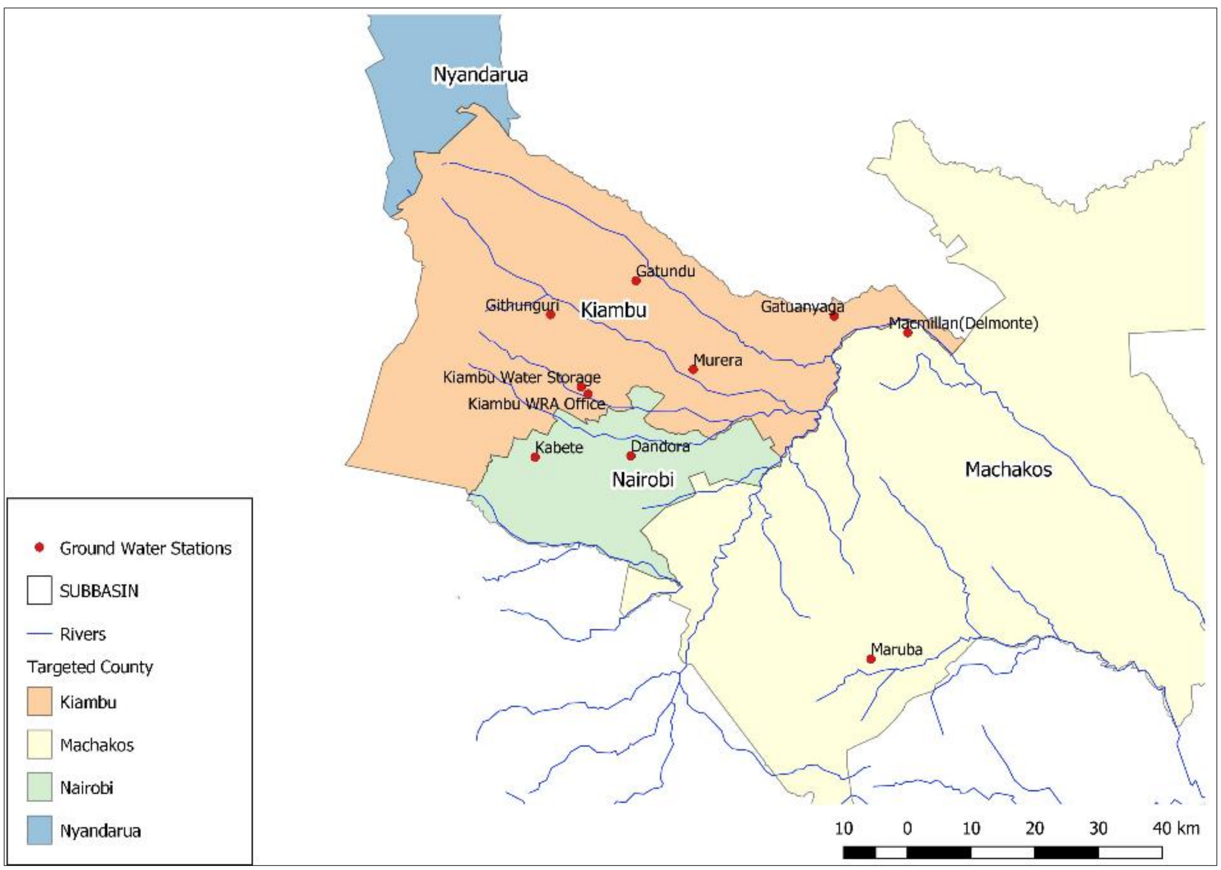
The selection criteria are;

- Reflected the opinions of WRA officers as much as possible
- Sites representing hydrogeology of the candidate area (example: existing tube well, existing monitoring well, etc.)
- Considering the surface water status (example: river, dam site) and potential pollution source (example: overcrowded area, large farmland, seepage site)
- Places where the use of land is acceptable by land owner, easy to access, anti-theft.

4.1.4.4 Recommended on Groundwater Monitoring Stations

It is selected 3 counties that is Kiambu, Nairobi and Machakos for groundwater monitoring area with WRA. The 10 stations are suggested for groundwater monitoring through the field survey. Table 20 and Figure 30 show the specific information of 10 nominated stations by each county. There is elevation, location, network status, and also the drilling depth information is based on the modified and new monitoring wells.

Figure 29: Location of 10 Nominated Stations for Groundwater Monitoring



There are 2 stations in Nairobi, 7 stations in Kiambu, 1 station in Machakos among 10 candidate groundwater monitoring stations. It is difficult to cover the entire of the upper Athi catchment area through 10 stations. However, survey team considered the stations to get the most effect.

There are matters for consideration. First is about development for monitoring wells. It is necessary to modify two existing monitoring wells and develop 8 of new monitoring wells. Second is about power supply of RTU. A battery can be used as the main power source and can add solar panel as optional power source. Third is about security. 9 stations are located in public institutions, so there is no need to concern about security. But, one station is located in a private company and needs cooperation for the installation.

The two existing monitoring wells are suggested for modified. It is in terms of environmental and economic problems. However, modifying of existing monitoring wells requires a lot of technical reviews, budget is the same as that of the new monitoring well. And it tries to consider technical and economic problems that may arise in the future.

Table 20: List & Contents of 10 stations for the Groundwater monitoring

No	Station Name	Elevation (m)	Coordinates		Network Status	Monitoring Well		
			Latitude	Longitude		Modified	New	Well Depth (m)
Nairobi County								
1	Kabete	1,808	-1.26074	36.756609	Good	0		250
2	Dandora	1,582	-1.25908	36.891457	Good		0	250
Kiambu County								
3	Kiambu WRA Office	1,684	-1.17133	36.831245	Good		0	150
4	Kiambu Water Storage	1,731	-1.16115	36.821490	Good		0	150
5	Githunguri	1,976	-1.05850	36,778282	Good		0	150
6	Gatundu	1,689	-1.01039	36.898933	Good	0		150
7	Macmillan (Delmonte)	1,421	-1.08441	37.282091	Good		0	150
8	Gatuanyaga	1,439	-1.06081	37.178436	Good		0	150
9	Murera	1,526	-1.13657	36.979514	Good		0	150
Machakos County								
10	Maruba	1,551	-1.54781	37.229826	Normal		0	200

(a) Kebete Station

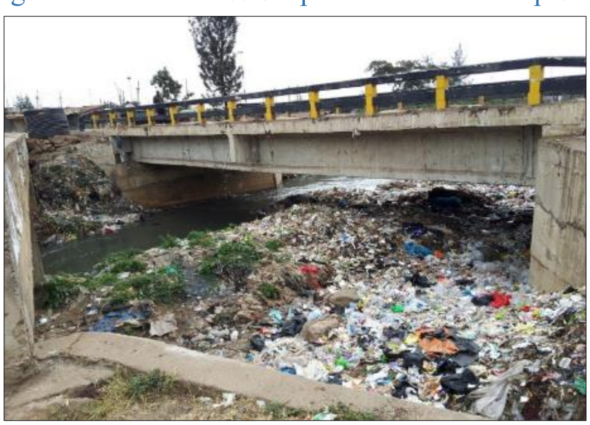
This is located in the kebete treatment and kebete lab of Nairobi water & Sewerage company. There is the existing monitoring well, in generally, water level and water quality are measured using portable equipment in past. And, there is Nairobi River at about 2 km below.

Figure 30: Kebete Station

(b) Dandora Station

The station is located in Nairobi. And there is the Dandora Dump Site & Nairobi River within 1km. The location of monitoring well is recommended within Kiambu Primary School. The reason for choosing this site is to understand the status of groundwater pollution status in Nairobi River and its surroundings due to the influence of the Dandora Dump Site.

Figure 31: Location & Scope of Dandora Dump Site/Nairobi River/Dandora Primary School



(c) Kiambu WRA Office Station

The existing tube well in Kiambu Sub-County Hospital is used as a water quality monitoring well. Semi water quality test was conducted at the site and the results that a little high at Ec 519us/cm, pH 8.37. The monitoring well site is recommended in Kiambu WRA Office because the existing tube well in the Hospital is used for patients. The reason for choosing this point is that it is located near the downtown of Kiambu.

Figure 32: Scope of WRA Office/Existing Monitoring Well of Kiambu Hospital

(d) Kiambu Water Storage Station

The location of the station is within Kiambu Water Storage. Also, there is existing well for Kiambu town. The reason for choosing this site is to understand the status of groundwater pollution status in Kiambu town and there is existing well.

Figure 33: Scope of Kiambu Water Storage Station

(e) Githunguri Station

This station is located in Githunguri Water Supply Site. There is existing well with machinery, electricity. It was selected as land use for monitoring, protection facility, existing well.

Figure 34: Scope of Githunguri Station

(f) Gatundu Station

This nominated station is located in the WRA Gatundu Office. There is an existing monitoring well within in this office. It is planned to modify the existing monitoring well.

Figure 35: Scope of Gatundu Station/WRA Gatundu Office

(g) Macmillan Station

This candidate is located in Delmonte Farmland. The existing well of farmland is being used as a water quality monitoring well. The result of semi water quality test is Ec866us/cm, pH 7.7. For develop the monitoring well, should be done in cooperation with farm owner.

Figure 36: Scope of Macmillan Station/near river

(h) Gatuanyaga Station

This candidate is located in Gatuanyaga Primary School. We selected the site as security, overcrowded area. There is the Thika River, the Athi River within 3km.

Figure 37: Scope of Gatuanyaga Station/Gatuanyaga Primary School

(i) Murera Station

This station is located within the Murera Water Supply Site. Considering that there is the existing well, an overcrowded area. In addition, the Athi River is about 1.5km away, and it is a place managed by public organization and suitable for security.

Figure 38: Location & Scope of Murera Station

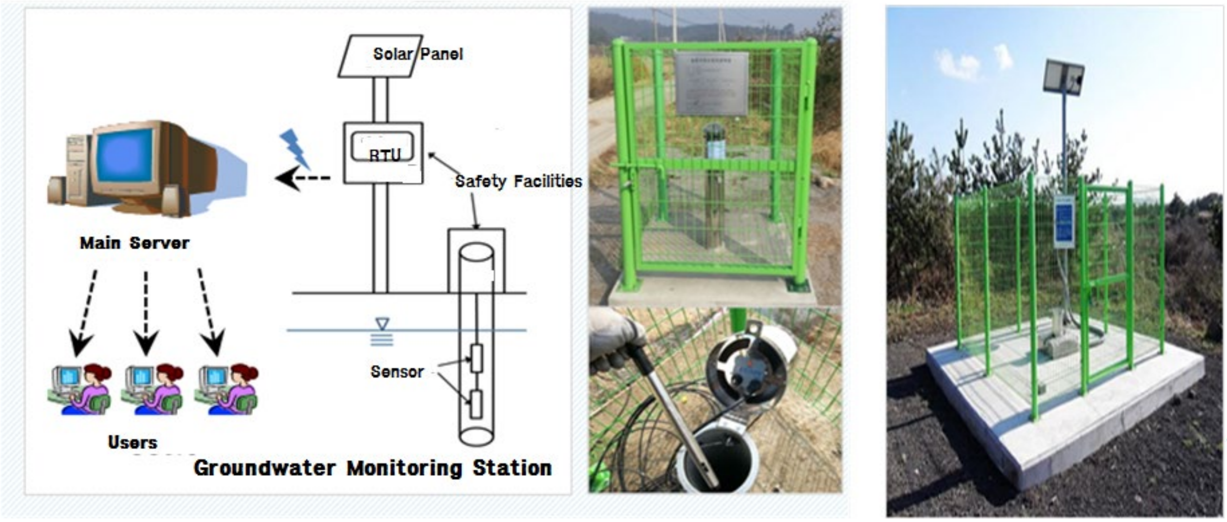
(j) Maruba Station

The site is located about 4km from the downtown of Machacos and near the Maruba Dam, Sewerage. Treatment Facility. It is an area suitable for water quality monitoring such as water discharge form dam and treated sewerage water.

Figure 39: Location & Scope of Maruba Dam / Maruba Station

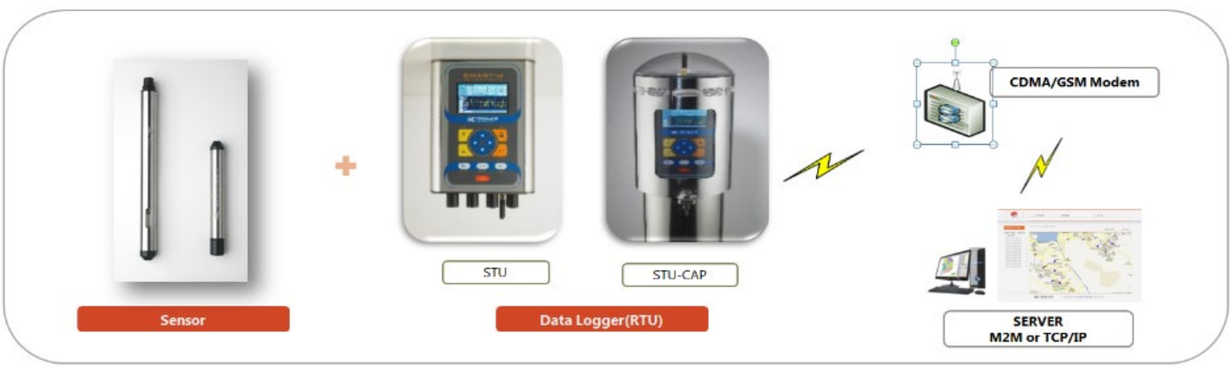
4.1.4.2 The Components of a Groundwater Monitoring System

Figure 40: Diagrammatic representation of a Groundwater Monitoring System



The system comprises four sections, namely a monitoring well, a sensor, a data logger, and management software.

Figure 41: Tools used in a Groundwater Monitoring System



(a) Monitoring Well

Figure 43 shows the recommended and preferred protocols followed in constructing, installing, and developing groundwater monitoring wells. It must be carried out by knowledgeable and experienced practitioners. The important thing of this work is to determine the diameter and depth of monitoring well. The diameter of the monitoring well is recommended from 6" to 12". It is reasonable to determine the depth of the monitoring well by gauging the hydrogeological properties and the aquifer characteristics around the station site. Generally, the depth of a monitoring well ranges from 100 m to 200 m. These, it should be determined by considering the hydrogeology in the detail design process.

Figure 42: The process of developing a monitoring well

(b) Sensor

The remote measuring instrument (sensor) acquires data on the water quality (including water level) of groundwater continuously. The sensor can measure water level, the conductivity of electricity, and water temperature, all at the same time. This is possible through use of patented technology that aims to improve the accuracy and reliability of the data measured as well as to maintain the system. Table 21 presents the most commonly used sensors in groundwater monitoring.

The cable that connects the sensor and the RTU may be stretched due to long-term use. It may also get worn-out. Both situations can reduce the reliability of the data. Therefore, it is important to select sensors and cables bearing these eventualities in mind.

Table 21: The Sensor Model that is most commonly used in the world.

BRAND/ Items	Solinst (LTC Level logger)	Diver CTD-Diver	In-situ (AQUATROLL200)	Hydronet (MK21-CTD)
Basic communication method	Optical Infra-Red	Optical Infra-Red	Rs-485, SDI-12	Rs-485, SDI-12
RS-485 & SDI-12 Support	Need Separate Converter	Need Separate Converter	Basic support	Basic support
Temperature Sensor	Inner mounted Type → Slow reaction rate	Inner mounted Type → Slow reaction rate	External Probe Type (small stick) → Little slow reaction rate	External Probe Type → Fast reaction rate
Pressure Sensor	316L SS	Ceramic → Low accuracy	Titanium	316L SS
Barometric Compensation	Self-Compensation X (Possible to compensate from separate Barometer)	Self-Compensation X (Possible to compensate from separate Barometer)	Self-Compensation O	Self-Compensation O
Memory (Sets of reading)	40,000	48,000	190,000	237,000
Power	Inner Battery [After Discharging: Not available]	Inner Battery [After Discharging: Not available]	Inner Battery [After Discharging: Not available]	Replaceable Inner Battery [After Discharging: Replacement & Operated with external power]
Measuring Accuracy	Level: ±0.1 %FS Temp :±0.1℃ EC: ± 2% of reading or 20 ㎲/cm	Level: ±0.05 %FS Temp :±0.1℃ EC: ± 1% of reading	Level: ±1.0 mbars Temp :±0.1 ℃ EC: ±0.5 % (0~100,000 ㎲/cm) ±1.0% (100,000~200,000 ㎲/cm)	Level: ±0.1 %FS Temp :±0.05 ℃ EC: ±0.5 % of reading or 10 ㎲/cm

(c) Remote Terminal Unit (RTU) and Data Logger

RTUs should be installed in the upper section of the groundwater monitoring well to transmit the data collected to the server. This device collects and saves the data and transmits it from the sensor to a remote server via GSM/CDMA communication system. This instrument must have durable and stable circuits to suit the outside environment. The power source of the latest RTU model is optimized for management as it supports both dry battery cells and solar power at a same time.

Table 22: The Common RTU Model

BRAND/ Items	Solinst (Level Sender)	In-situ (TUBE 300R)	Hydronet (STU)	Hydronet (STU-CAP)
Power Supply	3 x AA 1.5V replaceable lithium batteries	10.8V/19Ah Lithium battery pack	Lithium 2 x 7.2V/19Ah battery packs	Li-Ion 2 x 10.8V/2.6Ah Rechargeable Battery (with built in Solar controller)
Battery Life	Hourly sampling and daily reporting: 4 years with 1 Data logger, 3.3 years with 2 Data loggers	Up to 5 years when logging every 10 min. and uploading data 1/day	Up to 5 years when logging every 10 min. and uploading data 1/day	2 years guaranty
Solar Controller	N/A	N/A	N/A	12V 1A
UI (Display, control)	LED	N/A	3.2inch QVGA TFT LCD, 12 Key-pad	
MODEM	GSM 3G 4 bands (850, 900, 1800, 1900MHz)	GSM 2G 4 bands (850, 900, 1800, 1900MHz)	GSM 4G 5 bands (800, 900, 1800, 2100, 2600MHz) Applicable to Modem by region characters besides Europe	
Communication	Email or SMS data transfer, Dynamic IP	SMS, email, and FTP	TCP/IP, SMS	
Internal Sensors	N/A	Barometer, Temperature sensor	Barometer, Temperature, Humidity	
Barometric Compensation	Performed by user in Levelogger Software or external database	automates barometric pressure compensation	automates barometric pressure compensation	
Sensor compatibility	Connect to only Solinst sensor	Connect to only In-situ sensor	2 Port (RS-485, RS-232, Sdl-12 Support) Applicable to connect other brand's sensor(Hydronet, In-situ, OTT etc.)	
Memory Capacity	Between Reports : Up to 40,000 LT logs, or 28,000 LTC logs	512MB SD Card (not replaceable)	Internal 16MB flash (60,000 logs) And 4GB micro-SD card(replaceable)	
Dimensions	63mm x 238mm (with antenna folded down), cylinder	50mm x 480mm, cylinder	152mm x 46mm x 198mm, square	152mm x 46mm x 198mm, square
Materials	PVC, 316 stainless steel	Stainless steel	Aluminum(Anodizing)	STS304
Ratings	IP67	IP68 (cannot operate submerged)	IP68	IP68

(d) Management Software

Management software is installed in the main computer to check water level and quality remotely and to collect and analyze water quality data saved in the RTU. The software manages data effectively through real-time monitoring and through an unusual operating case. It is also easy to gather the information from the installed equipment and enable an alarm function to deal with any abnormal situation immediately. The data acquired by monitoring can be shared with stakeholders through the website. It is recommended that Kenya share the data with officials alone owing to various problems such as online security and poor internet connectivity.

4.1.4.5 O & M and Capacity Building

As mentioned above, water resources can be divided into surface and ground water. However, they are not independent, but are rather, interactive. Therefore, water management plans should take into consideration this interactive relationship between both surface and groundwater. This task cannot be achieved within a short period of time. It can be done only through a long-term initiative with a huge budget and specialists. I would like to mention a few things in this regard, hoping that this project will help.

First, this project can be carried out only if Kenyan organizations collaborate and cooperate. We should consider the ultimate goal of the project, away from the role of each institution or political issue. The purpose of this project is to preserve the Athi River Catchment Area. In order to achieve this goal, the cooperation and collaboration of Kenya organizations are of the highest priority.

Second, it is the maintenance of the facilities such as monitoring station and central control center. Of the 10 potential groundwater monitoring stations, 9 are located in public places with security and 1 is located in a private farmland. Local officers should manage these facilities from time to time such as through installed sensors and Remote Terminal Units(RTUs) and check for any abnormality.

The central control center should be installed only for the sake of operating the monitoring system. If the facility is used for any other purposes such as a common office or a warehouse, it can disturb the monitoring operation. Further, the monitoring system should be designed to manage surface water and groundwater at the same time.

Third, the Kenyan government should decide how to manage and use the acquired data. Whether the data will be shared only with the related officers or whether it will be made available to academics or will the public. If the government wants to share the data with the public through online, it must take efforts to protect the data.

Fourth, the depth of monitoring well is determined through hydrogeology study. This process requires understanding the hydrogeology, aquifer of the each monitoring area. This should be done more detail in design step. In this proposal step, we have suggested a general depth of monitoring well.

Fifth, the competence of stakeholders should be improved. The ability of the officers in charge of managing each facility will be different. All personnel must be trained in system maintenance and evaluation for many years in advance in order to acquire the required level of competence.

Sixth, the parameters to be measured in real time through these monitoring wells are Ec, Temp, water level. For more detailed monitoring of water quality, the additional parameters should be checked in the lab. For this task, the parameters generally include ions, trace metals, N species, microbiological, carbonate equilibria, oxygen status, and organic. Moreover, the number of checks to be conducted in a year needs to be decided.

Seventh, the implementation of this project should be carried out by a consortium of foreign and Kenyan companies. This way, it would be possible to transfer advanced technology from foreign companies to Kenyan companies for the project period. After the project ends, Kenyan companies can take over maintenance duties.

Eighth, the authorities should decide how to use the acquired and analyzed monitoring data. It is recommended to select and manage the lower limit of critical water level of each monitoring well. Based on the data for five years after the completion of this project, determine the threshold of the critical water level for each monitoring well. If the water level is near the critical level, please send a warning message to the central manager and the regional manager to manage the groundwater utilization.

4.1.4.6 Estimated Budget for groundwater monitoring stations

The following budget is for 10 stations meant for groundwater monitoring, excluding the budget for the central control center and software. The budgets include the surface monitoring cost (see Table 23).

Table 23: Estimated Budget

(price unit : USD)

Item	Unit	Cost/per	Quantity	Total Amount	Remarks
Drilling (A)	No	19,000	10	190,000	Including additional works and materials (outer casing, inner casing, logging test, and pumping test)
Civil Works (B)	No	3,000	10	30,000	Including protection facilities
Sensor, RTU (C)	No	18,000	10	180,000	Including installation works and the power source
Water Sampler(D)	No	1,000	10	10,000	Diameter is less than 80mm
Training (E)	No	10,000	5	50,000	Including maintenance works during the warranty period
Sub-Sum(F)			F=SUM(A:E)	460,000	
Reserve (G)			G=F*10%	46,000	
SUM (H)			H=F+G	506,000	

4.1.5 Rainfall Monitoring Stations

4.1.5.1 Current Situation

In the CMS 2014-2022, the Athi region has rationalized its rainfall station network and targeted 50 stations for monitoring, as against the 38 stations proposed in the NWMP 2030. According to the 2017 Hydro-meteorological Data Profile Report published by the WRA, the total number of rainfall monitoring points in the Athi Catchment Area was 53 in 2016. Of these, only four stations are gauged in 2016. At the other points, rainfall measuring ended before 2016, with a time interval. Rainfall monitoring has not conducted at any of the points so far.

4.1.5.2 Field Survey

WRA proposed 7 stations as sites for the installation of automatic rainfall monitoring systems as seen in Table 24. Survey team conducted meetings with stakeholders in three counties, namely, Nairobi, Nyandarua, and Kiambu, and field survey to evaluate the proposed rainfall monitoring stations between July 3 and July 13. Five out of the seven sites surveyed were found feasible for installation of automatic rainfall monitoring systems after considering various environmental factors such as project area, location, the status of data radio communication, and potential obstacles to the measurement of rainfall such as large trees.

Table 24: Proposed and Selected Rainfall Monitoring Stations

No.	Name of Station	Name of River	Coordinates		Selection
			Latitude	Longitude	
Nairobi County					
1	Wambaa Primary (WD 724)	Athi	-1.24512	36.62660	O
2	Ministry of Public Works (WD548)	Athi	-1.30049	36.83166	O
Nyandarua County					
3	Engare Narok Melghis Sub-Region of WRA		0.26723	36.54826	X
Kiambu County					
4	Kamwangi Dos Office	Athi	-0.95037	36.89615	O
5	Kieni Forest Station	Athi	-0.85372	36.67613	X
6	Upland Forest Station	Athi	-1.04691	36.65708	O
7	Ruiru Dam	Ruiru	-1.04829	36.75605	O

The instrument that can transmit the measurement data using wireless communication is installed at the Upland Forest Station as shown in Figure 48. However, it is currently in a state of repair. The other stations have manual rain gauges. Most of them are not operated and managed properly.

Figure 43: Wambaa Primary (WD724)

Figure 44: Ministry of Public Works (WD548)

Figure 45: Kamwangi Dos Office

Figure 46: Kieni Forest Station


Figure 47: Upland Forest Station

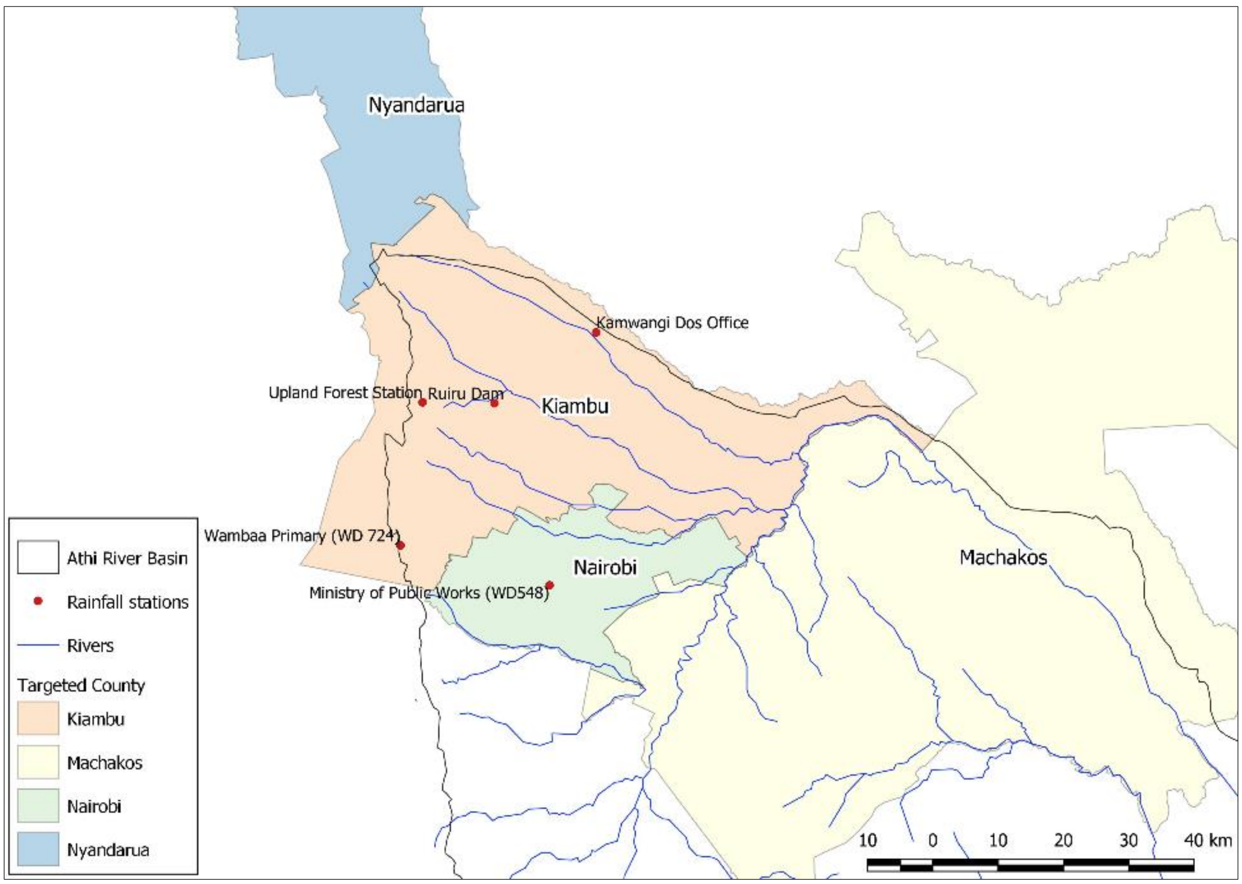

Figure 48: Ruiru Dam Station


4.1.5.3 System Installation Plan

Figure 50 shows the location of the automatic rainfall gauge stations selected in this project. It is recommended that the water level sensor, water quality multi-sensor, and the rainfall gauge be installed together for the Ruiru Dam Station. The automatic rainfall gauge is to be installed independently for the other stations. The rainfall gauge should contain a data logger to store and transmit data. The data logger should be integrated with a GPRS / GSM transmitter so that it can use a SIM and send data to central data servers or cloud-based storage maintained at the WRA and KMD.

The power supply necessary for the operation of the system should rely on a small but stable solar power source that is similar to what is used by surface water monitoring stations. Housing and fences should be installed to protect the equipment.

Figure 49: Location of the rainfall gauge stations



4.1.5.4 Operation and Maintenance and Capacity Building

WRA should be in charge of the operation and maintenance of the new rainfall stations. At the end of the maintenance period for the automatic rainfall monitoring system, the fresh contract for the maintenance is needed with the contractor within the budgetary allowance for the maintenance of the system such as inspection and repair can be performed continuously.

4.1.5.5 Estimated Budget for Rainfall Stations

Description / Item	Unit	Quantity	Unit Cost (USD)	Total amount (USD)	Remarks
EQUIPMENT					
Tipping bucket rain gauge C/W POLE	No.	5	1,900	9,500	Inclusive of labor
Manual rain gauge	No.	5	470	2,350	
Solar PV panel 30W + 70 Ah battery	No.	5	1,600	8,000	
Computer server	No.	1	8,000	8,000	
			Sub total	**27,850**	
CIVIL WORKS					
Topographical survey	L/S	5	1,500	7,500	
Data logger house	L/S	5	4,400	22,000	
Fencing works	L/S	5	2,500	12,500	
Branding	L/S	5	380	1,900	
			Sub total	**43,900**	
MAINTENANCE AND TRAINING					
Operation and maintenance cost	Per site	5	2,000	10,000	
Tools and spare parts for O&M	Lsum	1	15,000	15,000	
			Sub total	**25,000**	
			Grand Total	**96,750**	

4.2 Development of Water Resources Management Information System

4.2.1 Background

The Ministry of Water and Sanitation was established through an executive order to conserve, protect, and manage Kenya's water resources through its various state corporations and water service boards. The Ministry's vision is to ensure the availability and accessibility of water resources to all, and its mission is to contribute to national development by promoting and supporting IWRM to enhance the availability and accessibility of water. This is especially so through the environment, water, and sanitation sectors as part of the social pillar of the Vision 2030 blueprint.

The Ministry uses data and information for specifically intended purposes. Data and information pertaining to the water sector are collected for specific purposes determined by the Ministry, and, where appropriate, by other agencies or entities with whom the Ministry of Water and Sanitation has contractual, formal, or informal agreements in place for data and information sharing. Data generated by field activities are of little or no value if they cannot be accessed readily and confidently by potential users. There is concern that when more precise and reliable data and information pertaining to the water sector is necessary, the Ministry may not be able to provide them. The Water Research, Data, and Information Division hence aims to establish a web-based database comprising data and information pertaining to the water sector for the Ministry's use to inform policymakers, stakeholders, partners, and the general public.

The Ministry of Water and Sanitation, State Department of Water, is charged with the responsibility of formulation, review, and coordination of policies. Therefore, the availability of verified and reliable data and information becomes necessary. This helps meet the sustainable development goals and the appropriate standards of use of water and related resources. It also provides information to mitigate the impact of water-related disasters such as floods, droughts, salt-water intrusion, desertification, and pollution.

4.2.1.1 National Water Policy

The policy approach for water resources management and development is summarized as follows:

- Water is treated as a social and economic good;
- Available water resources must be preserved, conserved, and protected;
- Water resources should be allocated in a sustainable, rational, and economical manner;
- Safe wastewater disposal should be ensured for environmental protection; and
- A sound and sustainable financial system should be developed for effective and efficient water resources management, water supply, and water-borne sewage collection, treatment, and disposal.

To ensure integration with other sectors in managing water resources effectively and sustainably, the water policy is complemented by other policy documents that recognize water as an important catalyst for both social and economic development, and that effective institutions have a key role to play in the sustainable management of water resources and provision of services to the people.

4.2.1.2 The National Water Resources Management Strategy (2012)

The assessment of water resources is essential in establishing the status of the resources in terms of quantity, quality, and use. Based on such an assessment, information can be generated for strategically planning the management of water resources to ensure the equitable sharing and rationalizing of water use and to ensure a balance between demand and supply. To realize this, the following strategic actions have been developed.

(a) Classify water resources in accordance with type and location for effective and sustainable management of the resources

The management of water resources can be improved substantially if knowledge on quality and quantity of the resource is regularly updated. This can be realized through regular assessment based on a comprehensive program. Although projections have been made to reflect the changing scenarios driven by population growth and environmental changes, the current state of knowledge on water resources may not be accurate enough. A current comprehensive assessment is therefore necessary. This has been initiated and should be continued and completed in order to provide authenticated information on water resources for effective and sustainable management of the resources.

Classification of water resources is a fundamental requirement for effective and sustainable water resources management. A classification system has already been developed in which three broad and competing water use classes, namely commercial, livelihood, and environmental use, have been identified. The classification acts as a guide in water allocation and ensures that the process is undertaken equitably in accordance with the demand area and its needs.

In addition to the aforementioned classification, the catchment areas are classified into three categories of alarm, alert, and satisfactory levels depending on the status of the quantity and quality of water, as well as the importance and impact. The classification lays the ground for developing the Resource Quality Objectives (RQOs).

(b) Develop a functioning system for the consistent acquisition, analysis, and archiving of data on water resources

The consistent acquisition of data on both surface water and groundwater is a prerequisite for the effective management of water resources. So far, strategic monitoring stations of national, regional, and special interest have been identified through catchment management strategies. Groundwater monitoring is also being revived although this is mainly done through production boreholes. So far, no clear strategy has been developed to undertake groundwater monitoring systematically.

The challenges in acquisition of consistent surface water data relates to inconsistency in manual gauge reading and vandalism, which leads to inadequate and unreliable data. The main problem with manual reading is the lack of regular compensation to gauge readers while vandalism is more out of curiosity in most cases. Some of the aforementioned problems can be addressed by institutionalizing data collection. This is possible through the involvement of WRUAs and the possibility should be explored. Data transmission can be fast tracked through mobile phone technology to ensure that water resources management data are relayed in a timely manner.

Further, emphasis should be equally laid on data collection in groundwater monitoring, especially with regard to the assessment of the potential. This is because groundwater is increasingly becoming a major source of water supply both in urban and rural areas. The reason for this is that the quality and quantity of surface water is declining fast due to degradation, climate change, and increasing population, among other reasons. In ASALs, groundwater is almost exclusively the most dependable source of water. Therefore, there is a need to establish its potential in order to plan its utilization more effectively. Currently, Kenya's groundwater potential is not well known. Measures should therefore be put in place to undertake systematic, regional groundwater assessment to come up with detailed hydrogeological maps showing the status of groundwater in the entire country.

(c) Operationalize the Water Resources Information System to plan water resources development and policy formulation

Data acquired from monitoring systems do not mean much in terms of management of water resources even if they are properly processed and archived, unless the data are made available to planners and policymakers. The Water Resources Management Information System (WRMIS) that is meant to deliver water resources information to planners and policymakers should be made operational to ensure easy access to data. In order to realize this, hydrological software for data analysis and modeling should be utilized comprehensively.

The human resource capacity to manage the information system is still inadequate. This has resulted in an inadequate output from WRMIS. Capacity building for the application of all components of WRMIS needs to be prioritized so that the system can generate adequate information.

(d) Operationalize the criteria for reserve water determination to ensure the availability of water for basic human needs and the environment

The preservation of reserve water has been emphasized in a number of policy documents with fundamental provision outlined in the Water Act 2002. Further, Vision 2030 has set a benchmark in that 90% of the rivers should have reserve flow at all times. Water for basic human needs and the environment, that are the two key users of reserve water, have been captured in the Constitution of Kenya under articles 43 and 42 respectively. These are the mainstream laws upholding the right to access reserve water. The criteria for determining reserve water have been developed and should be enforced. The same criteria should be applicable to groundwater where safe exploitation of aquifers should be enforced.

Challenges have been encountered in the implementation of reserve water criteria, and in particular, with the enforcement of abstraction for other uses that are not taken care of by the reserve water. The enforcement of these criteria has been strengthened in the recent past through training of prosecution officers to focus on cases of violation of abstraction conditions as stipulated in the Water Resources Management Rules 2007. The gazettement of trained prosecution officers should be finalized and additional officers should be trained and gazetted during the period of the implementation of the strategy in accordance with the training plan.

(e) Build capacity through training, research, and technology transfer

Training and research need to be continuously carried out in order to build a knowledge base for sustainable water resources management. This can be achieved through the involvement of training and research institutions in developing relevant curriculums and undertaking applied research. This collaborative initiative will include the development and transfer of technologies that would lead to the identification of new water sources and improvement in the efficiency of water use.

4.2.1.3 National Water Master Plan 2030

The objective of the National Water Master Plan (NWMP) 2030 is to present a framework for water resources development and management consistent with the country's social and economic development. The plan offers information on how water will be managed and developed to meet the country's development needs as envisaged in Vision 2030. It is divided into nine sub-plans i.e.

- Water supply development plan
- Sanitation development plan
- Irrigation development plan
- Hydropower development plan
- Water resources development plan
- Water resources management plan
- Flood and drought disaster management plan
- Environmental management plan
- Institutional strengthening plan for water resources management

4.2.1.4 Requirements and Goals

The Water Research, Data and Information Division is the custodian of all data and information related to the water sector in the Ministry of Water and Sanitation. The term, "data and information" refers to any report, document, paper, correspondence, submission, recording (video, digital, and graphic) or any other item in which information is produced, managed, and maintained. The division has identified a gap in the water sector data and information. This gap has led to misplacement, wrong use of, or complete loss of data and information. There is, therefore, a need for the establishment of a system for data and information management and sharing in the Ministry.

A web-based platform or database that can capture, store, manage, disseminate, and share data and information on the water sector is recommended. The proposed system aims at demonstrating the successful implementation of an integrated approach to water resource management, based on the application of adequate governance methods, technologies, and public participation.

Table 25: Goals and Objectives of Monitoring and Information Management[50]

Goal: Provide necessary information to support proper planning and management of water resources
Objectives:
• To optimize the water resources monitoring network
• To enhance the data management system (data collection, analysis, storage dissemination, research and development)
• To upgrade the water resource information system (WRIS)
• To establish an effective monitoring, evaluation and reporting system for the implementation of CMS

4.2.1.5 Basic Approach

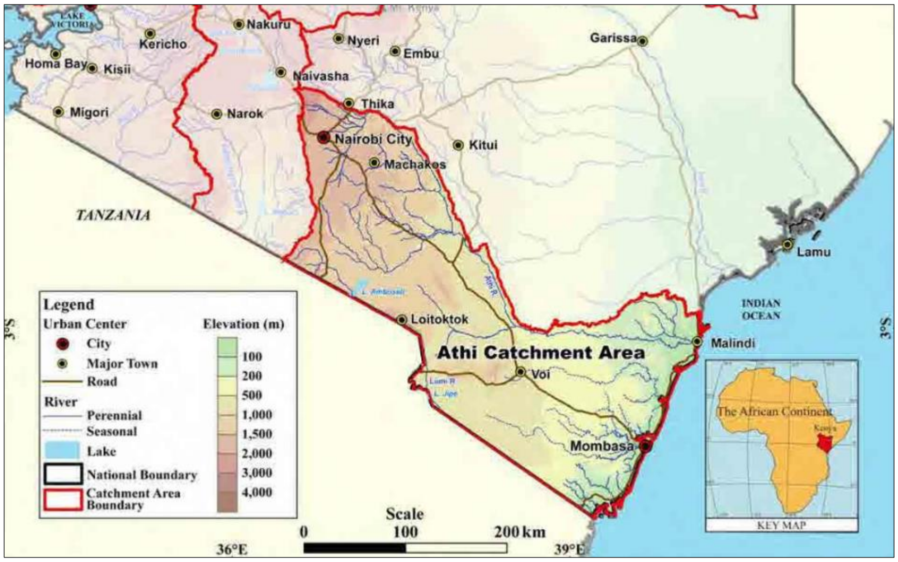
The proposed web-based network will comprise a stand-alone server that is, an adequately powerful desktop computer connected to a server and associated hardware. The latest software will be installed on both the server and PC. The system will be available online, and will have different security levels where one's access to the data and information is restricted to particular rights. For institutions mandated to have the data as a source of revenue, the option of payment for the data and information will also be available within the network.

The system will also be connected with on-field tele-metric stations for data capturing. Two technical experts (consultants) will be engaged to establish the web-based platform. Capacity building on management and maintenance of the system; Geographical information systems (GIS), Remote sensing & modeling as well as stakeholder analysis and consultation processes through workshops held at the various regional catchment areas.

The initial process is anticipated to take one year while the maintenance of the system and staff training programs (including refresher courses and technology upgrades) will remain a continuous process.

50 CATCHMENT MANAGEMENT STRATEGY(CMS) (2015-2022)

Figure 50: Map of the ACA



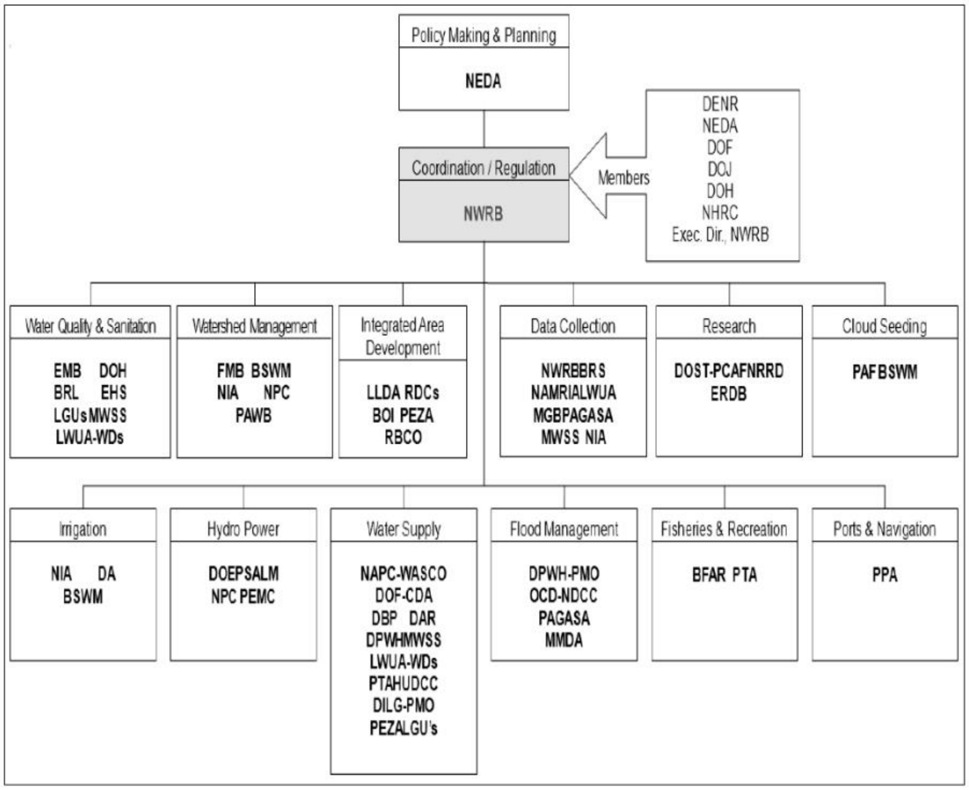
4.2.2 Case Studies on the Water Resources Management Information System

4.2.2.1 The Philippines

The Philippines' National Water Resources Board (NWRB) has the authority to regulate, manage, develop, conserve, and protect national water resources. One of main functions of the NWRB as a water regulator is to establish and regulate water resources policies and specify regulations governing the use of water resources through water-related system. In terms of policy coordinators, IWRM's water sector policy is formulated through consultations with water-related agencies and stakeholders, supporting decision-making on national water resources, and reporting all water-related data in the country through the national water resources network.

The Philippines' national water resources development strategy is based on the IWRM which manages water resources in an integrated and systematic manner. In particular, it does not hinder the sustainability of essential ecosystems through the development and management of water resources and hydrological categories.

Figure 51: The Philippines' National Water Resource Board and Other Authorities



Integrated Water Resource Management (IWRM) has been identified as the overall strategy for: (a) the effective protection and regulation of water for security and ecosystem health; (b) the provision of responsive services for present and future needs; (c) the improved effectiveness, accountability and synergy among water-related institutions and stakeholders, and (d) adaptive and proactive responses to emerging as well as future challenges. While the concept is widely accepted, however, IWRM practices have not been mainstreamed in policies, plans and programs. Similarly, integrating the efficient approach to the development of water infrastructure to support the desired transgenerational outcomes in the sector has yet to be realized. The experience of numerous recent instances of disasters, nonetheless, has raised awareness and increased the acknowledgement of the benefits of IWRM. Now is an opportune time, therefore, to implement coordinated activities to mainstream IWRM practices and promote the development of eco-efficient water infrastructure.

Because of the fragmented nature of the water sector, the establishment of a comprehensive and accessible information management system is necessary to ensure coordinated planning and implementation. Data collection methodologies have to be synchronized to support planning and budgeting of key programs and projects. Mechanisms that allow consistent updating and harmonization of raw data should be put in place alongside the sharing of such data among the relevant stakeholders, project developers and key policy-makers.

System Contents;

- Based on the GIS and remote exploration technologies, the integrated water resource management information system including the disaster and water resources database of the Pampanga basin is systematically constructed and utilized to develop a program to monitor and analyze the water resources status in real time
- Acquisition and construction of data related to water resources GIS
- Information management of Reservoir and Irrigation
- River Information Map Book
- Development of Flooding Analysis System
- Development of Dam Automation System
- Underground water information management and mapping
- Website for providing information of Water resources
- Capacity Building for water resource GIS experts

4.2.3 Current Status of, Gaps in, and Barriers to Water Resources Management

4.2.3.1 Current Situation of Water Resources Management in the ACA

The ACA has densely populated cities including the largest city Nairobi, as well as Kiambu, Machakos and surrounding areas, and the second largest city, Mombasa. The area is expected to have pressed water demand and supply balance in the future. Nairobi and surrounding areas may face a decrease in groundwater resources due to the over abstraction of groundwater.

Table 26 shows the current monitoring targets, numbers of operational stations and their achievement ratios for surface water and groundwater, water quality, and rainfall. Surface water level and groundwater level monitoring stations have not been maintained well.

Table 26: Current Monitoring Situations of Water Resources(ACA)

Item	Surface Water\ (SW) Level	Groundwater (GW) Level	SW Water Quality	GW Water Quality	Rainfall
Target	31	71	31	18	50
Operational	18	25	26	18	33
Achievement(%)	58	35	84	100	66

The current state of water permit issuance and management is shown in Table 27. The ratio of valid permits to issued permits is presented as well.

Table 27 : Current Situations of Water Permits(ACA)

Item	Application	Authorized	Issued Permits	Valid Permits	Ratio of Validity (%)
Surface Water	2,999	2,751	470	199	42
Groundwater	7,449	5,895	571	217	38
Total	10,448	8,646	1,041	416	40

The Aberdare Range, which is the major source of water for the Athi River, should also be conserved. Deforestation and forest degradation are rampant in the gazetted and private forests in the southern part of the Aberdare Range. The private forests are located in the upstream reaches of the Lokerish and Kaiti Rivers and to the west of Voi Town. According to the results of the satellite imagery analysis in Chapter 8 of the National Water Master Plan, the forest area in the ACA was about 120,000 ha in 2010, which amounted to 2.0% of the total forest cover. The deforested areas during the last two decades amounted to about 133,000 ha, which implies that there was a decrease of about 52.5% of the forest areas over 20 years since 1990.

According to interviews with stakeholders of watershed conservation including WRA and KFS in the ACA, there are deteriorations on small water sources such as 20 springs and 17 wetlands. Such issues affect the availability of water resources in the catchment area adversely as there are many semi-arid lands in the ACA that depend heavily on small water sources.

Management of water resources data and information is done through the database and information system which handle permit and hydrological data and generate information for users of water resources in the regions and sub-regions of the WRA. The system enables efficient data sharing for the effective management of water resources. To assess the performance of the database, information on ground water, surface water, and water quality have been extracted from the database in three categories of operational stations, duration of data collection, and frequency of updating data. The details are presented in Table 28.

Table 28: Status of the Water Resources Monitoring Database[51]

	Operational Stations			Duration of data collection			Frequency of update		
	SW	GW	WQ	SW	GW	WQ	SW	GW	WQ
Athi	19	25	63	25 yrs	3 yrs	9 yrs	Monthly	Monthly	Quarterly

4.2.3.2 Data Quality Status

The availability of automatic equipment that logs data on an hourly basis has ensured that all events are captured in the upgraded stations mentioned earlier. However, this practice can only be sustained if the stations are visited regularly and the batteries are changed promptly to avoid the loss of data.

51 WRMA Performance Report 5 (2016)

The equipment is regularly gauged in order to validate and improve the rating equations. The gauging plan involves continued measurement of discharge at the newly installed or rehabilitated stations. This is done to develop and/or improve the rating curves. This was done quarterly by the regions but the data needs to be entered in the database for updating of the rating curves.

Figure 52: Concrete Post Installed at Mwache 3 MB02 and Gauge Reader in the Athi Catchment Area

4.2.3.3 Current Situation of Drought and Flood Management

(a) Drought

Most of ACA, except for its most upstream parts in and around Nairobi and Machakos, is categorized as semi-arid land.

Drought damage in ACA is not as severe compared to the damage in RVCA or ENNCA. However, during the drought in January 2011, it was reported that agricultural production decreased remarkably. Further, there was an outbreak of livestock epidemic due to the deterioration of water quality because rains were exceptionally poor in localized parts of Malindi and Taita Taveta, where only 10-20% of the normal amount of rain was received.

There are eight existing dams for domestic water supply, namely Ruiru, Bathi, Mulima, Manooni, Muoni, Kikoneni, Maruba, and Kiserian (under construction). However, drought management including water use restriction of the reservoirs has not been implemented.

(b) Flood

Coastal areas in ACA suffer from flood damage nearly every year due to heavy rains. A flood in September 1997 caused 86 deaths and displaced 900,000 people in all, across Kilifi, Mombasa, and Kwale.

In the area around the Lumi River, which flows near the border with Tanzania, flood damage has continuously occurred since before NWMP (1992) was formulated. The floods led to mudslides in Taita

Taveta in 2008. The most affected areas by the floods in the Lumi River region are located downstream, on the side of the Yaveta urban area. These villages are smaller when compared to the Taveta urban area. The Njoro Spring, which is an important water source for this area, is also affected by these floods.

Large cities such as Nairobi and Momabsa, which are located in the upstream and downstream parts of the Athi River respectively, have also suffered due to floods. Once heavy rains occur in these cities, the rainwater that remains stagnant frequently causes traffic jams. In December 2009, thunderstorms, heavy rains, and winds were experienced in Nairobi. The Central Business District (CBD) and several slums were flooded.

It can be inferred that there is no systematic flood management system in place in ACA. Warning water levels have not been confirmed at major river gauge stations, either.

4.2.3.4 Gaps and Barriers

(a) Insufficient Links with Weather Information from the Meteorological Agency

WRA operates a weather monitoring network comprising rainfall, evaporation, and climate stations. During the year under review, 166 of 270 rainfall stations were operational, 47 of 65 evaporation stations were operational, and 22 of 32 climate stations were operational.

Table 29: Description of the Weather Monitoring Network[52]

	Rainfall	No. Operational	Evaporation	No. Operational	Climate	No. Operational
Athi	47	28	10	5	2	0

(b) Insufficient Hydrological Observation Facilities

- Spatial Distribution Evaluation for Hydrological Observation Facilities

The spatial distribution of hydrological stations can be evaluated using two types of information: rainfall and water level. The standards for judging the spatial distribution of rainfall and water level stations are different. For rainfall, the goal is to estimate the area average rainfall in the basin, while for water level, the goal is to estimate the basin response to rainfall using runoff. Therefore, while rainfall observation facilities take the entire basin into consideration, water level observation networks evaluate the rivers alone.

- Rainfall stations

In designing a rainfall station, the most important aspect is the number of observation points placed in the target basin and their locations. There is also the fundamental problem of how well measured rainfall data reflect the overall characteristics of the rainfall observation network as a population.

[52] NATIONAL WATER RESOURCES SITUATION REPORT FOR FY2015/2016

Table 30: World Meteorological Organization (WMO) Station Installation Standards[53]

Physiographic Unit	Precipitation(km^2)		Stream Flow(km^2)
	Non-recording	Recording	
Coastal	900	9,000	2,750
Mountains	250	2,500	1,000
Interior plains	575	5,750	1,875
Hilly/Undulating	575	5,750	1,875
Small islands	25	250	300
Urban areas	-	10-20	-
Polar/Arid	10,000	100,000	20,000

The weather monitoring stations operated by the WRA are strategically located at various parts in the catchment area. The WRA also obtains data from various stakeholders such as private institutions, government, and academic institutions. The data collected from these stations are used for modeling and planning purposes.

- Water Level Observation Network

In the case of water level observations, the goal is to estimate the basin response to rainfall using discharge. Therefore, while rainfall observation facilities consider the entire basin, the water level observation networks consider only rivers.

(c) Unstable communication Systems

Maintaining reliability and managing equipment are difficult because of the variety of transmission methods. In addition, the challenges keep increasing in station power consumption, spare parts management, and maintenance because receivers and transmitters are needed for transmission. Finally, it is difficult to ensure data security in the high frequency spectrum, and high costs are incurred due to use of several frequency spectrums.

(d) Inadequate Systematic Hydrological Data Quality Management

Hydrological data gathered from hydrological stations are an important component in all water management projects, such as flood forecasting in emergency situations, designing hydrological plans, and establishing policies. However, currently in the ACA, the hydrological data are not subject to systematic quality management due to the lack of quality control, the lack of standards to rank data quality, and the presence of inadequate systems for manpower and budgets.

53 WMO (No. 168, 2008)

(e) Absence of Scientific Flood Prediction

In a large-scale basin such as the ACA scientific flood prediction is an important factor in preparing for flooding and determining dam operation procedures ahead of flood seasons. However, no flood forecasting model has been developed for the ACA so far.

4.2.3.5 Issue Analysis

The previously described main problems and proposals for each field related to the ACA's water resource management are organized items in Table 31.

Table 31: Issue Analysis

Stage		Problems	Improvement
Rainfall forecasting		• Rainfall prediction data sharing system is unclear • Rainfall forecasting data needs to be gathered for warning activities	• Establishment of computerized data sharing system • Determining form and time intervals, and evaluating data accuracy
Information Gathering	Observation	• Inadequate number of hydrological stations • Absence of manual hydrological station data management	• Gradual expansion of hydrological stations • All stations needed automation
	Transmission	• Reliability and management difficulties due to variety of transmission methods available • Transmission network problems while extending observation networks into the future	• Review wireless network according to addition of observation equipment • Relay station improvements
	Quality Management	• Difficulty guaranteeing the quality of gathered data for rainfall and water levels due to the absence of a quality management system	• Establishment of system to link existing gathered data
Information Analysis	Decision Making	• Decision making delays and interference occur due to insufficient decision-making support system	• Establish decision making based on prediction results
Information Transfer	Issuance System	• Difficult to deal with relevant organizations and residents quickly when disaster occurs	• Establish an information transfer system
	Issuance Method	• There are limits to information transfer using manual transfer methods	• Establish a plan for speedy information transfer based on information technology

4.2.4 Roadmap for the Improvement of Water Resources Management Information System for ACA

The risk of drought and flooding is increasing in ACA due to climate change. Weather observations and forecasts are very important for the mitigation of climate damage and for the residents to prepare in advance. However, the process has not been implemented in an integrated and systematic manner. Our goal is to create a roadmap that includes the concepts and investment factors for the establishment of a climate warning and forecasting system in the ACA, so that the project can be executed systematically in the future.

4.2.4.1 Identifying Mechanisms for Improvement

(a) Establish a Shared System for Weather forecast data

- Very Short-term forecasting

This announces weather conditions for the next four hours at one hour intervals, including eight actual weather conditions, temperature, rainfall amount, rainfall type, relative humidity, wind direction, wind speed, sky conditions, and lightning, and four forecasted conditions, rainfall type, rainfall amount, sky conditions, and lightning.

- Short-Term Forecasting

The forecasts are announced for the next two days in three hour units, including 12 factors, temperature, maximum and minimum temperature, rainfall type, rainfall probability, rainfall amount, snow, wind direction, wind speed, humidity, and wave height.

- Mid-term Forecasting

This announces the weather for three to ten days in advance, twice daily, divided into AM and PM, or day units for eight to ten days, including weather outlook, land and ocean weather, maximum and minimum temperature, and wave height.

- Long-term Forecasting

This announces one-month and three-month weather forecasts.

(b) Expansion of Hydrological Observation Facilities

The existing hydrological observation facilities have been installed and operated for the purpose of monitoring water rather than for forecasting and warning. The number of hydrological observation facilities needs to be increased for areas in the ACA that are subject to major climate damage, and for areas where data are essential for forecasting and prediction requirements.

Figure 53: Water Resource Monitoring System

(c) Establishing a Reliable Telecommunications System

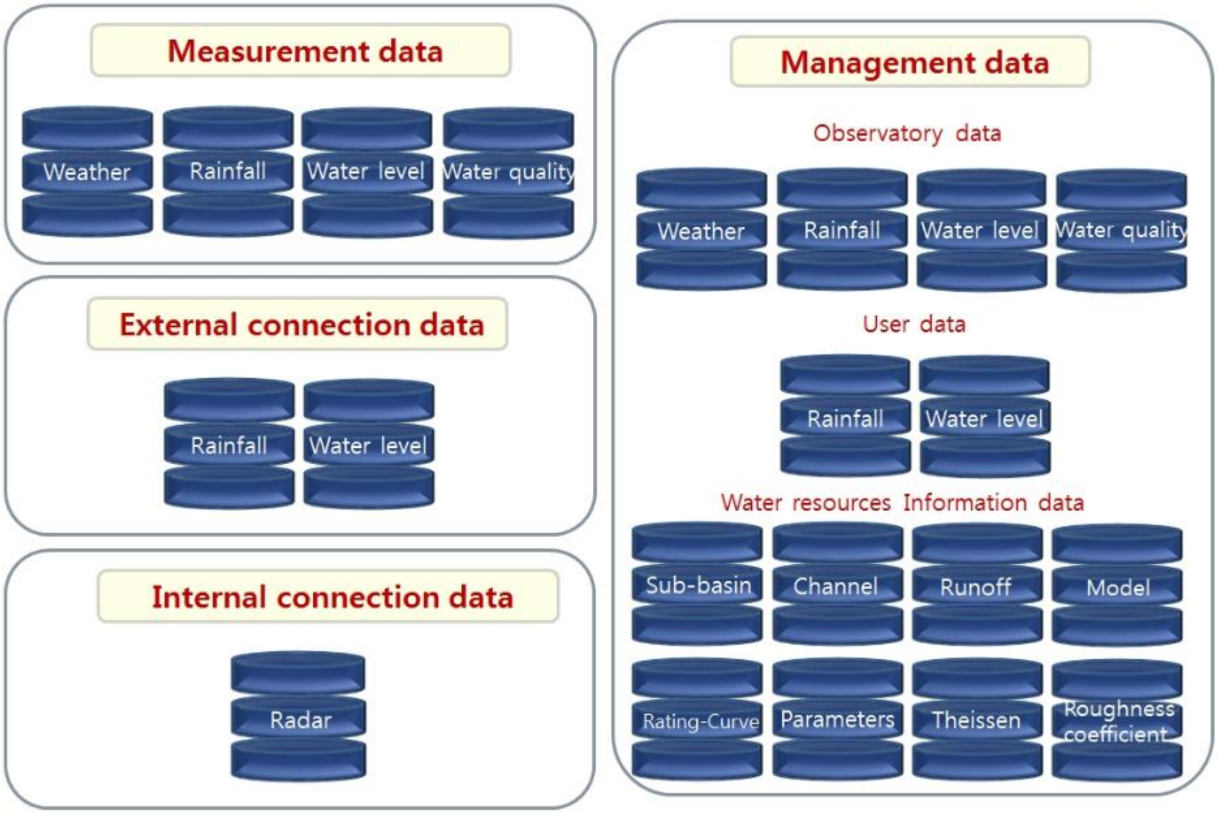
A single telecommunications network is required for the establishment of a reliable telecommunications system in the ACA. This requires upgrading the relay station equipment, integration of receiver-transmitters and controllers for transmitting to station equipment, expansion of the telecommunications network's management servers and DB servers, and the establishment of separate monitoring equipment that can confirm the voltage, transmission-receiving status, and solar cell operating state of stations and relay stations.

(d) Establishing a Deficient Hydrological Data Storage and Processing System

The data gathered from on-site equipment, such as rain and water level gauges, must be stored in an on-site data logger and transmitted via GSM to the data receiving server, and then checked for validity and stored on the database server.

To gather measurement data smoothly, a data sending-receiving program must be installed between the data logger and data collection server. It must be established in advance so that when abnormal situations occur, such as communications abnormalities, managers can manually gather the data stored in the data logger. The program also needs to have various features to confirm that the measurement data including a status bulletin, indicators for missing data, and odd status alerts have all been transmitted accurately.

Figure 54: Integrated Hydrological Database Layout Plan



(e) Systematic Hydrological Data Quality Management

High quality hydrological data are needed for overall water management operations in emergency situations, including flood forecasting and establishing hydrological designs and policies. For the efficient development and operation of water resources, providing accurate hydrological data should take precedence over other concerns. Therefore, it is important to improve the reliability of hydrological data.

In hydrological data quality management, the most important aspect is the maintenance and management of the stations and observation equipment that generate the data. The stations and equipment must be improved to avoid missing data and to correct error values in the data transmitted from the observation equipment. To recognize and correct error values, a standard must be set for the verification of error values at each observation point. Data that do not meet this standard must be automatically flagged in real time so that data correction can be performed through the quality management staff.

Figure 55: Korea's Quality Management System Concept Diagram

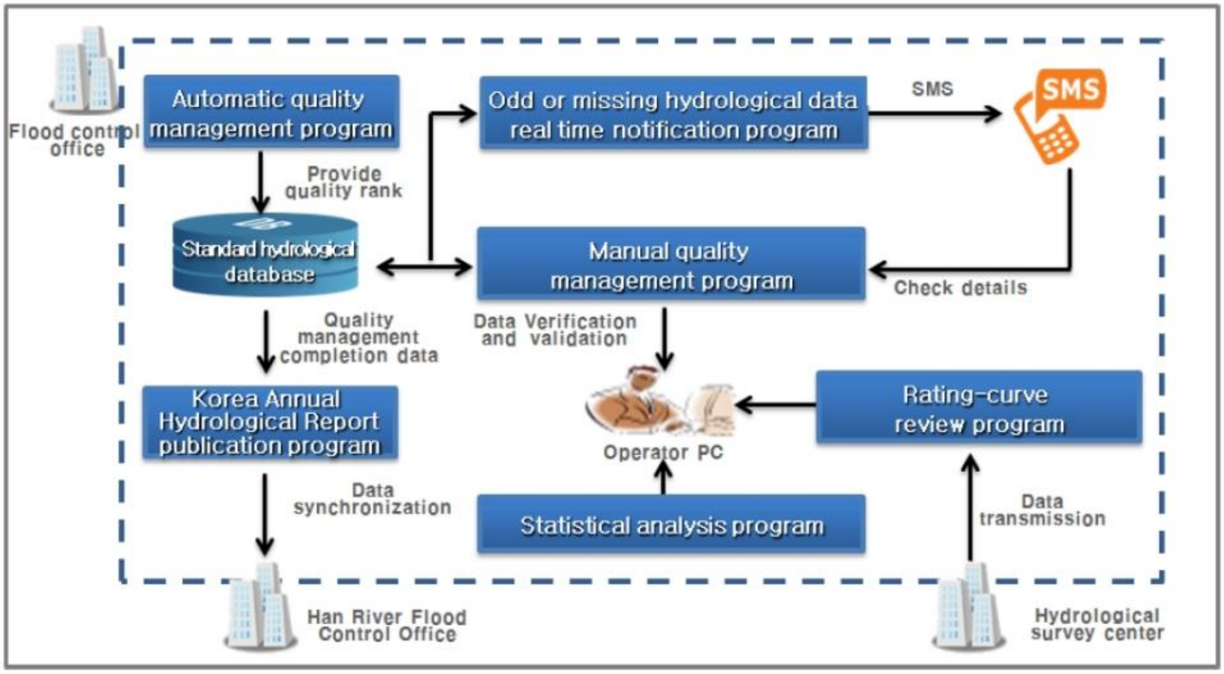


Table 32: Data Analysis Items for Setting an Error Value Standard for Hydrological Data

Rainfall	Water Level
▪ Maximum rain depth by observation time ▪ Difference in results between the corresponding and nearby observatories	▪ Highest and lowest changes in water level by observation time ▪ Difference in current slope and mean slope of the preceding two hours ▪ Observation period with the same water level
Notes: 1) Nearby observatory data use the existing observatory data, 2) Utilize statistical data that use existing hydrological examination results	

Table 33: Methods for Modifying and Supplementing Irregular and Missing Values in Rainfall Data

Using Corresponding Station Data	Using Nearby Station Data
▪ Modify normal observed values according to standard	▪ Modify using the arithmetic mean method
▪ Modify TM value at manager's discretion	▪ Modify using the RDS weighted mean method
▪ Recalculate rain depth data using TM value	▪ Modify using the CCWM
▪ At manager's discretion, modify appropriately	▪ Modify using the relation function

Table 34: Methods for Modifying and Supplementing Irregular and Missing Values in Water Level Data

Using Corresponding Station Data	Using Nearby Station Data
▪ Modify normal observed values according to a standard ▪ Modify using the linear interpolation method ▪ Modify using the curved rule method ▪ At manager's discretion, modify appropriately	▪ Modify using the relation function of pre-chosen up and upstream observatory values

4.2.4.2 Concept Design

The activities deployed to manage water resource information with the aim of reducing climate risk generally fall into one of the following stages: information gathering, analysis, and transfer. The primary components of each activity stage are shown in Table 35.

Table 35: Activities at Each Stage in Water Resources Information Management

Stage	Details
Information Gathering Stage	▪ Weather information to prepare for bad weather, such as several hours or days in advance ▪ Hydrological information to predict disaster by observing river water levels in real time ▪ River information to be used as parameter inputs for prediction models by providing GIS-based river attribute information
Information Analysis Stage	▪ Managers decide to issue actions at their discretion based on information gathered ▪ Information analysis is performed through analysis models
Information Transfer Stage	▪ Disseminate information between organizations or to the nation, and transmit information through various mechanisms, such as SMS, phone, mass media, and alarms

Figure 56: System Concept Diagram

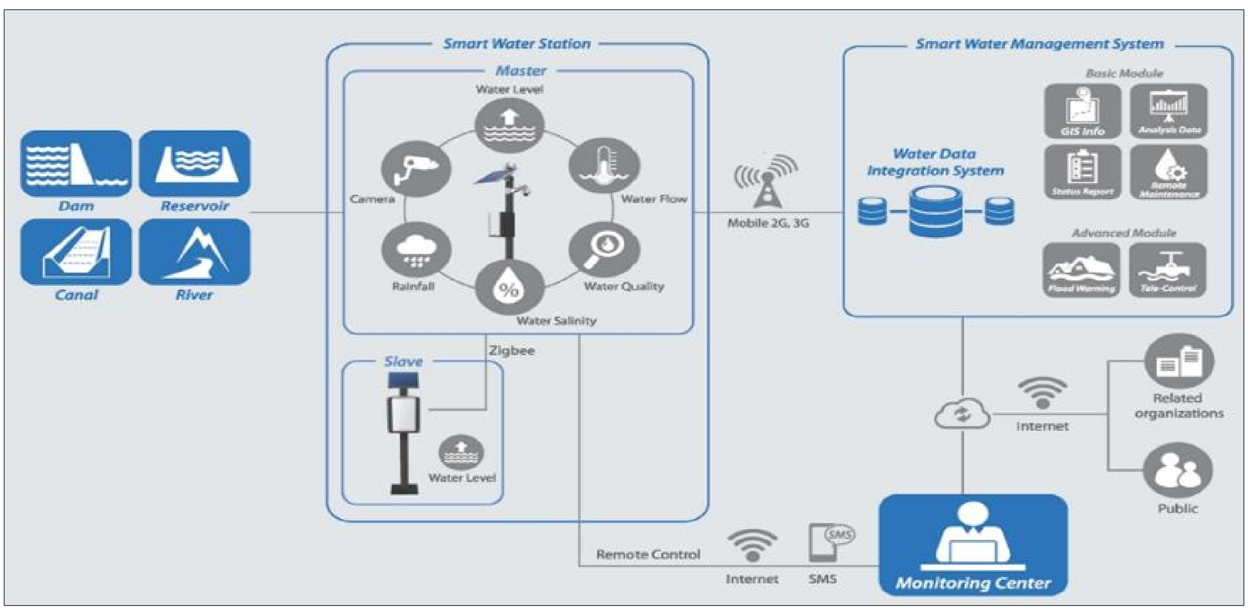


Table 36: System Structure Plan

Category	Function Conditions	Core Implementation Factors
Observation Data Gathering and DB System	▪ Reliable installation of water level, water quality and rainfall stations ▪ Communication with on-site observation and equipment ▪ Storage and management of gathered data in the database	▪ Overcoming poor weather conditions ▪ Using a GSM network as the main communication network
Data Management System	▪ Observation data, rainfall and water level, management	▪ Systematic data quality management ▪ Managing standards for error values and missing values
Real Time Monitoring System	▪ Monitoring the gathered observation data	▪ System establishment based on web GIS ▪ Real-time hydrological data monitoring screen design and display method considering current internet speed
Forecasting System	▪ Making predictions using actual measured rainfall and water level data	▪ Selection of a model suitable for ACA discharge characteristics ▪ Conducting a review of suitability with regards to past and establishing an optimal routing model

Figure 57: Data Management System

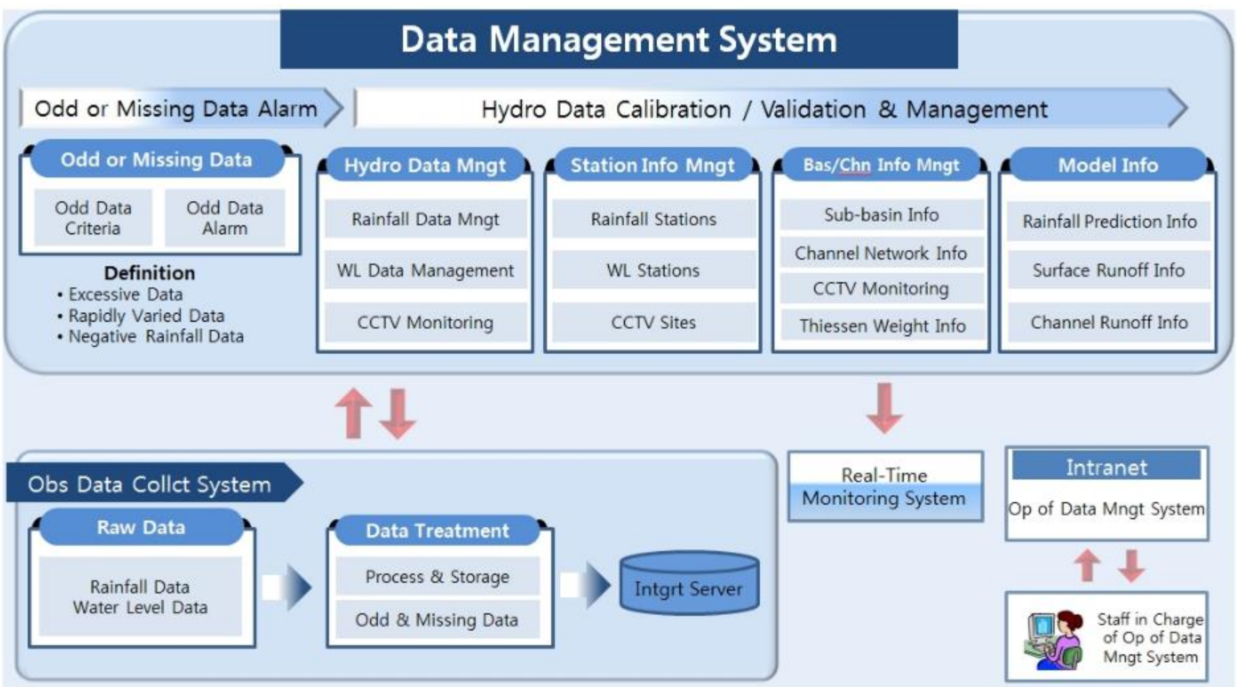
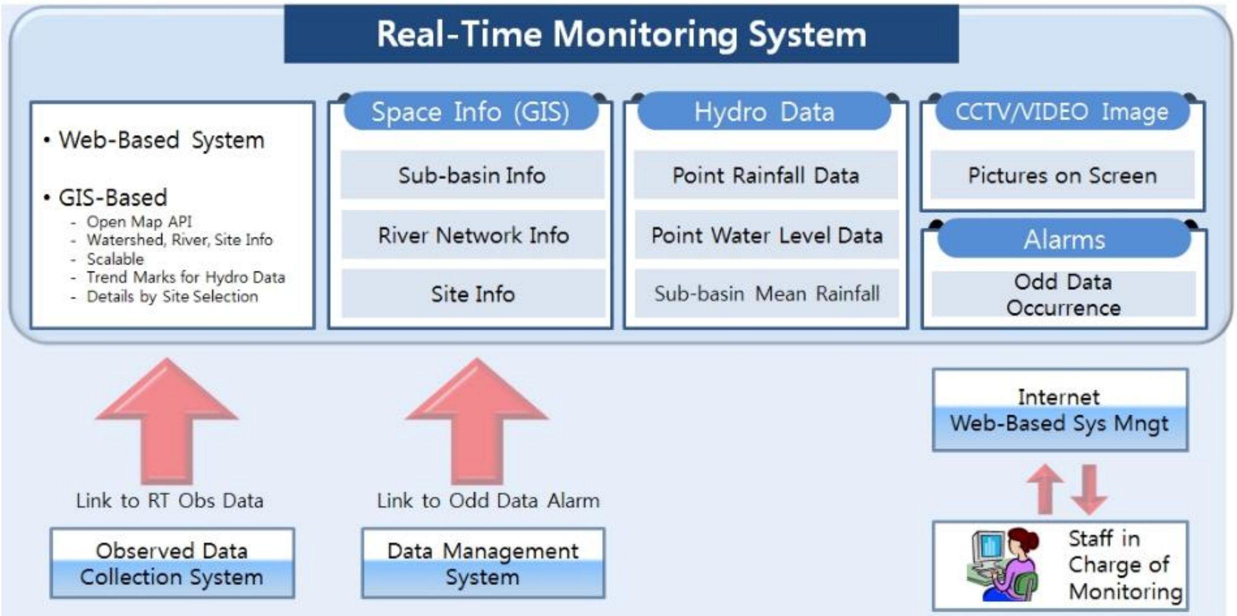


Figure 58: Real-time Monitoring System



4.2.4.3 Implementation Work

To establish the water resources management information system based on the previously described proposals for each field, it is necessary to have an execution plan for each stage in the future.

- **Activity 1: Basic plan and design**

Data are examined to establish the optimal ACA water resources management information system. A development strategy is established through status and requirements analyses. A prototype is developed.

- **Activity 2: River investigation**

The data needed to develop a system model are generated through river surveys and flow examination. This requires a review of the validity of existing survey results and flow measurement results.

- **Activity 3: Purchase and installation of equipment**

The materials required for forecasting and warning include hydrological stations, that is, rainfall and water level, monitoring equipment (CCTV), telecommunication relay station, control center, and IT equipment. The equipment is procured locally or imported.

- **Activity 4: Establishment of information system**

Observations are made through a real-time monitoring system based on data gathered in real time.

▪ **Activity 5: Capacity building**

The capabilities of the workers who operate the system and the participation of residents are important. The system operation capabilities of responsible operators are strengthened. Information on the process to engage area residents is disseminated so that and effective response is possible when an actual climate disaster occurs.

Table 37: Detailed Work Plan

Category		Detailed Work Plan
1. Basic plan and design (Activity 1)	**1.1 Basin Survey**	▪ ACA attributes examination (rainfall, geography, climate etc.) ▪ Dam operation regulations and actual condition ▪ Examination of climate damage conditions and characteristics
	1.2 Data Analysis	▪ Analysis of the rainfall-runoff relationship ▪ Analysis of the water level-rainfall relationship at major locations ▪ Creation of a climate risk map
	1.3 Basic Design	▪ Current system analysis and improvement plan ▪ Basic design of hydrological observation network including elements such as location, facility equipment, and communications
2. River investigation (Activity 2)	**2.1 River survey**	▪ Review of existing survey results ▪ River survey for drought and flooding
	2.2 Flow survey	▪ Review existing water level-discharge curve (rating curve) equations ▪ Flow volume examination
3. Purchase & installation of equipment (Activity 3)	**3.1 Hydrological observation**	▪ Rainfall stations, water level stations
	3.2 Telecommunication equipment	▪ Installation and sophistication of the system
	3.4 Operation equipment	▪ Control center and IT equipment
4. Establishment of information system (Activity 4)	**4.1 Observation data gathering and DB system**	▪ On-site observation, equipment and telecommunication ▪ Storage and management of collected data in DB
	4.2 Data management system	▪ Connection with the existing hydrological information system ▪ Establishment of hydrological data quality management system
	4.3 Real-time monitoring system	▪ Monitoring observation data ▪ Establishment of Web GIS-based system
5. Capacity building (Activity 5)	**5.1 System operators**	▪ Responsible operator training
	5.2 Local residents	▪ Resident evacuation drills using the forecasting and warning system

4.2.4.4 Estimated Budget for WMIS

The cost includes the cost incurred only in activities 4 and 5, which comprise system settlement costs for managing water resources.

Table 38: Estimated Budget

Activity		Unit	Cost(USD)	NOTE
Establishment of Water Resources Management Information System	**Integrated homepage establishment**	1.0	150,000	
	Information system integration	1.0	30,000	
	Real-time display of information	1.0	58,000	
	Update of facility & GIS information	1.0	24,000	
	Mobile web service	1.0	30,000	
	DB system (server, monitor, etc.)	1.0	118,000	Database managing system
	Sub-total		**410,000**	
Capacity Building		1.0	100,000	Training on GIS, remote sensing, and water resources modeling
Total			**510,000**	

4.2.5 Recommendations

4.2.5.1 Establishing a Comprehensive Water Management System

As mentioned previously, the water resources management information system is a part of the future comprehensive water management system. In addition to the most fundamental systems, systems for comprehensive water management such as water supply managers, water quality management, and linked operation of existing dams must be considered from the initial stage itself. Preparations must be made so that they can be combined and specialized gradually. Accordingly, with the completion of the water resources management information system, a comprehensive water management system must be built in the long term, for which plans must be established. It would be beneficial to establish plans for observation site facilities and systems for combined water management through basic facility designs, if possible.

4.2.5.2 Specialized Institutions and Managing Personnel Growth

Specialized institutions and managing personal growth are lacking as the management system is still in its implementation stages. In the future, either specialized operational institutions must be established or there must be a focus on fostering management of personnel growth and development in the early stage of establishing the forecasting system. Relevant laws or systems must also be established to achieve this. Further, there must be a process of dividing the operational processes and categorizing them into data collection, management, analysis, decision-making, and forecasting stages, instead of performing operations by relying on the discretion of managers as was done in the past. Case studies and operational conditions prevailing in other countries must be thoroughly assessed while training and educating managers to ensure efficient training by integrating these examples into understanding the Athi River context better.

4.3 Institutional Strengthening and Capacity Building Measures

4.3.1 Background

Every year about 4million people are severely affected by flooding on the major basins such as Athi, Tana, Lake Victoria North and Lake Victoria South. The floods are thereafter followed by cyclic drought, leading to loss of lives, livestock and economic opportunities to the affected communities and the government. The country is regarded as water scarce country with per capita natural water resources at about 500 cubic meters per person against the global reference of 1,000 cubic meter per person. The demand for agricultural production due to high population growth rate has led clearance of forest and encroachment into water catchments and water major water towers such as Aberdare Ranges. Equally, rapid industrialization and urbanization around major urban centers such as Nairobi and Mombasa has piled pollution pressure on water resources and groundwater over-abstraction. The government institutions responsible for water resources, environment and disaster management are therefore faced with multiple challenges that overstretches both their technical and logistical capacities. Equally, the affected communities continue to face the cyclic challenge of intense drought and floods without early warning systems to assist in adaption and assimilation to the harsh natural and economic environment. This report, is prepared as part of the Technical Feasibility Study with a focus on identification of capacity building and institutional strengthening needs and proposed remedial measures for the relevant institutions.

4.3.2 Rationale

The National Climate Change Response Strategy of Kenya, 2010 aims to enhance understanding of the global climate change regime, assess the evidence and impacts of climate change, and apply a scientific understanding of climate change and its impacts as the core platform for vulnerability assessment, impact monitoring, and capacity building framework. It therefore recommends research, innovation and technology transfer, conducive and enabling policies, and a legal and institutional framework to combat climate change. The strategy encourages entities to adopt a concerted program-based action plan coupled with resource mobilization plans, as well as monitoring and evaluation. All of these plans are to be applied in an integrated approach toward combating climate change.

The communities in the Athi Catchment Area are vulnerable for the following reasons: (i) inadequate hydro-meteorological modeling and simulation expertise within relevant government institutions such as WRA and KMD to predict climate change and environmental disasters, (ii) poor maintenance of the hydrological and meteorological stations leading to the loss or lack of essential data, (iii) ineffective public participation in water catchment management (iv) poor resource mobilization efforts, (v) poor collaboration among government institutions, (vi) lack of alternative livelihood opportunities for the local communities, and (vii) inadequate public participation and gender consideration.

4.3.3 Policy Framework

4.3.3.1 The Constitution of Kenya 2010

Following the passage of the new Constitution in 2010, a part of the responsibility for water resources management and water supply services was transferred from the national government to the county governments. Thus, water resource management now requires greater collaboration between the national government entities such as WRA, NEMA, and KMD, and the county governments. Given that the county governments have only existed for a few years (since 2013), significant capacity building is necessary to support the county governments to function as local authorities. A unified and consistent legal and institutional framework forms the basis for the execution of national and local policies and strategies.

4.3.3.2 National Climate Change Adaptation Strategy

The need for capacity building is enshrined in Article 9 (d) of the United Nations Framework Convention on Climate Change (UNFCCC), which calls upon the Convention to facilitate and support endogenous capacity building in developing countries on climate change assessment, understanding, and adaptation. Consequently, Kenya developed the National Climate Change Response Strategy, 2010 to define the national approach to capacity building by creating a framework focusing on training personnel and strengthening institutions on climate change competencies, capacity building in adaptation measures, reduction of emissions from deforestation and environmental degradation programs, and facilitation of technology transfer.

4.3.3.3 National Water Master Plan, Vision 2030

The National Water Master Plan, Vision 2030 (NWRMP) identified key gaps for due consideration to achieve the goals laid out in Vision 2030. They include: (i) inadequacy of institutions for water resource management; (ii) weaknesses in the regulatory framework for transboundary, inter-catchment, and multi-sector issues; (iii) the lack of a scientific basis for quantitative allocation and regulation of water resources; (iv) inadequate transparency and lack of scientific approaches to management of water resources; (v) gaps in water storage, conservation measures, and social responsibility; (vi) unfulfilled capacity needs of WRA regional offices such as RBOs; (vii) poor legal position of the WRUAs; and (viii) insufficient financial resources for water resources management. The NWRMS is to be implemented in two consecutive phases with each phase covering seven year plans at a time, that is, from 2015 to 2022 and from 2023 to 2030. Currently, the first phase is being implemented.

4.3.3.4 Athi Catchment Management Strategy

The Water Act 2016 requires that the WRA should develop a Basin Area Water Resource Management Strategy[54]. The WRA developed the Athi Catchment Management Strategy, 2015-2022, in line with the objective of the NWRMP. The strategy recognizes the Athi Catchment Area as comprising both arid and semi-arid land, denoting the presence of a reasonable level of water stress and vulnerability among the

[54] Water Act, 2016; Part II-Section 29.

population. The Climate Change adaptation measures has been mainstreamed into the Strategy for the Athi Catchment Area. In addition, it outlines the following key capacity building gaps;

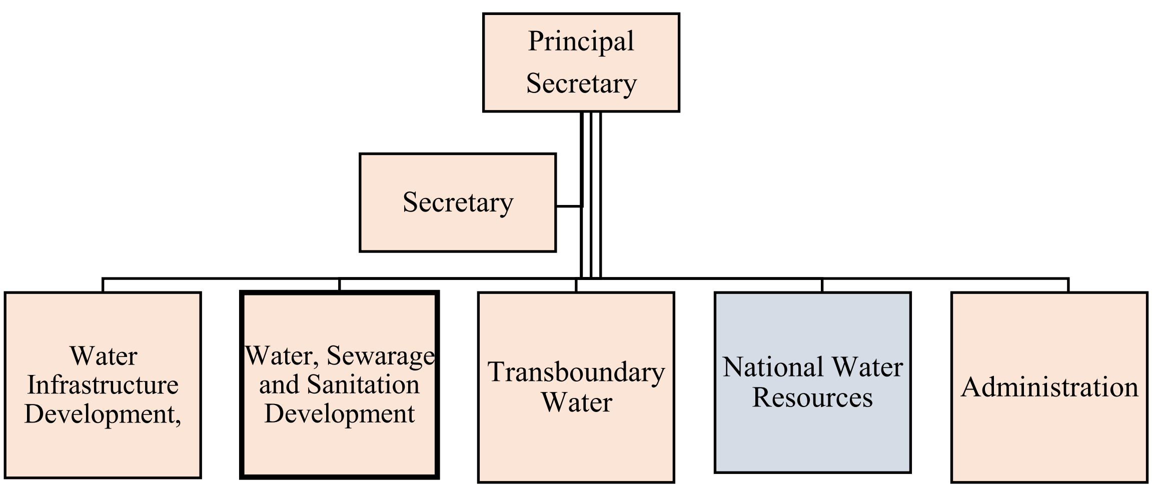
- Inadequate resources (financial, equipment, materials, infrastructure like offices, monitoring stations, laboratories);
- Inadequate technical skills of WRA staff;
- Need to enhance Basin Water Resource Committee (formerly CAAC[55]) capacity;
- Inadequate capacity of WRUAs;
- Need to enhance capacity in County Governments on IWRM;
- Low level of public awareness on the mandate of WRA;
- Low enforcement capacity by WRA;
- Lack of strong partnerships in WRM;
- Inadequate reporting framework to the public.

4.3.4 National Government Institutions

4.3.4.1 Ministry of Water and Sanitation

The Ministry of Water and Sanitation (formerly Ministry of Water and Irrigation) is headed by the Cabinet Secretary and Principal Secretary, both of whom are appointed by the President. The Ministry is responsible for the formulation and implementation of policies for and the implementation, and monitoring of water resources and water services. The Ministry discharges its responsibility through its several departments and state agencies. The Ministry has five departments, each headed by a Director as seen in Figure 60.

Figure 59: Organizational Structure of the Ministry of Water and Sanitation



[55] Catchment Area Advisory Committee (CAAC) is an entity designated under Water Act 2002 to support coordination in the management of water resources at the catchment level. It has been replaced by Basin Water Resource Committee (BWRC) under Water 2016 (part II, Section 25).

Under the Ministry, the department of National Water Resources is responsible for the administration and coordination of policy-related issues on water resources. The functions [56]of the department are;

- Framing water resources management policy and strategies
- Assessment of water resources, namely groundwater and surface water
- Maintaining water quality and pollution control
- Domestic water quality surveillance
- Coordination of research on water resources
- Registration and licensing of professionals and contractors in water resources management

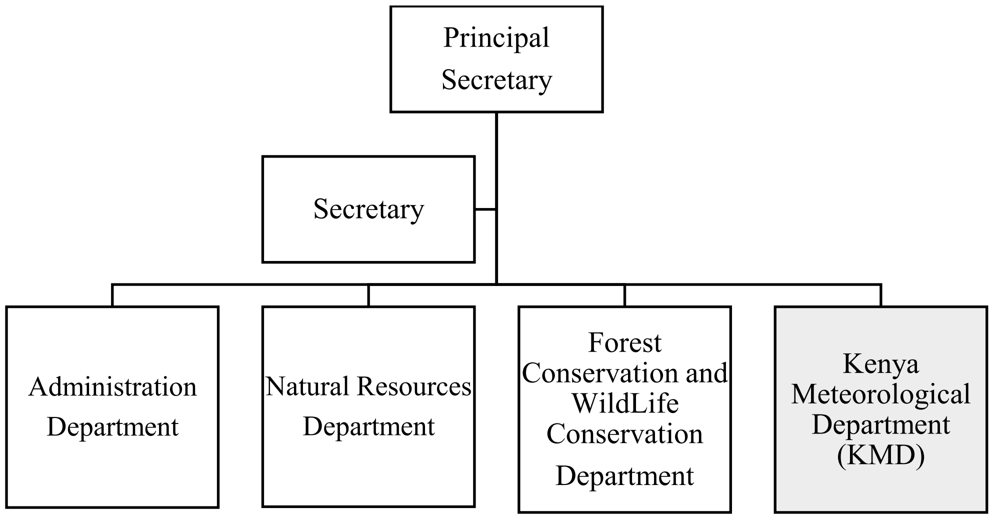
The MWS hosts consultations with various stakeholders to implement the Water Act, 2016. It was reported that, the Ministry is in the process of formulating the National Water Resources Policy, National Water Resources Strategy and review of the National Water Quality Management Strategy. In addition, the MWS is planning to develop an integrated online water sector data and information system to support research as a structured foundation for appropriate and responsive policy guidance. It is also mainstreaming climate change and adaptation strategies in its key policy frameworks to guide the water resources and water services sectors. The detailed regulation of the management and use of water resources is delegated to the WRA and the NWHSA by the Water Act 2016. Both WRA and NWHSA[57] are governed by boards that are represented by diverse, but relevant, stakeholder groups.

4.3.4.2 Ministry of Environment and Forestry(MEF)

The MEF (formerly known as the Ministry of Environment and Natural Resources), is now headed by the Cabinet Secretary and Principal Secretary, both appointed by the President. It is responsible for the protection, conservation, and management of the environment and natural resources to advance socio-economic development. The MEF has four departments, each headed by a Director as represented in Figure 61.

[56] http://www.water.go.ke/water-services/
[57] Sectoral Report L of the National Water Resources Master Plan, Vision 2030, and Part III of the Water Act 2016).

Figure 60: Organizational Structure of the Ministry of Environment and Forestry



The MEF established a framework for environmental management and conservation through the EMCA of 1999 and subsequent amendments. EMCA established five key institutions: the National Environment Management Authority, the Public Complaints Committee, the National Environment Tribunal, the National Environment Action Plan Committees, and the County Environment Committees.

Other Semi-Autonomous Government Agencies (SAGAs) under the MEF include the Kenya Water Towers Agency, the Kenya Forest Service (KFS), and the Kenya Forest Research Institute.

Based on their mandates, the following section defines their roles with respect to the proposal to the GCF Further, the roles and capacity building needs of NEMA and KMD are also presented.

4.3.4.3 National Environmental Management Authority (NEMA)

The NEMA was established in 2004 as the principal government agency in charge of implementing environmental policies and exerting supervision and coordination on all matters relating to the environment. In consultation with the lead sectoral agencies (such as the WRA), the NEMA is responsible for the development of regulations, outlining of measures and standards, and issuing of guidelines for the management and conservation of natural resources and the environment. NEMA controls the developmental impacts of projects on the environment using tools such as environmental impact assessment (EIA), environmental audit and monitoring, and specific orders on environmental restoration, conservation, and easements. It is authorized by the Ministry to enter into specific Multilateral Environmental Agreements.

In March 2016, NEMA was accredited by the GCF as the implementing entity for micro-projects (worth up to a maximum of 10 million USD) under Direct Access with the GCF. Accordingly, NEMA will bear the full responsibility for the overall management of the proposed project including financial, monitoring, and reporting responsibilities.

(a) Capacity Building Needs for NEMA

NEMA has drafted the Strategic Plan 2013-2018 which presents a roadmap to achieve its mandate. The plan reports that staffing level is at about 27% (360 of targeted 1,334 staff). Strategic objective item number three aims to develop and strengthen institutional capacity for the effective and efficient management of the environment. With the devolution of duties under the Constitute of Kenya (CoK) 2010 and its ambitious own national development plans, NEMA has overstretched its existing staff.

The proposed GCF project is likely to stretch the organization's human resource capacity even further. Due to the diversity and complexity of stakeholders and implementing entities, the inadequate resource capacity presents a challenge for the efficient and effective implementation of the GCF project. It is, therefore, apparent that NEMA may face difficulties in achieving effective and efficient results, and may face challenges in the coordination, supervision, and monitoring and evaluation of the project. Based on these foreseeable gaps, recommended measures to strengthen the institution are presented in Table 39.

Table 39: Capacity Building Measures for NEMA

	Capacity Building Needs	Proposed Measures
1	Lack of focal personnel for the monitoring and evaluation of the GCF Project	Recruit personnel for monitoring and evaluation as well as a Risk Management Expert for the GCF project on a contract- basis
2	Inadequate personnel for the management and coordination of the GCF project	Recruit a project management expert and project coordination officer to support the GCF project management needs
3	Inadequate technical capacity to supervise contractors and suppliers	Recruit an engineering consultant to supervise contractors and verify supplies

4.3.4.4 Kenya Meteorological Department (KMD)

The KMD is a department under the Ministry of Environment and Forestry. It is headed by the Director who reports to the Permanent Secretary of the MEF. The functions[58] of the department as outlined by the MEF are as follows:

- Provision of meteorological and climatological services to agriculture, forestry, water resources management, civil aviation, and the private sector including industry, commerce, and public utilities for the better exploitation and utilization of natural resources for national development;
- Provision of meteorological services to shipping in the western Indian Ocean including the issuing of cyclone warnings for the safety of merchant and other ships;
- Provision of meteorological services to military aviation for the safety of Kenya Air Force aircrafts for national defense;
- Organization and administration of surface and upper air meteorological observations within its area of responsibility and the publication of climatological data;

[58] http://www.environment.go.ke

- Maintenance of an efficient telecommunications system for the rapid collection and dissemination of meteorological information required for national and international use in accordance with the procedures of the World Meteorological Organization (WMO) and the International Civil Aviation Organization (ICAO);
- Coordination of research in meteorology and climatology including cooperation with other authorities in all aspects of applied meteorological research and the maintenance of the National Meteorological Library;
- Evolution of suitable training programs in all fields of meteorology and other related scientific subjects that are relevant to the development of Kenya and other countries that participate in the department's training activities.

(a) Information to the Public

The KMD set up its National Public Weather Services (NPWS) section in mid-1995 in accordance with the recommendations made by the two expert meetings on the Public Weather Services in Geneva in March 1992 and April 1994. The main objectives are to enhance awareness of available meteorological services and their benefits to the public and policy makers. In addition, the NPWS is geared to ensure that correct public understanding and interpretation of the meteorological information is achieved. It is premised that the more knowledge the public and policymakers have on weather, the more they will appreciate and be supportive of efforts aimed at improving the quality of weather forecasts.

(b) Capacity Challenges

A field visit by the consultation in March 2018 to the weather monitoring stations in the county of Nyandarua revealed the following capacity challenges:

- Poor maintenance of the weather stations led to the stalling of weather stations. For example, the automatic weather station at Sasumua Dam was temporarily out of order due to the expiry of the battery.
- Lack of traveling and logistical equipment and the lack of vehicles to support monitoring and maintenance of the weather stations at the county level.
- Over-dependency on the goodwill of station hosts to read weather data regularly led to the collapse of the station when the host institution or organization was no longer interested.

Figure 61: Rain Gauge Station (not operational), Sasumua Dam in Nyandarua County

Figure 62: Automatic Weather Station, Sasumua Dam: (Data logger not functional due to lack of battery)

(c) Capacity Building Needs of KMD

Table 40 presents both the key capacity building needs and institutional gaps in the KMD and proposed measures that can be implemented.

Table 40: Capacity Building Needs and Measures Proposed for the KMD

	Capacity Building Needs	Proposed Measures
1	Lack of technical and logistical capacity for the calibration and maintenance of automatic weather stations	Train staff on calibration, trouble shooting, operation and maintenance of synoptic and automatic weather stations
2	Lack of expertise on climate change adaptation and meteorological information systems	Supply and install new climate analysis software packages and decision support tools
		Train staff on climate change and adaptation

		Train staff on computer networking and cloud computing systems
3	Lack of tools and equipment for maintenance	Procure one double cabin pickup equipped with a maintenance tool-kit
4	Inadequate Computers and data management systems	Procure computers and accessories for data storage and analysis

4.3.4.5 Water Resources Authority (WRA)

The WRA has adopted a policy for IWRM. It has divided the country into six catchment areas based on the drainage areas: Lake Victoria South, Lake Victoria North, Rift Valley, Tana, Athi, and Ewaso Ngiro. The WRA has developed a management structure in conformity with IWRM's basin-wide approach to water resource management. Each catchment has a designated WRA regional office. Each regional office has been structured according to the sub-basins within the catchment area. For overall coordination, administration, and management, the WRA has its headquarters located in Nairobi.

(a) Regional Office in Machakos

The WRA regional office for the Athi Catchment Area is located in Machakos. The present water resources management at the WRA regional offices, however, has progressed rather well given that there are not only limited human and financial resources but also limited experience since the establishment of the Water Resources Management Rules in 2007.

The WRA has developed the Athi Catchment Management Strategy 2015-2022, which presents the existing gaps in institutional strengthening processes. The gaps and proposed measures are outlined in Table 41.

(b) Capacity Building Needs of and Measures Proposed for the WRA

Table 41: Capacity Building Needs of and Measures Proposed for the WRA

	Capacity Building Needs	Proposed Measures
1	Poor enforcement of abstraction and discharge permit conditions	Strengthen enforcement units through training of staff on the application of national policy, law, and regulations on water resources
	Poor collaboration with complimentary agencies such as NEMA, the Public Health Department, and county governments to monitor, control, and enforce regulations	Train staff, and develop and pilot key collaborative frameworks such as MOUs, for the coordination of the control and enforcement of water permits and effluent discharge conditions
	Delayed implementation of Catchment Management Strategy 2008-2014 and 2015-2022	Train staff and implement specific annual enforcement plans for each CMU
	Inadequate understanding of the Constitution of Kenya 2010, County Government Act 2012, Climate Change Act 2016, and Water Act 2016	Sensitize water sector institutions on legal and policy frameworks on water resources management in Kenya
2	Poor implementation of CMS Lack monitoring and evaluation tools	Establish and strengthen the monitoring and evaluation system
		Establish baseline information on water resources in the catchment area

		Develop work plans, and a monitoring and evaluation system tool for the Athi Catchment Area
		Train staff on monitoring and evaluation of CMS
3	Poor maintenance of monitoring equipment	Develop a preventive maintenance system
	Inadequate skills at the regional office and sub-regional offices for the operation and maintenance of water resource monitoring equipment	Develop operation and maintenance plans for the hydro-meteorological monitoring system in the Athi Catchment Area
	Inadequate infrastructure at the regional and sub-regional office such as the sub-regional office in Kiambu, vehicles, ICT etc.	Construct and equip the sub-regional office at Kiambu. Provide fixed and mobile maintenance tool boxes for the Upper Athi Catchment Area
4	Poor revenue generation system	Strengthen and diversify the revenue generation structure of the organization such as through fees, grants, Public-Private Partnership (PPP), subscriptions, etc.
	Inadequate revenue generation due to low collection of water use charges, fines, and debts, and depressed Government of Kenya (GOK) allocations	Review revenue generation strategies and train staff on resource mobilization and debt recovery
	Low public-private partnership (PPP) initiatives toward investment and participation in water resource management	Develop a pilot public-private partnership proposal for catchment conservation, monitoring, and maintenance frameworks such as an afforestation program
	Lack of a resource mobilization strategy	Develop and pilot a resource mobilization strategy for the Athi Catchment Area
	Weak organizational structure for resource mobilization	Review organizational structure with integrated unit for resource mobilization and donor or partnership coordination
5	Poor capacity for monitoring advanced substances	Train staff and supply water quality monitoring equipment
	Inadequate skills to monitor complex compounds and pollutants from industrial and settlement complexes in Nairobi and other areas	Train water quality monitoring staff on telemetric water quality monitoring, emerging contaminants, and data interpretation and presentation, etc.
	Insufficient equipment for monitoring complex compounds	Equip the regional laboratory at Machakos
6	Delay in the establishment of the Basin Water Resource Committee (BWRC) [59] for the Athi Catchment Area and other catchments	Establish the BWRC for the Athi Catchment Area

4.3.5 County Governments

In 2010, the Republic of Kenya adopted a new Constitution, designated as the Constitution of Kenya (CoK) 2010. The new Constitution transformed the administrative governance structure from a centralized to a devolved system. Thus, it created 47 semi-autonomous local administrative units called counties. Of these, 11 counties are based in the Athi Catchment Area: Upper Athi (Nyanadarua (partly), Muranga (partly), Kiambu, and Nairobi), Middle Athi (Kajiado, Machakos, Makueni, Kitui (partly), and Taita Taveta), and Lower Athi (Kilifi, Mombasa, Tana River (partly), and Kwale). However, the proposed project focuses on the area occupied by the following counties: Nyandarua, Kiambu, Machakos, and Nairobi.

[59] It was reported by WRA that the establishment of the BWRC was delayed as necessary consultations were still to be conducted, mainly between the WRA and County Governments.

Based on the CoK 2010, the responsibility of the WRM has been entrusted to the national government with significant responsibility endowed to the county governments as well. Based on the principle of supremacy of the Constitution over subsidiary legislations, the county governments expect to play a greater role and participate in key decision-making processes on all matters affecting the counties. It is, therefore, imperative that the management of water resources by the WRA encompasses a deeper consultative and collaborative approach to mitigate mistrust and misunderstanding. The regional and sub-regional offices of the WRA and the WRUAs are, therefore, expected to play enhanced roles to work closely with the county governments.

The capacity building requirements for the county governments of Nyandarua, Kiambu, Machakos, and Nairobi are as follows:

- Enhancing the participatory and decision-making approaches within the scope of the project.
- Capacity building for water storage and conservation measures as part of the project.
- Mainstreaming climate change and adaptation measures into key county government policies on water resource management and disaster management.

4.3.6 Community Based Entities

4.3.6.1 Water Resource Users Association (WRUA)

The WRUA is a formally registered group of community members at the sub-basin level for the collaborative management of water resources. Membership is voluntary and mainly comprises water users, riparian land owners, and interested groups within a sub-catchment area designated by the WRA. Best practices that have been evolved by the IWRM and the Constitution of Kenya 2010 emphasize public involvement, participation, and collaboration with local communities on the management of water resources. By virtue of its locality and dependency on the water resources, WRUAs benefit from the properly managed water resources. Conversely, they become first victims to the climate change induced calamities such as droughts, floods, pollution, human and wildlife water-related conflicts.

Section 29(1) and (2) of the Water Act 2016 prescribes the establishment and function of the WRUAs at the sub-basin level. WRUAs are responsible for the facilitation of the collaborative management of water resources and conflict resolution. At the grass-root level, WRUAs are the agents of the WRA.

(a) WRUA Development Cycle

WRAs facilitate the formation of WRUAs through the WDC, whereby stakeholders are publicly invited to apply to join designated WRUAs for a specific sub-catchment area. Successful applicants are appointed after interviews and subsequently trained on three modules: (i) climate change adaptation, (ii) flood and drought management, and (iii) livelihood enhancement. The WRUAs undergo formal government registration in order to become a legal entity. Based on the Basin Water Resources Strategy, the WRUAs are supported by the WRA to develop their specific sub-catchment water conservation plans (SCMP). The activities in the SCMP are thereafter implemented once funding is made available.

(b) Challenges faced by WRUAs

WRUAs face the following key the challenges:

- **Funding for the implementation of SCMP:** Few SCMPs that have been partially implemented have been financed by the WSTF and other donors. With recession, there is a reduction of donor funding. Thus, the implementation of SCMPs has been a major challenge for WRUAs in particular and the WRA in general.
- **Administrative infrastructure:** WRUAs lack offices, office equipment, and vehicles for monitoring and supervision of the implementation of SCMP. Cheaper alternatives such as centralized offices for WRUAs in the WRA sub-regional office can be an effective medium-term solution to this issue.
- **Gender Imbalance in WRUAs:** Most WRUA committees are dominated by men, with the number of women being less than 30%, which is the minimum constitutional threshold for either gender. Gender sensitization and enforcement of the national gender rule (minimum 30% of both gender) should be upheld in all WRUAs. Since women bear greater responsibility in water resource issues, the progressive improvement of the gender balance should be set as a GCF program indicator.
- **Inadequate Technical Capacity to Develop SCMP:** Sub Catchment Management Plan (SCMP) is a planning tool for catchment improvement, conservation, and climate change adaptation in a particular-sub catchment Most members of most WRUAs do not have the required technical knowledge to develop and update the SCMP. WRUAs, therefore, depend on consultants and WRA staff to support the development of the SCMPs.

(c) Proposed Capacity Building Measures for WRUAs

It is proposed that WRUAs should be trained to enhance their capacity on IWRM, resource mobilization, climate change adaptation, and sustainable livelihoods. The following training sessions are proposed:

- Updating existing SCMPs to incorporate a component on climate change:

WRA revised the WRUA operation framework through the Water Resource Users Association Development Cycle 2014 (WDC 2014) to incorporate climate change activities, following the implementation of a Nordic Climate Facility project that developed climate change maps and training modules for communities. Under this, 29 SCMPs will be updated to incorporate a component on climate change in order for the communities to implement climate change adaptation activities and enhance the resilience of communities. Out of 31 SCMPS in the Upper Athi Area, 29[60] are proposed to be updated to incorporate potential climate change risks and community adaptation measures. This process will include the sensitization of the WRUAs based on the revised WDC 2014, and the harmonization of the existing county water resource policies with climate change adaptation measures.

[60] Two out of 31 WRUAs (Kirichwa and Ruiru) will be supported by World Bank financed project; Kenya Water Security Climate Resilience Project to update the SCMPs and pilot its implementation.

- Resource mobilization for the implementation of SCMP:

After the SCMPs are updated, a comprehensive funding strategy will be prepared by the WRUAs through a technical assistance framework supported by the proposed GCF Funded program. The funding strategy for three clusters of WRUAs will be prepared, namely Upper Athi -(9 SCMPs), Nairobi -(8SCMPs), and Middle Athi (12 SCMPs). The funding proposal for the clusters shall be developed for the mobilization of financial resources to implement the SCMPs. Potential sources of funding and support in kind include: WSTF, planned and ongoing financed water resource and supply infrastructure projects for Kiambu, Nairobi, and Machakos, the county government, major water service providers, private corporations and public-private partnerships, and Corporate Social Responsibility, etc.

- Training on Project Management:

Under pilot activities to be implemented under each SCMP, members of the WRUAs will be trained. Committee structures will be established for project development, financial management and reporting, record keeping, progress reporting and communication, project monitoring and supervision, and operation and maintenance.

(d) Capacity Building Needs of and Measures Proposed for WRUAs

Table 42: Capacity Building Needs of and Measures Proposed for WRUAs

	Capacity Building Needs	Proposed Capacity Building Measures
1	Outdated SCMPs lacking a component on climate change	Update SCMPs and incorporate climate change adaptation strategies
2	Gender disparity in WRUAs	Sensitization, training, and restructuring of WRUAs to attain gender balance
3	Weak resource mobilization capacity	Training on income generation activities and resource mobilization
4	Inadequate skills on project management	Training on project management, project coordination, and operation and maintenance

4.3.6.2 Water Pan Management Committee

The Constitution of Kenya 2010 requires public participation and consultation on planning and implementation of public projects financed by or through the government. The Water Act 2016 and National Water Resources Master Plan Vision 2030 requires communities to play a greater role and take on a greater responsibility in the management and operation of their water supplies project system. This responsibility is meaningful only if the communities genuinely have the interest and the capacity to manage their water supplies. Typically, the community is always interested in the project as the principal beneficiary of water supply. In addition, the operation and management of a water supply project requires awareness, skills, and experience that communities do not necessarily have, especially if their water-related project or resource is new or has not been operational for a long time. Typically, the management of pans or dams is vested in the hands of the Dam Management Committee (DMC). The capacity of the DMC needs to be strengthened so that they can manage their water supply appropriately.

Capacity building exercises for community operation and management of water supplies involves the following steps:[61]

- Carry out a needs assessment prior to training.
- Develop an appropriate training program.
- Train management committee and sensitize other general community members.
- Follow up regularly to monitor progress on operational and management issues.

The focus of the capacity building will be on the following areas:

- Leadership, financial management, and technical operation and management
- Water and Sanitation and Hygiene (WASH)
- O&M

(a) Training Needs Assessment

Given that a comprehensive capacity assessment was not carried out during the feasibility stage for the pan/dam management entities, it is recommended that a full training needs assessment be conducted at the initial stages of the project. The Training Needs Assessment (TNA) will involve discussions with the community using PRA tools to help the community identify their priorities. The TNA shall ensure that the opinions of different members of the community (e.g., women, youth, agriculturists, and pastoralists) are expressed. The community will be encouraged to identify its strengths and weaknesses, so that topics covered in the training program can clearly be identified as arising from the community. The output of the training needs assessment should be written as a report providing details on the key issues that need to be addressed during the capacity building training. The development of an appropriate training program requires a broad-based approach with unique site-specific orientation due to the differences among all the communities. It is important to adapt approaches and topics to the needs of specific community. The general approach is to develop a training program which uses participatory tools (such as drama, role-play games, picture games etc.) to build the train the community to operate and manage their water pan/dam.

Historically, most pans/dams have a traditional background of communal ownership. This implies that capacity building for community management should build on the existing systems and discourage the formation of new or parallel management structures.

In line with the principle of the Integrated Water Resource Management approach adopted by WRA, it is recommended that the training of Dam/Pan management committee is undertaken, as initial step towards them to transformation into WRUAs as a cluster based on the geographical locations. In addition to the

[61] Water from ponds, pan,s and dams: A manual on planning, design, construction and maintenance-TECHNICAL HANDBOOK No. 32

operation and maintenance of pans and dams, the committee shall be trained on WDC and guided by WRA to become WRUA.

(b) Training for Community-Based Units

The following are the key factors in capacity building and training of community-based units:

- Community mobilization and awareness play major roles
- Training should be on-site and make use of participatory approaches
- Thorough training and capacity building at few sites are preferred over partial training at several sites
- Long-term follow-up process is essential
- Training should involve and encourage affirmative action. Decision-making should be sensitive to gender and youth needs

Key areas of training and capacity building measures for CBU:

- Community organization and alternative management structures, including leadership, gender, equity, and conflict resolution.
- Community self-reliance and organizational sustainability which deals with issues of dependency, organizational records, constitutions, and by-laws.
- Building financial sustainability and financial records (budgeting, bookkeeping, and accounting).
- Operation and maintenance which deals with technical sustainability and includes accessing technical services and spare parts and carrying out other routine maintenance activities. This module also covers catchment conservation measures and environmental impacts.
- Water, sanitation, and hygiene education. Typically, health benefits from improved water supplies can be obtained only through changes in water use habits. The management committee are generally cast in the role of community leaders and have a responsibility to the community to raise awareness on good environmental health practices at the household, homestead, and community levels.
- Community action plans and community monitoring and evaluation. Indicators are discussed to help the community monitor their adherence to their action plans and to monitor any environmental or social impacts of their plans.

4.3.7 Approaches to Capacity Building

The methodology used and approaches toward capacity building and institutional strengthening are key factors in delivering cost effective and efficient training to the beneficiaries. Generally, the use of external expertise is preferred over the use of internal resources in capacity building. This follows the global best practice wherein internal capacity building is considered a continuous part of organizational development rather than a project-based effort. For cases, The specific approaches proposed are outlined as follows:

4.3.7.1 Technical Assistance Experts

The institutional strengthening measures include hiring temporary staff to support project management at NEMA and project implementation and supervision at WRA and KMD. The staff includes experts in project management, monitoring and evaluation, civil engineering, meteorological and water resource modeling experts, and decision support experts. The experts are competitively recruited and hired on a three-year contract that is renewable once. The experts are fully accountable and answerable to their respective institutions and are integrated as part of the organizational structure.

4.3.7.2 Technical Training of Staff

The training of staff is proposed to be conducted by local training institutions. This due to sufficient level of training capacity of the proposed local and international institutions located in Kenya. Compared to foreign institutions, local institutions demonstrate several advantages in administering training for staff. These advantages include better academic performance, cost effectiveness (more than 50% cheaper than foreign institutions), flexibility in offering tailor-made courses, and focus on the study site taking into account social considerations for beneficiary employees who are mostly likely to have families.

The following are the key factors that are considered in identifying training institutions:

- Public-owned non-profit institutions
- Year of establishment, years of existence, and performance
- Proximity to Athi Catchment Area and Nairobi
- Collaboration with other international organizations
- Cost of training courses offered
- Flexibility in providing tailor-made courses to suit hydro-meteorology and the specific needs of the Athi Catchment Area.

Table 43: Proposed Institutions for Staff Training

	Institution	Ownership	Location of Main Campus
1	University of Nairobi	Government owned; public service	Nairobi
2	Kenya Water Institute	Government owned ; public service	Nairobi
3	Regional Centre for Mapping of Resources for Development	Inter-governmental organization, African Union; public service	Nairobi
4	Kenya School of Government	Government owned; public service	Nairobi
5	Institute for Meteorological Training and Research (Kenya)	Government owned: public service	Nairobi

4.3.7.3 Athi Catchment Case Study Approach to Training

Technical trainings at all levels should adopt relevant issues within the Athi Catchment Area as case studies and practical reference. For short-term courses, training modules should be tailor-made to suit the needs of the participants where the number of participants is more than five. It is strongly recommended that beneficiaries of academic and professional courses at PhD and Master's levels devote their thesis to issues in the Athi River Catchment Area that can be studied. This will enable the participants to explore and expand the understanding of the catchment area, its dynamics, and perspectives around it that can stimulate further research and knowledge sharing within and across various fields.

4.3.7.4 Use of Consultants

The consultancy approach should be adopted to train staff at WRA, KMD, County governments, WRUAs, and the Pan Management Committee on both cross-cutting and general issues. A firm with a demonstrated pool of experts should be competitively recruited to provide short- term (two days to two weeks) training to the staff. Training outcomes shall be monitored based on clear indicators of achievement, expected impact, and other outcomes, specified by the training institution. Attention should be paid to the experience of the training firm and the expertise, qualifications, and experience of individual trainers. As standard rule, training firms shall be recruited based on the Quality Cost Selection Method.

4.3.7.5 Training on Operation and Maintenance

When new equipment is procured by KMD and WRA, the supplier or manufacturer is required, as a condition of the tender or contract, to provide training on the operation and maintenance of the equipment. After the delivery of the equipment on site, the staff in charge of operation and maintenance will be trained by the supplier's expert, who is responsible for the installation. For each cluster of equipment, a daily training log is to be signed by the trainer and trainee. The supplier shall ensure that the learners understand the assembly and installation steps, testing, and commissioning thoroughly. After the installation and testing the supplier shall conduct follow-up training for the staff on trouble shooting, calibration, operation, and maintenance of the equipment.

4.3.8 Budget for Capacity Building and Institutional Strengthening Measures

The following tables present estimates of costs associated with the proposed capacity building measures.

Table 44: Capacity Building and Institutional Strengthening of WRA

	Proposed Measure	Beneficiaries	Total Cost (USD)
1	Consultancy for the development collaboration frameworks on surveillance and enforcement for water permits and effluent discharge control	Board of Directors and Top Management of WRA and NEMA	45,000
2	Training of various levels of staff through different courses (Annex 5)	61 Staff of WRA	197,300
	Construction of a Sub-Regional office block at Kiambu	1,000 sqm	160,000
	Procure 1-Double cabin pick fixed with Toolkit	1 Unit	80,000
3	Consultancy services to support the development of public-private partnership proposals and resource mobilization strategy	Finance and Technical Department of WRA	20,000
4	Procure laboratory equipment	1 Assorted Equipment	30,000
5	Establishment of the BWRC	Stakeholder conferences, office and logistics	0.000
6	Review National Water Quality Management Strategy for MWS	Consultancy services and workshops	50,000
		Sub-Total	**582,300**
		Contingency	58,230
		Grand Total	**640,530**

Note: Establishment of the BWRC is deferred due to ongoing legal and technical consultations by WRA

Table 45: Capacity Building and Institutional Strengthening of NEMA

	Proposed Measure	Target	Unit Cost (USD)	Total Cost (USD)
1	Recruit and contract experts for GCF project on a contract-basis for five years (three-year and two-year renewable contracts)	Project coordinator, monitoring and evaluation and risk management, and civil /water engineering experts	102,000	510,000
2	Training of NEMA staff	1 PhD in Climate Change and Adaptation 1 Masters in Climate Change Adaptation	L.S	50,000
	Sub-Total			**550,000**
	Contingency -10%			55,000
	Total			**615,000**

Table 46: Capacity Building and Institutional Strengthening of KMD

	Proposed Measure	Beneficiaries	Unit Cost (USD)	Total Cost (USD)
1	Basic Automatic Weather Stations (AWS) Operational Course: 1 week theory and 1 week practical	24 staff members	650	15,600
2	PhD in Climate Change and Adaptation	1 staff member	30,000	30,000
3	Masters in Climate Change and Adaptation	2 staff members	20,000	40,000
4	Training on Computer Networking and Data Management (4 weeks)	4 staff members	1,600	6,400
5	Procure 1 mobile maintenance kit (1 double cabin pick with fixed tool box)	1 unit	80,000	80,000
6	Procure computers and accessories for 4 work stations	4 work stations	5,000	10,000
	Sub-Total			**182,000**
	Contingency			18,200
	Grand Total			**200,200**

Table 47: Capacity Building and Institutional Strengthening of WRUAs

	Proposed Measure	Beneficiaries	Unit Cost (USD)	Total Cost (USD)
1	Consultancy for capacity building of WRUAs by updating SCMPs, gender training and project management	30 WRUAs	2,000	60,000
2	Consultancy for resource mobilization for WRUAs	30 WRUAs	1,000	30,000
	Sub-Total			**90,000**
	Contingency-10%			9,000
	Grand Total			**99,000**

Table 48: Capacity Building and Institutional Strengthening of Dam Committee

	Proposed Measure	Beneficiaries	Unit Cost (USD)	Total Cost (USD)
1	Training needs assessment and gender mainstreaming for the Dam/Pan Committee	25 No	500	12,500
2	Consultancy for training on project management, operation, and maintenance of pans and dams	25 No	1,000	25,000
	Sub-Total			**37,500**
	Contingency-10%			3,700
	Grand Total			**41,250**

Table 49: Capacity Building and Institutional Strengthening of County Government

	Proposed Measure	Beneficiaries	Unit cost (USD)	Total Cost (USD)
1	Updating the County Integrated Development Plan (CIDP) of Nyandarua, Kiambu, Nairobi, and Machakos and mainstreaming Climate Change	4No	5,000	20,000
2	Consultancy for training on project management, operation, and maintenance of pans and dams	4 No	5,000	20,000
	Sub-Total			**40,000**
	Contingency-10%			4,000
	Grand Total			**44,000**

Table 50: Summary of Capacity Building and Institutional Strengthening Expenditure

	Proposed Measure	Total Cost (USD)
1	Capacity Building and Institutional Strengthening of NEMA	**615,000**
2	Capacity Building and Institutional Strengthening of WRA	**640,530**
3	Capacity Building and Institutional Strengthening of KMD	**200,200**
4	Capacity Building and Institutional Strengthening of WRUAs	**99,000**
5	Capacity Building and Institutional Strengthening of the Dam Committee	**41,250**
6	Capacity Building and Institutional Strengthening of the County Government	**44,000**
	Sub-Total	**1,639,980**

CHAPTER 5 : Improvement of Water Conservation and Storage Measures

5.1 Background

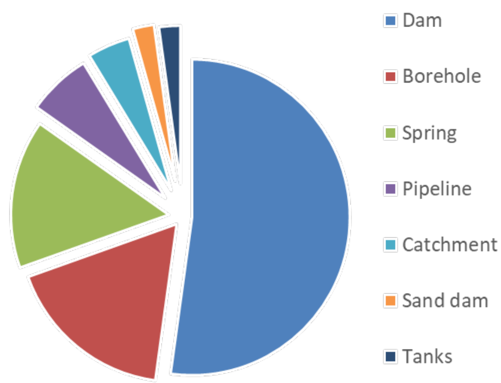
Degraded water storage facilities significantly undermine people's access to water resources in the upper ACA. To address this problem, it has been recommended to rehabilitate or construct new water harnessing and storage facilities for communities and local institutions in the four counties. Degraded water storage facilities include water pans, sand dams, boreholes, and water supply pipelines and rehabilitating these facilities will significantly enhance water access for communities in close proximity to the structures.

Extensive field surveys, stakeholder consultations, and desktop analyses have been done to identify potential sites for the rehabilitation of water structures. The feasibility assessment captured the following information; 1) Analysis of demand for water for both human and livestock population in the area, 2) Existence of adequate exploitable water resources to meet the local water demand and 3) Viability of various technologies in harnessing water resources. The work was organized to respond to the data that was collected through interview/discussions with the various stakeholders, observations and measurements using various instruments (topographical profiling, etc.).

As a result, a total of 46 sites were assessed for technical feasibility, and technical designs were made available to guide project activities. Key information captured in the designs are:

- Accessibility, adequacy (quantity) and quality of the proposed source of water
- Detailed technical and infrastructure requirements
- Detailed project area Map clearly showing the location of all the proposed infrastructures.
- Detailed engineering design report of the sites, so that they can be used in the construction.
- Where necessary equipment specifications were provided
- Costed Bills of Quantities

Figure 63: Distribution of the various types of structures assessed in Upper Athi River Catchment



5.2 Current Situation and Proposed Interventions

For this intervention, only Nyandarua, Kiambu, and Machakos are targeted given the limited funds available for this project. The following paragraphs assesses the baseline of each county and shows projected costs and beneficiaries of the interventions. Each household has an average of six members.

5.2.1 Nyandarua County

Proposed interventions in Nyandarua were primarily, water pans and springs. There are 12 water pans/water pans that require rehabilitation. In addition, two springs and boreholes will require rehabilitation. The status, provisional cost and estimated number of beneficiaries in Nyandarua county are given in Table 51. These sites were suggested through extensive consultations with the county stakeholders and all were considered for rehabilitation.

Table 51:Characteristics of different structures assessed in Nyandarua County

Type of structure	Status	Number	Provision cost (USD)	Number of beneficiaries(HH)	Number of beneficiaries(Individuals)
Borehole	Rehabilitation	2	59,682	1,050	6300
Water pan	Rehabilitation	12	1,717,811	4,720	28320
Spring	Rehabilitation	2	40,414	5,200	31200
Total		**16**	**1,817,907**	**10,970**	**65,820**

These structures are expected to serve about 65,820 individuals with clean water supply. Currently most of these communities rely on rainwater harvesting or unsafe waters sources. Development of these structures will provide potable water for domestic use by the beneficiaries. Furthermore, this will also serve as source of water for over 40,000 livestock, made up of cattle, sheep and goats.

The water will also support small scale irrigation currently been practiced around the water pans.. Unique to Nyandarua County is the use of water from the water pans and water pans for washing carrots (Figure 4). Carrots from regions outside the county are brought here for washing before repackaging them for market. This activity employs over 500 youths daily.

Figure 64: Youths washing carrots in Kariani small dam in Nyandarua county

The structures will also support environmental conservation activities, hence some structure which may not be a source of potable water might be considered given that they support flora and fauna. It is proposed that around the structures tree planting will be included.

To be able to explore the potential of these structures fully, it is important to rehabilitate them to their initial conditions. The water pans have aged, on average most of them are over 45 years. They will require desilting to restore their original volume or even increase in the event of increasing population and diversified uses. The other important intervention is reclaiming the original area of the structure sites. Most the structures (except Gachuchu spring) proposed for rehabilitation are located in public utility land. However, there is encroachment into the area reserved for most of these structures. Therefore, the area will be surveyed to determine the official boundary and then fenced to prevent further encroachment.

5.2.2 Kiambu county

Proposed interventions in Kiambu were primarily rehabilitation and/or extension of dilapidated water distribution network, protection of springs, sinking of boreholes and rehabilitating existing ones and catchment protection to reduce erosion risks. In Kiambu County there are four springs that are proposed for protections, three water pans that are proposed for rehabilitation and protection and four boreholes are proposed for rehabilitation. The status, provisional cost and estimated number of beneficiaries in Kiambu County are given in Table 52. In the table where the number of beneficiaries is not shown means that the supply will feed into an already existing system which has been accounted for. Like the case of Nyandarua County, these sites were pre-selected by stakeholders and some were also selected for rehabilitation.

Table 52: Characteristics of different structures assessed in Kiambu County

Type of structures	Status	Number	Provisional cost (USD)	Number of beneficiaries - HH	Number of beneficiaries(Individuals)
Borehole	Rehabilitation	3	248,050	6,000	36000
Water pan	New	1	27,341	-	
	Rehabilitation	2	464,185	3,000	18000

Spring	New	2	203,616	-	
	Rehabilitation	2	390,243	-	
Catchment	Rehabilitation	2	63,524	11,500	69000
Total		**15**	**2,010,121**	**20,500**	**123,000**

These structures are expected to serve about **123,000** individuals with clean water supply. Currently most of these communities rely on intermittent supply within the county, with some receiving once a week. Development of these structures will provide potable water for domestic use by the beneficiaries.

Furthermore, this will also serve as source of water for livestock, like cows which are mostly zero grazed and requires a constant supply of water. The water will also support small scale irrigation currently been practised around the structures.

Kiambu County, being in close proximity to Kenya capital city – Nairobi, provides accommodation to the peri-urban population who commute to and from the city. Hence any available water resources should be adequately protected and utilized. This could include even abandoned quarries as shown in Figure 67. The structures will also support environmental conservation activities. It is proposed that around the structures tree planting will be included.

Figure 65: Unutilized water from abandoned quarry in Kikuyu, Kiambu County

To be able to fully utilize the potential of water, Kiambu stakeholders proposed development of four new structures and rehabilitation of existing 11 structures. The water pans in this county are highly affected by siltation, hence catchment conservation was proposed. In Ndarugu river catchment which is the main source of quarry stones rehabilitation is proposed. It is expected that planting of indigenous trees in this catchment will restores the former quarry sites. In Kikuyu town an abandon quarry, Ruggeri, will be considered as an alternative source of portable water. In all the proposed structures the designated location will be surveyed demarcated and fence to reduce chance of human encroachment. Most the structures (except Romo springs) proposed for rehabilitation are located in public utility lands. The forest land is under the Government control hence it will be possible to get permission. These interventions are expected to increase access to portable in the county and contributed to environmental conservation in Kiambu County under climate change scenarios.

5.2.3 Machakos County

Proposed interventions in Machakos County were primarily water pans. There are 9 water pans that were selected for rehabilitation in Machakos County. In addition, a spring and two boreholes were proposed for rehabilitation and establishment, respectively. The status, provisional cost and estimated number of beneficiaries in Machakos County are given in Table 53. These sites were proposed by county stakeholders and all were considered for rehabilitation.

Table 53: Characteristics of different structures assessed in Machakos County

Type of structure	**Status**	**Number**	**Provisional cost** (USD)	**Number of beneficiaries - HH**	**Number of beneficiaries - individuals**
Borehole	New	2	211,877	4,800	28800
Water pan	Rehabilitation	9	1,435,580	132,000	792,000
Spring	Rehabilitation	1	160,640	3,000	18000
Tanks	New	1	402,490	20,000	120,000
Sand dam	Rehabilitation	1	89,800	1,500	9000
Total		**14**	**2,300,387**	**161,300**	**967,800**

These structures are expected to serve about 967,800 individuals with clean water supply. Currently most of the communities relies on rainwater harvesting or unsafe waters sources. Women and children water walk for long distance each day in search for water for domestic use. Development of these structures will provide portable for domestic use by the beneficiaries. Furthermore, this will also serve as source of water for over 40,000 livestock, made up of cattle, sheep and goats. The water will also support small scale irrigation currently been practised around the water pans. The structures will also support environmental conservation activities. It is proposed that around the structures tree planting will be included.

Figure 66: A farmer growing vegetables with water from Muumandu small dam in Machakos county

To be able to explore the potential of this structures fully is important to rehabilitate them to their initial conditions. The water pans have aged, on average most of them are over 45 years. They will require desilting to restore their original volume or even increase in the event of increasing population and diversified uses. The other important intervention is reclaiming the original area of the structure sites. Most the structures (except Gachuchu springs) proposed for rehabilitation are located in public utility land. However, there is encroachment into the area reserved for most of these structures. Therefore, the area will be surveyed to determine the official boundary and then fenced to prevent further encroachment.

5.3 Technical Design of Various Interventions

The technical designs considered the individual water structure identified by the various counties stakeholders. The philosophy was to provide access to clean water whole year round. Hence the small reservoirs the current volume was increased so that the can provide water whole year. In addition, a filtration system made of sand filters was introduced. Thus, the water from the source will be less laden of particulate matter. The design of the filtration system, storage and means of water abstraction is described in the subsequent section. The subsequent section also present design of spring and borehole water distribution system.

5.3.1 Water pan / Reservoirs with water filtration units

5.3.1.1 Filtration system

In household filtration system a sand filter with a pulverized charcoal filter medium supported by a bed of gravel will be used to remove suspended solid. The pulverized charcoal will be added to remove any odour and increase the acceptability of water. In the reservoir, the water entering the reservoir requires filtering and purification before human consumption. Hence, a filtration system using sand filters is proposed to be coupled with the reservoir.

A 2 mm pre-filtration screen will be used to remove any large particles which might not have settled in the reservoirs. The screen will be attached to the flexible pipe with a floating ball to suspend just below the water surface. The screen will also be protected with a steel to prevent it from sucking any deposited silt at low water level.

The maximum infiltration rate (Qmax) can be estimated by applying Darcy‘s equation

$$Q_{max} = kh\frac{h_{max} + d}{d}$$

where k is the hydraulic conductivity of the soil filter (m/s), A is the surface area of the sand filter (m^2) h_{max} is the depth of pondage above the sand filter (m) and d is the depth of the filter media (m). To maximize on the capture potential of the filter to capture the gross pollutants the reservoir is expected to promote sedimentation of a majority of particles within the inlet zone. Further particle remove will be done by the screen before the water is transmitted to the sand filter. Hence a single layer of sand was proposed in this study. The sand to be used will have an effective size (d10) of 0.2 mm and a uniformity coefficient of 2.

This sand characteristic will result in a head loss of about 1.25 m. This means that for water to flow through the sand filter a head of at least 1.25 m should be provided. Hence in the proposed design the sand filter will be located at about 1.5 m below the lowest level of water in the reservoir. Further the sand filter will have a steel at the lower and upper side. In the upper a geotextile material will underlie the steel frame to prevent the mobilization of the sand when the head is at maximum.

5.3.1.2 Storage

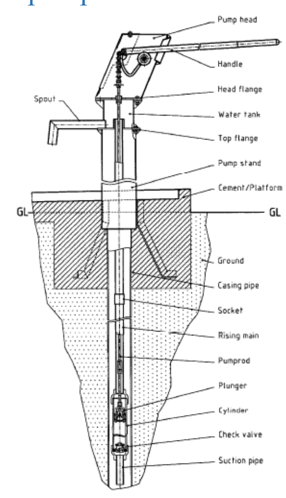
The capacity of the storage tank was marched with filtration rate of the sand filter and average possible of abstraction rate. Considering the rate of infiltration (0.001 m/s) through filter and the fact we need to store water for 12 hours (overnight). The unit per area of the yield will be 43.2 m^3. For a 2 m^2 sand filter then the yield will be 86.4 m^3. Hence the minimum required storage tank of 31.53 m^3. This assumes that even during water abstraction, filtration process will continue at an average rate of 7.2 m^3/h. To avoid long queues and provide for the sand filter, the storage capacity was increased to 87.92 m^3 and considering the filtration of the sand filters, this could be filled in about 6 hours. This also took into consideration of the dry period when the water level in the pan are likely to be low

The water level in the tank will be controlled primarily by the water level in the reservoir. The water level will also affect the filtration rate hence the rate of storage recharge. During dry season when the water level is low and filtration rate is also low the tank capacity had to be increased to store enough water for the estimate daily abstraction estimate.

5.3.1.3 Abstraction

The water in the storage tank will be abstracted using a Hand pump. Hand pump is a mechanical pump with low maintenance that rely on human power. In this study we propose to use India Mark II brand which has a maximum lift of 50 meters. A drawing of India Mark II hand pump is shown Figure 64 (Source from SKAT – RWSN, 2008).

Figure 67: Drawing of India Mark II Hand pump



The installation will be as described by the manufacturer. The slab should however, be built with sufficient gradient to drain away any wastewater. Since every drop counts this will be drained into a small cistern where the community can fetch it for cleaning. The designed sand filter is shown in Figure 64.

5.3.2 Spring Protection

Springs were identified within the catchment for possible project consideration. These springs flow throughout the year indicating that they can be a reliable source of water to the community. In the catchment the springs were also noted to be sources of good quality water that the local community rely on for their daily water uses including domestic purposes. However, to maintain good quality water, the spring should be well protected. In protecting the spring, the catchment area above it is protected from animals and humans to prevent contamination. Further a cutoff drain above the spring is constructed to prevent surface runoff and contaminated water from entering or mixing with spring water. With variation in climate where extreme rain and droughts are experienced there is need to protect the springs. This will ensure that the springs catchment wall and water quality is not destroyed by excess floods.

Springs eye is protected by filling the area behind the catchment dam with stones and gravel, with smaller stones being placed nearer the eye and larger ones near the wall. In addition, a spring box and a pipe for delivering the water to the users is constructed. This can be achieved by having a collection chamber with valve chamber connected to an open system where water flows freely through a pipe and collected by users. When the spring water carries sediment to the opening, a filter or sump may be required and should be located below the spring. In cases where the spring is located on a higher ground than the population it is supplying to, the water can be collected into a storage tank and then distributed by gravity. On the other hand, from the spring the outlet pipe can be connected to a sump and then pumped to storage reservoir which supplies water to local population through gravity.

To pump water to the storage reservoir which is located at higher grounds than the spring, a pump with either electrical, petrol, diesel or solar power is required. A submersible solar pump can be used to reduce the operation costs incurred when using other fuel and electricity.

5.3.3 Environmental Conservation

The main environmental conservation activities proposed are mainly planting of trees. In the different part of the catchment trees will be planted for catchment conservation purpose as a stand-alone project (e.g. in Ndarugu river, Kiambu County) or part of the other proposed project in several sites. It is proposed that indigenous trees will be planted in the catchment. For instance, Nyandarua county has a plan of protecting the water catchment areas by planting river line trees and controlling soil erosion with the sub catchment (CGoNyandarua, 2018). The county is also focused to contribute in reducing the impacts of climate change by enforcing laws and regulations regarding encroachment of forests, wetlands and promoting alternative sources of energy for instance solar power other than the use of wood. This is in line with the commitment by Government of Kenya measures to secure the country's development against the risks and impacts of climate change as presented in National Climate Change Action plan, 2013 – 2017 (GOK, 2013). The plan considers rehabilitation and conservation of water towers by planting trees.

Under future climate intervention trees would play various critical roles. This include increased forest cover, providing alternative source of fuelwood, contribution to biodiversity diversification and carbon sequestration, reduction of overland erosion losses. In each project we have proposed the cost of planting a tree like bamboos with additional cost.

5.4 Operation and Maintenance of the Proposed Projects

The following are actions proposed for operations and maintenance of the proposed projects.

1. The proposed structure will be constructed and handed over a committee who will be responsible for their operation and maintenance. This committee should have a cross cutting representation with a clear road map on addressing gender related issued.

2. The silt traps should be desilted regularly where applicable. The silt should be disposed at a suitable site where environmental impact is minimal.

3. Catchment restoration should be sustained near all the structures. The cost of planting trees is covered. However, this should be sustained through the proposed tree nurseries.

4. The filtration system and the composite filtration should be backwashed regularly to enhance the rate of flow. The interval will be site specific depending on the usage. For the filtration system a 9 HP centrifugal sludge pump is provided to assist with backwashing of the sand filtration unit.

5. The water supplied, where applicable, should be regularly subjected to physical-chemical and biological to determine their suitable for human consumption. This should include testing of residual chlorine where transmission is concerned.

6. Develop and maintain a regular surveillance for leakages in the pipeline. There should be a regular monitoring of the pipelines against vandalism and breakage. Any breakage should be addressed immediately. A regular maintenance of valves and joints should be done.

7. Adhere to operations and maintenance recommendation from the manufacturer for such items as pumps etc.

8. The committee should purchase appropriate machinery, equipment and tools, where applicable, for repair of maintenance.

CHAPTER 6: Economic Analysis

An economic feasibility analysis is conducted to estimate the economic feasibility of a project by comparing and analyzing the costs and benefits of the projects in monetary terms. The economic feasibility of a project depends on the sustainability of the project and its impact. It can be secured only if there is a net profit or a positive effect during its entire life cycle. Apart from financial analysis, which is a method used by project operators, economic feasibility analysis is used to identify whether the project is acceptable to the national economy or not.

Unlike an economic feasibility analysis, the analysis of financial validity is carried out from the perspective of a private investment operator to understand whether the project is practicable financially if it is carried forth through private investment. Therefore, the main purpose of financial validity analysis is to figure out whether the return on investment from the project achieves the expected profit. If not, the analysis makes basic data available to set up plans to make the project feasible.

6.1 Economic Feasibility Analysis Method

The analysis did not carry out a financial analysis as all expenditures incurred under the project and revenues resulting from it could not be taken into account. It thus undertook an economic analysis. The analysis adopted the Benefits-Costs Analysis (BCA) approach. In particular, the analysis used the following criterion tools: - The Net Present Value (NPV); Internal Rate of Return (IRR); Discounted Payback Period; Annual Economic Value; and, Benefit-Costs ratio.

The economic feasibility analysis in this study was carried out in accordance with the ECDF project feasibility guidelines. Benefit and Cost (B/C) is calculated as the total expected benefit divided by the value of the total cost. It is considered feasible when B/C≥1.

$$\text{Benefit-Cost Rate (B/C)} = \sum_{t=0}^{n} \frac{B_t}{(1+r)^t} \Big/ \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}$$

Here, B_t : Current value of benefits

C_t : Current value of costs

r : Discount Rate (Interest Rate)

n : Durability year of the project (Period of analysis)

Net Present Value (NPV) is the current value of the cost subtracted from the current value of expected benefits. If NPV≥0, it is considered feasible.

$$\neq t\, Present\ Value\ (NPV) \ = \ \sum_{t=0}^{n} \frac{B_t}{(1+r)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}$$

The Internal Rate of Return (IRR) is a discount rate to make the present value of the benefit and cost zero. If the IRR value is greater than the social rate of discount, it is considered feasible.

$$IRR \ : \ \sum_{t=0}^{n} \frac{B_t}{(1+r)^t} = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t}$$

To determine the feasibility of a project, "B/C ratio" can be utilized. To determine the priority order of various projects and to develop project strategies, NPV and IRR are examined simultaneously. Sensibility analysis is implemented to cope with unstable changes since there are many uncertainties in the process of calculating the benefits and costs during an economic feasibility analysis.

6.2 Conditions and Assumptions in the Economic Feasibility Analysis

The economic analysis was based on the following assumptions and conditions. General statistical data is based on national statistical data, such as data from the Kenya Statistical Office. If there was no official statistical data, data were secured through interviews with local government officials and collected through field studies.

The analysis took into account the following general assumptions

Project duration: The project life is given as four years. However, the analysis assumes that the government will continue supporting the project even after the project life. The analysis has also assumed a maximum timeline of 30 years.

Factoring inflation: Where inflation has been factored, the analysis has used the average annual Inflation rate for the last 5 years (2015 to July 2019) for Kenya which stood at 6.156%. To convert the 2009 reported costs of floods to real terms, the study has used Kenya's consumer Price Index (CPI) for 2009 which stood at 102.10 and for 2019 which stood at 159.60.

Population growth rate: Where the population has been assumed to grow over time, the average annual population growth rate for Kenya for the last 5 years (2015 – 2019) has been used I.e. 2.38%.

Discount rate: To calculate the present value of benefits and costs, the study has used the discount rate of 12% as base case scenario. The estimated discount ranges from 10% to 14.5% and thus a 12% real discount rate is used as an appropriate rate for Kenya to be used in project evaluation, and investment decision making (Ghanbariamin, 2015). Discount rate of 12% is applied. <Estimating the Economic Opportunity

Cost of Capital for Kenya>, published by Roskan G (2015): Estimating the Economic Opportunity Cost of Capital for Kenya.

Exchange rate: To convert Kenya Shillings (Kshs) into US dollars (USD) and vice versa, the analysis has used the KSHS/USD exchange rate of 77.34 as the mean exchange rate for 2009 and 110.0071 as the mean exchange rate on 2nd February 2021. The analysis has also assumed that the exchange rate will remain fixed over the coming years.

The analysis indexes are IRR, Benefit·Cost Rate (B/C), and NPV.
The residual value of facilities does not apply.

6.3 Costs

- The analysis has used the project budget figures as the costs figures. The budget figures are an aggregation of what is expected from the GCF and the co-financing from the Government of Kenya (GoK).

- **GCF funding**: The total GCF funding is sort for the four years is USD 9,853,497.21 broken down as shown in *Table 54*

Table 54: *GCF Funding*

	Year 1	Year 2	Year 3	Year 4	Year 5	Total
USD	**5,622,366**	**3,007,982**	**1,153,627**	**1,025,658**	**1,507,936.68**	**10,809,633**

- **GoK co-financing**: The Gok is expected to offer support to the project from Year 1 and throughout the project in terms of office space, staff time, vehicles, and utilities. These figures have been estimated as at Year 0 and grown over time with the average inflation rate. The figures for Year 0 are presented in *Table 2.2*. The analysis has also assumed that the Gok will support the project from Year 5 to a tune of USD 531,784 and this figure has been assumed will remain constant for a lack of a better estimate. This operations and maintenance (O&M) estimate supported by an O&M plan (attached)

Table 55: Gok support to the project in year 0

Item	USD	Description
Office Space	**27,000.00**	USD 45,000million per month * 12 months * 5% of office space
Staff time	**30,000.00**	50 staff * Average salary of USD 1,000 per month * 12 months * 5% of staff time.
Gok Vehicles	**1,500.00**	3 vehicles, worth USD 50,000 each, depreciated over 5 years (20% pa), and used for the project only 5% of the time.
Utilities	**2,400.00**	Utilities estimated at USD 200 per month for 12 months.
Totals	**60,900.00**	

- **Total financing**: *Table 56* thus represents the total financing (costs of the project) from Year 1 to Year 30.

Table 56: Total costs of the project (Year 0 – Year 30)

Year	Total costs (Budget) USD - Un-discounted
Year 0	-
Year 1	5,687,015
Year 2	3,076,611
Year 3	1,226,481
Year 4	1,102,997
Year 5	613,883
Year 6	618,937
Year 7	624,302
Year 8	629,998
Year 9	636,044
Year 10	642,462
Year 11	649,276
Year 12	656,508
Year 13	664,186
Year 14	672,337
Year 15	680,990
Year 16	690,175
Year 17	699,925
Year 18	710,276
Year 19	721,264
Year 20	732,928
Year 21	745,311
Year 22	758,456
Year 23	772,409
Year 24	787,222
Year 25	802,947
Year 26	819,640
Year 27	837,360
Year 28	856,172
Year 29	876,141
Year 30	897,340

6.3 Project Details

Only the direct benefits of economic analysis were calculated. The indirect benefits were excluded. This project is planned in order to consolidate the weather change maneuver and for the efficient management and usage of water resources of the ACA in Kenya by establishing an automatic watergate monitoring system. The target areas are four counties: Nairobi, Nyandarua, Kiambu, and Machakos.

Table 55: Surface water, Rainfall and Groundwater Monitoring System

County	Surface Water			Rainfall	Groundwater
	Total	Water Level	Water Level & Water Quality		Water Level & Water Quality
Total	38	3	20	5	10
Nairobi	8	2	2	2	2
Nyandarua	-	-	-	-	-
Kiambu	27	1	16	3	7
Machakos	3	-	2	-	1

6.4 Benefit Analysis

Numerous benefits/outcomes (environmental, social, and economic) are expected to accrue from the successful implementation of the project. The analysis has however singled out three key benefits that have been monetized and assessed. These are - I.e. Flood related benefits, Health related benefits, and time savings benefits.

Benefits are divided into direct and indirect benefits. In this case, only the measurable direct benefits are considered. The direct benefits of this project are 1) Flood Reduction, 2) Health Promotion, and 3) Social Cost or response cost).

6.4.1 Flood related benefits

- The project is aimed at providing timely early warning information to the downstream beneficiaries to act whenever there is likelihood of a flood in an area. The project intends to give early warning signals to the families and thus expect to reduce the losses from floods.

- The flood related benefits are based on the anticipated saving from potential losses if families do not act in time to floods. It is anticipated that if families received timely information they can move their valuable to safety and reduce potential losses.

- The Athi River Catchment Area has four potential flood risk areas in Kiambu, Machakos, Nairobi, and Nyandarua. The floods in Nairobi are mainly due to poor drainage in the city and although to some extent the Early Warning System (EWS) may have impact, it may not have as much impact as in the case of the other counties.

- The population in the targeted counties is about 4,176,013. The project took a conservative figure of 10% of this population with the assumption that this number will utilize the EWS information to move property. The targeted population has also been assumed to grow in numbers of time at the average annual population growth rate.

- The cost saved was calculated based on SEI (2009). According to the report, the 1997/98 floods in Kenya affected almost 1 million people and were estimated to have total economic costs of USD 0.850 billion to USD 1.213 billion arising from damage to infrastructure (roads buildings and communications), public health effects (including fatalities) and loss of crops. For lack of better alternative, the analysis used this data to calculate the per capita cost of floods in Kenya which stood at USD 2,276.85 in real terms. Again due to lack of data on variability of floods occurrences, intensities, and subsequent losses, the analysis has assumed that the per capita costs will remain fixed over the years.

- The project team also took a conservative figure of 5% of the total property that the families could save from floods in responding to the EWS. The analysis further assumed that only 5% of the cost saved could be fully attributed to the project. The costs saved (and thus benefits) by the households as a result of project intervention is indicated in *Table 2.3.*

6.4.2 Health related benefits

- The health related benefits were calculated based on the cost saved from reduced diarrhea incidents in the household, thus reduced treatment cost.

- Protected water sources such as borehole, and springs would significantly reduce the level of water borne diseases[62] and households would use clean containers to collect water from the water sources and thus reduce the risk of contaminating the water.

- The factor of population growth was calculated for the spring sources as the water supply from this source was significantly higher than the current population and even with this growth factor keyed in, the water supply from this source can supply households growth for over 40 years, assuming a 2.65% growth rate (average population growth rate).

- To monetize these benefits the analysis relied on a study by Cook, Kimuyu, & Whittington (2015) on the health benefits related to improved water supply, a case study of Meru county. The assumption made here is that the cost is applicable to the context of Athi River Catchment Area and thus could be used to deduce the health benefit for the families utilizing the water sources.

- The project intends to rehabilitate stalled boreholes in the catchment and it is estimated that about 36,500 individuals will benefit from this sources. Since the water expected from this source can just sufficiently support these individuals, it is assumed that only this number will benefit from this source and no increment in population size is factor in for this source as shown in the calculation. As

[62] Several studies have been done around this and it has been accepted that ground water is the best source of water as the water is filtered as it get to the aquifers and is thus purified.

mentioned above, it is expected that the water from the springs is more than adequate to benefit up to 1.6 million individuals.

- From the Meru study it was noted that families that fell sick and reported diarrhea spent about USD 4.74 per week on treatment. The analysis made an assumption that 50% of the cases reported could directly be linked to water quality issues and thus USD 2.37 could be attributed to the water quality issues. As mentioned above, the spring source is could initially benefit about 100,000 individuals benefit from it. Since the water from this sources can supply up to 1.6 million individuals the population growth factor was imputed for this source. However, the supply from the boreholes was assumed to be adequate for about 36,500 individuals and this is what was taken to do the calculation for the boreholes. The Meru study showed that of the population interviewed, only 7.5% reported diarrhea incidents. The analysis has taken a conservative approach and used 3% as the diarrhea incidents that would be averted due to the project intervention.

6.4.3 Times savings benefits

- From the same study in Meru, calculation of travel time saved by beneficiaries if the water source was within the premises was used for the calculation.

- The project intends to work on five different water sources i.e. rain water harvesting, boreholes, springs, water pans and sand dams. The baseline population to benefit from the interventions is as follows: 20,000 (rain water harvesting), 11,850 (boreholes), 8,200 (springs), 139,720 (water pans) and 1,500 (sand dams).Thus, the total population benefiting from this project is about 181,270 individuals under the baseline year.

- The study indicated that on average, the walking and wait time cost saved by families in Meru per month during the dry season is USD 40 and USD 11 during the rainy season. The targeted areas experience 7 dry months and 5 wet months in a year.

- For the purposes of calculation time savings benefits, the analysis has assumed that only 10% of the total population within the targeted areas would significantly reduce the time to the water sources and wait time to almost zero. Further the analysis has taken a conservative estimate of 10% as the times savings that could be wholly attributed to the project.

Table 56: Beneficiaries per Project (per month, per capita)

Type of Structure	Beneficiaries - HH	Beneficiaries - Individuals
Rain water harvesting through suply of tanks	20,000	120000
Boreholes	11,850	71100

Springs	8,200	49200
Water pans	139,000	834,000
Sand dams	1,500	9000
Total	180,550	1,083,300

6.5 Total Benefit Calculation

The total benefits of the project are thus the aggregation of the three economic benefits as indicated in Table 58

Table 57: Total benefits of the project

Year	Flood related benefits (USD)	Health related benefits (USD)	Time savings benefits (USD)	Total benefits (USD)
Year 0	-	-	-	**-**
Year 1	-	-	-	**-**
Year 2	1,751,647	-	620,719	**2,372,367**
Year 3	1,793,337	215,775	637,137	**2,646,249**
Year 4	1,836,018	221,561	653,989	**2,711,569**
Year 5	1,879,715	227,502	671,287	**2,778,505**
Year 6	1,924,453	233,602	689,043	**2,847,098**
Year 7	1,970,255	239,866	707,268	**2,917,388**
Year 8	2,017,147	246,297	725,975	**2,989,419**
Year 9	2,065,155	252,900	745,177	**3,063,232**
Year 10	2,114,305	259,681	764,887	**3,138,873**
Year 11	2,164,626	266,642	785,119	**3,216,387**
Year 12	2,216,144	273,791	805,885	**3,295,820**
Year 13	2,268,888	281,131	827,201	**3,377,220**
Year 14	2,322,888	288,667	849,080	**3,460,635**
Year 15	2,378,172	296,406	871,538	**3,546,116**
Year 16	2,434,773	304,351	894,591	**3,633,715**
Year 17	2,492,721	312,510	918,252	**3,723,483**
Year 18	2,552,047	320,887	942,540	**3,815,475**
Year 19	2,612,786	329,489	967,470	**3,909,745**
Year 20	2,674,970	338,321	993,060	**4,006,351**
Year 21	2,738,635	347,389	1,019,326	**4,105,350**
Year 22	2,803,814	356,701	1,046,288	**4,206,802**
Year 23	2,870,545	366,262	1,073,962	**4,310,769**
Year 24	2,938,864	376,079	1,102,368	**4,417,311**
Year 25	3,008,809	386,159	1,131,526	**4,526,494**
Year 26	3,080,418	396,509	1,161,455	**4,638,382**
Year 27	3,153,732	407,137	1,192,175	**4,753,044**
Year 28	3,228,791	418,049	1,223,708	**4,870,548**
Year 29	3,305,636	429,253	1,256,075	**4,990,965**
Year 30	3,384,311	440,758	1,289,298	**5,114,367**

6.6 Cost Analysis

The project cost includes direct investment expenses such as those incurred on the installation of a water level and water quality monitoring system, water and institutional overheads.

Table 58: Calculation of Investment (Economics)

Item		Unit	Cost (USD)
Monitoring	Surface Water	23	986,880
	Groundwater	10	506,000
	Rainfall	5	96,750
Water Resource Management Information System		1	510,000
Capacity Building	NEMA		615,000
	WRA		640,530
	KMD		200,200
	WRUAs		99,000
	Committee		41,250
	Government		44,000
Conserve Water Catchment Area & Water Storage and Supply Infrastructure	Kiambu		2,010,122
	Nyandarua		1,817,908
	Machakos		2,300,387
Total	-		9,868,027

6.7 Results of the Economic Feasibility Analysis

The economic analysis was done at 30, 20 and 15 years and the results are presented in *Table 60*

Table 60: Economic analysis results

	30 years, 12% discount rate	20 years 12% discount rate	15 years 12% discount rate
NPV (USD)	9,747,248.48	7,585,142.92	5,551,275.52
IRR	13%	12%	11%
Discounted payback period	7.22	7.22	7.22
AEV (USD)	1,210,059.08	1,015,489.68	815,061.81

Benefits/Costs Ratio	1.78	1.63	1.48

From the results, the project is economically viable at 30, 20 and 15 years. The NPV values are all positive, the IRR values are all greater than the discount rates and the BCR is greater than 1.

Besides the three key benefits used for analysis, other benefits (Economic, Environmental and Social) are due from the successful implementation of the project. These benefits were not quantified and thus not monetized. Some of the economic benefits not included for the analysis are: -

- Reduction of economic losses from flooding events due to climate information as there will also be a decrease in loss of assets and lives;
- Improved livelihoods from tree nursery establishment by Water Resource User Associations (WRUAs); and
- Enhanced agricultural productivity from catchment rehabilitation which is expected to improve soil fertility. Enhanced productivity is expected to increase food security and incomes in the target areas.

6.7.1 Environmental benefits expected from the project and that have not captured in the analysis include: -

- Improved biodiversity in catchment forests;
- Improved river water quality due to stabilization and rehabilitation of riparian areas;
- Reduction of biodiversity loss in catchment forests and national reserves and parks; and,
- Improved soil fertility due to catchment rehabilitation measures.

6.7.2 Unquantified social benefits also due from the project include: -

Increased capacity and awareness on water efficiency and conservation from awareness raising activities implemented through local institutions; and,

Increased awareness and knowledge at institutional and community level on climate change risks to water availability.

6.8 Sensitivity analysis

Sensitivity analysis was undertaken on the discount rate and the inflation rate. On the discount rate, the analysis tested two scenarios – scenario 1 discount rate at 10% and at scenario 2, discount rate at 14.5%.[63] On the inflation rate, the analysis tested one scenario in which inflation was taken out (i.e. zero inflation). The results are indicated in *Table 4.1* and *Table 4.2*.

Table 61: Sensitivity analysis on the discount rate

	30 years, factoring in inflation			15 years, factoring in inflation		
	12% discount rate	10% discount rate	14.5% discount rate	12% discount rate	10% discount rate	14.5% discount rate
NPV (USD)	9,747,248.48	13,274,827.71	6,403,153.95	5,551,275.52	7,119,851.91	3,791,428.95
IRR	13%	15%	10%	11%	13%	9%
Discounted payback period	7.22	6.88	7.88	7.22	6.88	7.88
AEV (USD)	1,210,059.08	1,408,183.74	944,717.96	815,061.81	936,073.82	632,774.07
Benefits-Costs Ratio	1.78	1.98	1.56	1.48	1.58	1.35

Table 62:Sensitivity analysis on the inflation rate

	30 years		15 years	
	Inflation rate – 6.156%	**Zero inflation rate**	**Inflation rate – 6.156%**	**Zero inflation rate**
NPV (USD)	9,747,248.48	10,141,293.99	5,551,275.52	5,747,575.19
IRR	13%	13%	11%	12%
Discounted payback period	7.22	7.15	7.22	7.15
AEV (USD)	1,210,059.08	1,258,977.33	815,061.81	843,883.36
Benefits-Costs Ratio	1.78	1.84	1.48	6.51

Under all scenarios, the project remains economically viable as shown by the sensitivity analysis results. The NPV remains positive, the IRR is greater than the discount rates in all cases, and the Benefits Costs ration in all cases is greater than 1.

[63] Ghanbariamin (2015) found out that the appropriate discount rate to be used in project evaluation, and investment decision making in Kenya ranged from 10% to 14.5%.

CHAPTER 7 : Summary and Conclusion

In recent years, there has been increased attention to climate change due to its impacts on the lives of Kenyans. This has been mainly due to an increase in the intensity and frequency of extreme climatic events such as severe drought and flooding. These extreme events have had negative socio-economic impacts on almost all sectors of Kenyan society. Especially, water security is a key issue given that Kenya's people and economy are highly vulnerable to erratic climatic patterns and limited water availability.

The Upper ACA is classified as one of the most vulnerable area to the impact of climate change such as increasing temperatures and unpredictability of rainfall characterize. Additionally, the communities in the Upper ACA are very vulnerable to floods and droughts for the following reasons: (i) inadequate hydro-meteorological modeling and simulation expertise within relevant government institutions such as WRA and KMD to predict climate change and environmental disasters and poor maintenance of the hydrological and meteorological stations leading to the loss or lack of essential data, (ii) difficulty in accessing water resources due to the lack of water supply facilities and maintenance resource, (iii) ineffective public participation in water catchment management (iv) poor resource mobilization efforts, (v) poor collaboration among government institutions, (vi) lack of alternative livelihood opportunities for the local communities, and (vii) inadequate public participation and gender consideration.

The proposed project is designed based on three strongly linked components considering the opinions of various stakeholders at the community level, local government level and central government level, the environmental constraints on project implementation, national climate change policy and direction of water resources development and management. This approach will improve the cost-effectiveness and long-term sustainability of the proposed components. The components are; establishment of water resources monitoring system and development of water resources management information system; institutional strengthening and capacity building based on needs and proposed remedial measures for the relevant institutions; improving, upgrading and restoration of irrigation facilities such as water pan, sand dam, spring, borehole and environmental conservation by planting trees. This proposed project would integrate such best practice and facilitate being used as a model for the interventions to be undertaken in other river catchment areas.

Annex 1. Kenya Climate Hazard Index

Table 59: Kenya Climate Hazard Index (r50mm, rx5day) by four county

year	Nyandarua r50mm (day)	Kiambu r50mm (day)	Nairobi r50mm (day)	Machakos r50mm (day)	Nyandarua rx5day (mm)	Kiambu rx5day (mm)	Nairobi rx5day (mm)	Machakos rx5day (mm)
1976	0.5	0.6	0.4	0.3	114.2	133.1	123.2	114.1
1977	0.5	0.7	0.6	0.3	107.6	130.5	121.2	110.3
1978	0.6	0.7	0.5	0.4	107.7	133	122.6	119.5
1979	0.4	0.6	0.6	0.4	103.3	129.1	120.7	121.2
1980	0.3	0.6	0.5	0.4	94.3	125.3	117.6	111.3
1981	0.3	0.4	0.3	0.3	100.6	119.4	109.7	108.5
1982	0.4	0.7	0.6	0.5	106.4	134.1	123.6	113.6
1983	0.2	0.4	0.3	0.2	93.4	113.8	105	105.1
1984	0.4	0.5	0.3	0.3	105.6	130.3	123.7	111.1
1985	0.6	0.8	0.6	0.5	117.4	139.4	129.7	116.4
1986	0.5	0.9	0.7	0.5	112.2	142.9	132.3	129.1
1987	0.3	0.4	0.3	0.3	97.1	121.9	114.7	115.6
1988	0.4	0.5	0.4	0.3	103.9	124	114.8	115.3
1989	0.4	0.7	0.6	0.6	111.9	136.2	127.8	124.9
1990	0.2	0.5	0.4	0.3	101.7	127.1	119.9	112.9
1991	0.4	0.6	0.5	0.4	109	136.8	126.7	118.2
1992	0.4	0.5	0.4	0.3	105.9	128.6	119.5	110.4
1993	0.3	0.5	0.5	0.3	99.2	122.4	115.2	111
1994	0.3	0.4	0.4	0.3	95.1	121.4	114.9	117
1995	0.3	0.4	0.4	0.2	103.6	124.2	115.7	109.6
1996	0.3	0.5	0.4	0.3	102.7	127.7	119.5	121
1997	0.4	0.4	0.3	0.2	101.3	119.2	111.3	105.5
1998	0.6	1	0.8	0.6	110.4	139	130.4	124.5
1999	0.4	0.7	0.6	0.5	107.2	128.1	119.8	119
2000	0.4	0.7	0.6	0.4	110.8	141.1	130.2	126.8
2001	0.4	1.1	0.9	0.6	107.5	155.3	146.1	137.9
2002	0.4	0.6	0.4	0.4	98.3	123.6	117.3	111
2003	0.4	0.6	0.5	0.4	103.8	131.4	122.1	116.2
2004	0.4	0.7	0.6	0.4	102.3	125.4	116.1	114.7
2005	0.4	0.8	0.7	0.5	102.6	130.3	122.8	121
2010	0.6	1	0.9	0.7	105.2	134.3	128.5	116

2011	0.4	0.8	0.6	0.5	108.5	135.5	124.9	123.5
2012	0.5	0.7	0.7	0.4	109	128.2	121.5	117
2013	0.5	0.7	0.6	0.4	115.3	137.8	130.1	120.6
2014	0.5	0.6	0.4	0.4	100.9	122.5	115.2	110.6
2015	0.5	0.8	0.6	0.5	115	143	135.1	123
2016	0.5	0.6	0.5	0.3	108	123.7	114.5	112.7
2017	0.8	1	0.9	0.7	117.4	143.4	135.1	130.3
2018	0.8	1.5	1.3	0.9	128.1	163.5	157	141.6
2019	0.4	0.7	0.6	0.4	101.2	134	125.9	118.1
2020	0.6	1	0.9	0.8	111.2	138.3	132.1	131
2021	0.4	0.7	0.6	0.4	99.8	124.9	117.4	108.3
2022	0.5	0.8	0.7	0.5	114.4	141	133	121.3
2023	0.4	0.5	0.4	0.4	105.9	125.3	117.6	111
2024	0.6	0.8	0.8	0.7	114.4	134.5	129.2	124.1
2025	0.7	1.2	1	0.8	125.2	163.4	157.9	145.4
2026	0.6	0.8	0.7	0.5	113.9	145.9	137.8	131.2
2027	0.4	1	0.9	0.6	109.3	146	139.4	126.4
2028	0.5	0.7	0.7	0.6	114.2	128.2	123.3	118
2029	0.6	0.9	0.8	0.6	116.7	147.4	141	124.5
2030	0.4	0.6	0.6	0.6	105.7	132.5	122.2	126.4
2031	0.6	0.9	0.9	0.6	114.6	139.4	134.2	125.3
2032	0.6	0.9	0.7	0.6	118.7	143.6	136.6	126.5
2033	0.6	1	0.9	0.8	121.8	151.6	144.8	134.4
2034	0.6	0.9	0.7	0.6	113.6	139.4	131.9	125.7
2035	0.5	0.8	0.7	0.6	113.1	147.1	140.6	132.3
2036	0.6	1.1	0.9	0.7	107.8	144	135.5	130.4
2037	0.7	1.2	1	1	118.4	149	138.3	139.7
2038	0.8	1.2	1.1	0.7	120.6	157.2	149.3	137.6
2039	0.6	0.8	0.6	0.5	108.6	135.4	127.4	121.7
2040	0.6	0.9	0.8	0.5	107.2	129.8	120.7	118.7
2041	0.7	1.2	1.1	0.9	113.3	142.3	135.5	130.4
2042	0.7	0.8	0.7	0.6	122.6	144.8	138	132.9
2043	0.4	0.7	0.6	0.5	108.1	141.3	134.5	125.5
2044	0.5	0.6	0.5	0.4	109.3	130.2	120.3	119.7
2045	0.7	1.1	0.9	0.8	113.1	141.3	133.7	128.2
2046	0.7	1	0.9	0.7	114.6	138.2	130.4	129.4

2047	0.8	1.3	1.1	0.8	121.7	153.7	145	133.2
2048	0.9	1	1	0.7	126.6	146.1	140.1	132.7
2049	0.9	1.4	1.3	1	120.5	150.9	144.4	146
2050	0.7	1	0.7	0.7	109.7	136.3	127.9	126.6
2051	0.7	0.9	0.8	0.6	120.7	143.3	134.4	126.6
2052	1	1.9	1.6	1.1	138.8	185.1	176	153.8
2053	0.5	0.8	0.7	0.6	109.5	136.3	126.6	123.4
2054	0.6	0.8	0.7	0.5	112.1	134.6	126.7	121
2055	0.5	0.7	0.5	0.5	105.9	133.1	123.7	123.5
2056	0.7	1	0.8	0.6	112.8	138.6	130.6	122.1
2057	0.8	1.6	1.7	1.2	123.5	165	163.4	143.3
2058	0.7	1.3	1.2	0.9	116.8	152.2	146.2	135.9
2059	0.6	1	1	0.6	112.9	141.2	135.2	126.8
2060	0.8	1.3	1.2	0.9	121	152.4	146.1	138.2
2061	0.7	1.1	0.9	0.8	118.1	148.2	140.4	134.5
2062	0.8	1	0.8	0.8	123.9	149.1	141.4	133.7
2063	0.5	1	0.8	0.9	108.8	152.1	145.2	143.7
2064	1	1.5	1.4	0.9	128.7	158.3	153.1	133.9
2065	0.9	1.2	1.1	0.9	124.5	150.7	144.9	135.3
2066	0.6	0.6	0.5	0.5	116.2	133.9	126.8	121.6
2067	0.7	1.1	1	0.8	117	141.2	136	130.3
2068	0.5	0.6	0.5	0.5	106.5	127.3	117.4	120.2
2069	0.6	1	0.9	0.6	111.8	139.7	132.3	125.3
2070	0.7	1.1	0.9	0.8	116.5	142.2	132.2	136.2
2071	0.8	1.2	1.2	0.8	119.6	146.4	141.1	128.5
2072	0.9	1.7	1.5	1.2	125.4	162.7	156.2	145.7
2073	0.9	1.3	1.1	1	136.5	170.6	162.8	150.3
2074	0.8	1.5	1.3	1	126.5	147.6	137.9	129.8
2075	0.7	0.9	0.7	0.6	115.6	139.3	131.2	127.7
2076	0.8	1.5	1.4	1	116.6	152.8	145.9	135.4
2077	0.6	0.7	0.5	0.4	113.3	132.7	125.2	119.6
2078	0.9	1.2	1	0.7	118.2	141.5	132.6	123
2079	0.9	1.4	1.3	0.9	119.6	155.7	150	139.1
2080	0.7	1.1	1	0.8	110.6	145.6	141.2	137.3
2081	0.7	0.9	0.8	0.6	123.3	146.4	138.5	131.6
2082	0.8	1.3	1	1	119	147.7	140.1	135.4

2083	0.6	1.1	0.9	0.7	116.2	142.1	134.6	128.7
2084	0.7	1.1	0.9	0.6	115.6	142.4	136.9	126.3
2085	0.7	1.1	1	0.6	113.3	139.4	132.9	126.2
2086	0.8	1.1	1	0.8	124.3	157.3	151.4	142.9
2087	1	1.3	1.1	0.9	125.6	149.2	142.7	135.1
2088	0.6	1.2	1.1	1	107.2	145.2	141.6	138.1
2089	0.7	1.3	1.2	0.9	117.4	147.7	140.5	132.6
2090	0.6	0.9	0.9	0.8	122.4	144.2	136	134.9
2091	0.5	0.8	0.7	0.5	109.4	136.4	128.9	124.6
2092	0.7	1.2	1.1	0.7	123.9	156.6	151.2	138
2093	0.7	1.1	1.2	0.7	122.9	151.1	147	134.6
2094	0.8	1.2	0.9	0.8	125.9	154.5	143.6	144.3
2095	0.9	1.3	1.1	1.1	118.2	148.6	141.6	134.6
2096	0.8	1.2	1	0.8	119.1	144.2	136.4	138.3
2097	0.7	1.3	1.2	1	123.1	157.6	152.7	142
2098	0.7	0.9	0.8	0.7	115.5	133.5	124.8	126.7
2099	0.9	1.4	1.2	0.9	133	171.6	162	144.9
2010	0.5	0.9	0.8	0.7	104.6	134.6	126.5	116.8
2011	0.5	0.8	0.7	0.6	115.7	136.6	128.1	119.8
2012	0.5	0.7	0.5	0.6	106.4	138.9	130.1	131.4
2013	0.7	1	0.9	0.6	119.1	145.3	140.3	131.9
2014	0.6	1.2	1.1	0.8	109.1	145.1	140.3	133.2
2015	0.4	0.8	0.8	0.6	102.5	133.5	125.9	119.1
2016	0.7	1	0.9	0.5	113.8	140.7	133	122.1
2017	0.4	0.7	0.5	0.5	110.6	133	123.8	126.5
2018	0.5	0.9	0.7	0.5	104.5	133.2	125.3	122
2019	0.6	0.7	0.7	0.5	111.6	131.2	121.9	118.6
2020	0.4	0.9	0.8	0.6	102.6	132.1	126.3	124.3
2021	0.6	0.6	0.6	0.5	111.8	129	121.6	114.5
2022	0.7	1.1	1	0.8	122.9	158.4	153.1	144.7
2023	0.7	0.9	0.6	0.6	110.2	135.3	125.3	121.3
2024	0.6	0.9	0.8	0.6	109.8	139.4	132.2	127.2
2025	0.6	0.6	0.4	0.3	108.7	124.1	115.3	109.6
2026	0.5	0.7	0.5	0.5	112.4	136.9	127.7	128.4
2027	0.8	1.1	0.9	0.7	119.7	144.8	135.6	127.6
2028	0.5	0.8	0.6	0.6	107.4	134.3	125.1	122.6

2029	0.7	1	0.8	0.8	117.2	145.6	136.9	139.4
2030	0.5	1	0.9	0.7	110.9	140.1	134	124.7
2031	0.6	0.9	0.8	0.6	109.4	136.6	127.7	123.1
2032	0.7	1.1	1	0.7	115.6	143.1	136.4	128.6
2033	0.5	0.7	0.6	0.5	102.7	118.5	110.7	110
2034	0.6	1	0.9	0.7	119	148.1	141.2	133.3
2035	0.6	0.8	0.7	0.4	113.2	137.2	127.7	125.1
2036	0.7	1.4	1.1	0.8	114.2	142.8	134.1	127.1
2037	0.6	0.9	0.7	0.6	110.2	134.5	125.4	119
2038	0.7	1.1	1.1	0.8	112.2	142.1	136.3	129.5
2039	0.8	1.2	1.2	1.1	121.8	157.5	154.9	146.4
2040	0.4	0.6	0.6	0.6	102.7	126.5	118.8	124.1
2041	0.9	1.2	1.1	0.9	130.4	149.6	140	131.8
2042	1.1	1.7	1.6	0.9	129	159.4	153.8	137.7
2043	0.6	0.9	0.8	0.7	116.5	141.1	133.7	129.9
2044	0.9	1.2	1.1	1	122.4	154.9	148.2	144.2
2045	0.7	1.1	0.9	0.8	117.8	149	141.7	137.7
2046	0.9	1.4	1.2	0.9	121.9	155.2	145.2	135.3
2047	0.6	0.9	0.9	0.7	112.9	141.6	136.2	126.7
2048	0.8	1.4	1.4	0.9	123.1	151.6	143.8	130.6
2049	0.8	1.4	1.2	1	122.8	157.6	151	142.5
2050	0.8	1.3	1.1	0.9	127.4	152.9	143.7	137.1
2051	0.7	1	0.8	0.6	114.1	135.4	127.9	124.5
2052	0.6	0.8	0.7	0.7	109.2	129.3	118.7	128
2053	1	1.6	1.6	1	129.6	163.2	161.7	142.8
2054	0.8	1.2	1.2	0.9	114	146.9	143.8	135.5
2055	0.6	1.4	1.1	0.9	116.5	154.3	148.5	139.5
2056	0.7	1.2	1.1	0.9	112.5	151.2	142.7	144.9
2057	0.9	1.4	1.3	1.1	121	151.4	145.3	137.2
2058	0.8	1.5	1.3	1	119.5	153	144.6	137.8
2059	0.7	1.2	1	0.8	114.2	145.6	138.9	129.7
2060	1	1.2	1.2	1	125.9	145.8	141.5	141.4
2061	0.8	1.2	1	0.8	124.9	154.4	145.6	140
2062	0.8	1	0.9	0.9	117.7	134.4	124.7	119.7
2063	0.8	1.2	1.1	0.8	114.3	144.2	137.9	134.8
2064	1	1.4	1.2	0.9	128.6	156.5	147	139.3

2065	0.5	1.1	0.9	0.7	101.8	137.9	133.5	129.8
2066	0.6	0.9	0.8	0.7	116.1	135.3	128.3	124.7
2067	1.3	2	2	1.4	141.5	165	161	145.6
2068	0.8	1.3	1.2	0.9	122.7	160.5	156.7	142.7
2069	0.9	1.1	0.9	0.8	125.6	150.4	144.8	139.7
2070	0.8	1.1	1.1	0.8	117.2	149.2	141.7	138.5
2071	1	1.4	1.3	1	128.4	143.9	139.7	128.5
2072	1.1	1.4	1.2	1	128	150.6	142.8	136
2073	1.1	1.6	1.5	1.2	131.6	159.2	151.8	148.1
2074	0.9	1.7	1.6	1.3	122.8	157.9	153.7	143.8
2075	1.2	1.6	1.3	1.2	129	159.8	150.6	150.8
2076	1.3	1.8	1.5	1.1	145.1	182.4	173.6	152.7
2077	1.3	2.1	2	1.5	143	190.7	185.6	163.8
2078	1.3	1.5	1.3	0.9	135.7	161.8	156.1	143.8
2079	1.1	1.4	1.3	0.9	134.1	161.3	152.9	141.2
2080	1.3	1.6	1.5	1	135.1	160.5	157.2	147.2
2081	0.9	1.3	1.2	1	114.6	150.6	144.4	137.9
2082	0.9	1.1	1	0.7	125.9	146.3	140.1	132.6
2083	1.4	1.8	1.7	1.3	145	173.7	170.8	153.6
2084	1	1.5	1.3	1.1	123.1	156	146.1	145.6
2085	1.3	2.2	2.1	1.4	143.2	180.9	173.9	155.3
2086	1.4	2	1.9	1.5	142.3	176.3	169.7	160.2
2087	1.3	1.7	1.6	1.3	139.1	168.7	164.5	153.6
2088	1.1	1.3	1	0.9	132.9	152.1	141.6	138.7
2089	1.1	2	2	1.4	132.4	169	167.8	150.8
2090	1	1.6	1.5	1.3	130.3	172.6	166.9	144.6
2091	1.1	2	1.7	1.2	140.7	173.5	165.9	151.5
2092	0.9	1.4	1.2	1	122.8	152.6	147	144.3
2093	1.5	2.4	2.3	1.7	141.2	170.5	162.3	152
2094	1.2	1.8	1.6	1.3	139.2	174.7	167.1	152
2095	1.4	2	1.8	1.2	139.7	168.9	164.3	143.3
2096	1.5	2	1.9	1.5	140.6	182.1	179.7	160.2
2097	1.3	1.4	1.2	1.2	129.2	151.9	142.2	146.5
2098	1.3	1.8	1.7	1.4	137.6	172.5	166.7	160.8
2099	1.4	1.9	1.6	1.3	144.1	170.2	162.8	145.8

Table 60: Kenya Climate Hazard Index (r95ptot, sdii) by four county

year	Nyandarua r95ptot (mm)	Kiambu r95ptot (mm)	Nairobi r95ptot (mm)	Machakos r95ptot (mm)	Nyandarua sdii (mm/day)	Kiambu sdii (mm/day)	Nairobi sdii (mm/day)	Machakos sdii (mm/day)
1976	216	190	171.3	133.6	6.5	7.2	6.8	7.2
1977	201.7	194.6	172.5	129.1	6.6	7.4	7	7.4
1978	251.8	248.9	207.8	182.2	7	8	7.5	8.1
1979	182.6	196.1	175	145.2	6.6	7.7	7.2	7.8
1980	175	186.2	160	139.8	6.4	7.4	6.9	7.4
1981	181.2	189	165	134.9	6.4	7.4	6.9	7.5
1982	195	214.9	187.8	152.3	6.5	7.4	6.9	7.4
1983	164.5	162.8	142.3	131.2	6.3	7.2	6.7	7.3
1984	201.7	217.8	188.6	149.2	6.7	7.8	7.3	7.8
1985	234.7	234.4	206.2	150.3	6.7	7.7	7.2	7.5
1986	232.9	258.8	225.3	198.9	6.9	8.3	7.8	8.5
1987	150.6	146.2	131.5	127.9	6.3	7.2	6.8	7.6
1988	203.2	193.1	169.7	141	6.6	7.4	7	7.5
1989	195.2	212.3	197.2	172.1	6.6	7.8	7.3	8
1990	182.5	183.9	165.6	125.9	6.5	7.5	7.1	7.5
1991	197.8	208.5	178.8	138.8	6.6	7.6	7.1	7.6
1992	178.1	188.2	161	119.9	6.3	7.2	6.8	7.2
1993	163	162.2	142.3	125.3	6.5	7.4	7	7.6
1994	181.8	183.1	159.4	146.2	6.6	7.7	7.3	7.8
1995	165.1	151.4	133.9	114.6	6.3	7.1	6.7	7.3
1996	181.6	198.9	172.1	156.6	6.5	7.5	7.1	7.7
1997	185.9	169	150.2	119.2	6.5	7.3	6.9	7.4
1998	238.5	251.9	222.2	186.8	6.9	7.9	7.5	7.9
1999	223.9	203.8	171.9	151.8	6.7	7.6	7.1	7.7
2000	213.3	241.5	204.8	176.9	6.6	8	7.5	8.1
2001	232	296.2	259.3	232.1	6.8	8.5	8	8.7
2002	173.4	184.5	165.5	145.5	6.4	7.4	7	7.7
2003	211.3	234.9	202.6	176.9	6.6	7.9	7.5	8.1
2004	189.1	203.2	178.9	153.8	6.5	7.5	7.1	7.5
2005	186.8	197.3	173.8	149.5	6.5	7.6	7.1	7.7
2010	225	234.1	209.7	182.9	6.6	7.7	7.2	7.9
2011	248.2	278.1	242.3	212.4	6.8	8.2	7.7	8.3
2012	232.1	229.5	208.5	174.1	6.8	7.7	7.3	7.9

2013	227.1	231.9	208	165.4	6.7	7.8	7.4	7.8
2014	202.7	219.2	195.5	168.4	6.4	7.6	7.2	7.8
2015	229.3	239.7	213.9	166.4	6.6	7.7	7.3	7.6
2016	212.1	199.5	173.6	144	6.5	7.3	6.9	7.4
2017	264.6	261.1	232.8	206	6.9	7.9	7.5	8.2
2018	291.6	322	295.5	243.6	7.1	8.4	8.0	8.5
2019	204.2	243.5	214.4	182.2	6.6	7.9	7.5	8.0
2020	252.7	256.4	230.2	205.3	6.8	8.2	7.7	8.3
2021	187.2	205.9	186.5	151.9	6.5	7.5	7.1	7.6
2022	244.9	234.5	203	170.9	6.8	7.7	7.3	7.8
2023	204	206.5	182.6	159	6.4	7.4	7.0	7.6
2024	226.4	248	230.9	204.1	6.8	7.9	7.5	8.0
2025	261.4	289.5	264.2	220.3	7.0	8.3	7.9	8.5
2026	229.3	248.9	222.8	185.7	6.6	7.9	7.5	8.0
2027	226.5	265.4	247	205.7	6.6	8.0	7.6	8.1
2028	256.4	235.2	226.7	190.3	6.8	7.7	7.3	7.9
2029	230	222.1	201.9	168.2	6.6	7.6	7.2	7.7
2030	209.1	232	209.3	195.9	6.7	8.0	7.5	8.3
2031	252.9	248.3	231.2	195.9	6.8	8.0	7.6	8.1
2032	255	252.2	221.9	191	6.8	7.8	7.4	7.9
2033	245.3	265.1	241.9	204.7	6.7	8.0	7.6	8.1
2034	235.6	264.9	235.5	201.8	6.6	7.8	7.4	8.0
2035	256.1	280	250.8	211.1	6.9	8.2	7.8	8.3
2036	227.6	268	244.3	212.7	6.6	8.0	7.6	8.2
2037	296.2	340.9	308.4	268.8	7.2	8.6	8.2	8.9
2038	268.9	295.8	271.1	231.2	7.0	8.4	8	8.5
2039	230.6	266.5	245.5	200.3	6.7	7.9	7.6	8.1
2040	230.3	247.5	223.8	190.7	6.6	7.8	7.4	8.0
2041	241.5	289.4	265.4	244.9	6.7	8.3	7.9	8.6
2042	256.8	256.6	234.7	215.2	7.0	8.0	7.6	8.4
2043	212.6	227.3	210	178.4	6.6	7.6	7.2	7.8
2044	231.2	234.7	209.7	185.8	6.7	7.8	7.4	7.9
2045	259.8	285.3	263.6	226.6	6.9	8.2	7.8	8.4
2046	272.8	265.5	235.5	218.4	7.0	8.3	7.8	8.6
2047	281.2	316.8	290.7	239.6	7.1	8.7	8.3	8.8
2048	272.4	264.4	240.3	204	7.0	8.1	7.7	8.2

2049	268.8	316.9	300.7	273.5	6.9	8.5	8.1	8.9
2050	231.8	257.8	229.1	207.7	6.6	8.0	7.5	8.1
2051	251.4	247.2	217.2	193.5	6.9	8.0	7.6	8.2
2052	336.3	387.5	349.1	278.3	7.3	8.9	8.4	8.8
2053	216.6	234.1	207.9	192.9	6.6	7.7	7.2	7.9
2054	252.8	251	225.5	193.7	6.9	7.8	7.3	7.9
2055	232.3	235.6	202.5	181.8	6.7	8.0	7.6	8.2
2056	254.2	273.8	248	214.2	6.9	8.0	7.6	8.2
2057	296.5	330.6	312.9	253.6	7.0	8.4	8.0	8.5
2058	263.3	294.4	265.6	227.6	7.0	8.4	8.0	8.6
2059	252.7	287.4	263.5	223.3	7.0	8.3	7.9	8.5
2060	273.3	298.4	273.7	238.8	6.9	8.3	7.9	8.4
2061	263.4	282.5	257.6	223	6.8	8.1	7.7	8.4
2062	291.9	283.9	254.2	234.1	7.0	8.3	7.8	8.6
2063	265	322	295.4	272.4	7.1	8.7	8.3	9.0
2064	290	335.1	317.4	247.1	7.0	8.5	8.2	8.5
2065	293.1	312.4	288.2	250.9	7.1	8.6	8.2	8.9
2066	235.7	228.7	203.3	184.6	6.8	7.8	7.4	8.1
2067	292.8	313	295.9	241.1	7.2	8.4	8.0	8.5
2068	249.9	246.9	217	190.7	6.9	8.1	7.6	8.2
2069	252.2	263.4	246.2	201.9	6.8	8.1	7.7	8.3
2070	277.5	308.8	279	251.9	6.9	8.3	7.9	8.6
2071	299.3	292.1	267.7	208.1	7.2	8.2	7.8	8.1
2072	305.6	356.8	331.9	277.7	7.2	8.7	8.3	8.8
2073	300.9	333.7	307.8	255.2	7.0	8.3	7.8	8.5
2074	342.5	364.5	334.2	282.1	7.3	8.6	8.2	8.8
2075	273.8	277.8	250.1	219.7	6.9	8.1	7.6	8.2
2076	276.5	323.7	302.4	253.3	7.1	8.7	8.4	8.9
2077	228.6	225.1	204.5	171.4	6.7	7.8	7.3	7.9
2078	289.9	307.3	276.3	218.2	7.1	8.4	8.0	8.4
2079	332.1	365.3	344.5	294.5	7.2	8.9	8.5	9.1
2080	258.5	268.9	258.5	217.7	6.7	7.9	7.6	8.2
2081	298.4	311.1	285.9	238.5	7.0	8.3	7.9	8.5
2082	302.3	328.1	289.5	257.9	7.1	8.5	8.1	8.8
2083	266.8	283.6	257.6	225.2	6.9	8.2	7.8	8.3
2084	253.9	267.4	241.8	201.3	6.9	8.2	7.8	8.4

2085	259.9	291	272.1	226.1	7.1	8.5	8.1	8.6
2086	298.2	317.8	291.1	244.4	7.2	8.5	8.1	8.7
2087	324.1	330.6	302.4	249.4	7.3	8.7	8.2	8.8
2088	266.4	322.9	300.3	271.7	7.0	8.5	8.1	8.8
2089	269.3	298.1	282.5	236.8	6.9	8.4	8.0	8.5
2090	277.2	279.9	254	219.3	7.0	8.2	7.8	8.4
2091	249.9	251	224.3	200.1	6.9	8.1	7.6	8.1
2092	322.8	335.4	306.3	254.3	7.3	8.7	8.3	8.7
2093	313.7	346.1	320.3	267.1	7.3	8.7	8.3	8.9
2094	294.1	322.6	296.6	255	7.1	8.6	8.2	8.8
2095	293.3	302.2	276.3	239.9	7.1	8.4	8.0	8.4
2096	299	301.3	274	248.5	7.1	8.3	7.9	8.6
2097	266.3	288.4	274.1	231.2	6.9	8.3	7.9	8.4
2098	275.5	282.1	262.8	234.1	7.1	8.3	7.9	8.7
2099	339.2	382.2	344.3	275.5	7.3	8.8	8.5	8.9
2010	190.7	215.8	196.3	160.7	6.3	7.5	7.1	7.5
2011	232.8	239.8	213.5	187.8	6.8	7.9	7.5	8.1
2012	210.2	250.8	220.5	204.4	6.7	8.0	7.5	8.3
2013	247.1	253.4	233.9	197.2	6.9	8.2	7.8	8.4
2014	228.2	274.7	246.7	210.2	6.9	8.4	8	8.5
2015	199	217.3	198.3	159.7	6.5	7.5	7.1	7.6
2016	235.9	248.1	226.8	172.6	6.9	8.0	7.7	8.0
2017	209.5	210.3	181.9	173.5	6.7	7.7	7.2	8.0
2018	202.2	222.6	198.2	167.8	6.6	7.8	7.4	8.0
2019	202.1	206.1	180.1	155.3	6.7	7.8	7.4	8.0
2020	183.9	207.7	189.1	170.6	6.4	7.7	7.2	7.9
2021	209.3	183.1	161.6	135.3	6.7	7.5	7.1	7.7
2022	300.5	273.8	250.3	224.4	7.3	8.4	7.9	8.6
2023	242.9	259.1	231.1	203.9	6.8	7.8	7.4	7.9
2024	216.6	238.2	215.1	178.8	6.7	7.9	7.5	7.9
2025	187.6	179.4	156.5	134.8	6.4	7.6	7.1	7.7
2026	247.8	268.3	233.5	212	6.9	8.3	7.9	8.5
2027	256.7	277.5	252.3	219.1	6.9	8.1	7.7	8.4
2028	201.8	230.7	205	182.3	6.5	7.7	7.3	8.0
2029	249.3	272.5	250.3	230	6.8	7.9	7.5	8.0
2030	226.2	240.8	215.3	184.6	6.7	7.9	7.5	8.2

2031	228.3	241.2	216.6	189.4	6.8	8.0	7.5	8.1
2032	238.7	264.5	238.1	204.2	6.9	8.3	7.8	8.6
2033	204.8	199.4	181.8	152.7	6.5	7.5	7.2	7.8
2034	264.3	263	238.7	206.1	7.0	8.2	7.9	8.5
2035	259.2	268.5	240.1	206.9	7.0	8.1	7.6	8.2
2036	249	288.7	265.2	226.2	6.8	8.2	7.9	8.4
2037	247.1	240.5	204.3	183.7	7.0	8.1	7.6	8.1
2038	252	264.9	248.7	224.5	6.9	8.1	7.7	8.3
2039	258	287.6	264.2	234.7	7.0	8.4	8.1	8.7
2040	193.1	209.4	191	190.2	6.5	7.6	7.2	8.0
2041	253	265.4	240.2	211.5	7.0	8.4	8.0	8.6
2042	326	360.1	334.7	273.8	7.3	8.8	8.4	8.8
2043	238.1	260.4	236.3	206.5	6.8	8.2	7.7	8.4
2044	270.2	289.7	259.4	238.1	7.1	8.3	7.9	8.6
2045	240.1	251.1	230.4	206.3	6.8	8.0	7.7	8.3
2046	262.4	290	261.5	206.9	7.0	8.3	7.9	8.3
2047	262.4	279.3	256.9	210.3	7.0	8.4	8.1	8.6
2048	250	290	264.5	209.6	6.8	8.2	7.8	8.3
2049	271.3	304.2	277.5	241	7.0	8.4	8.1	8.6
2050	282.1	292.1	257.2	223.9	7.1	8.4	7.9	8.6
2051	229.1	241.2	220.6	192.2	6.9	8.0	7.6	8.4
2052	233.4	252.8	218.9	217	6.9	8.2	7.7	8.6
2053	311.6	332.9	320.2	255.5	7.2	8.5	8.3	8.7
2054	248.5	279	264.2	226.9	6.9	8.2	7.9	8.5
2055	271.9	325.9	301	252.8	7.0	8.5	8.1	8.6
2056	236.8	298.8	273	256.1	6.9	8.6	8.3	9.0
2057	264.3	287.3	267.9	223	6.9	8.2	7.9	8.5
2058	257.5	301.8	273.9	246.8	7.0	8.5	8.2	8.9
2059	255.9	300.2	277.9	233	7.0	8.5	8.1	8.7
2060	320.3	301.5	286.5	241.6	7.4	8.4	8.1	8.7
2061	299.4	313.5	289.6	240.9	7.2	8.7	8.2	8.7
2062	273.7	271.5	244.6	214.7	6.9	8.0	7.6	8.3
2063	271.9	293.7	276.6	239.8	7.2	8.5	8.1	8.7
2064	292	301.3	269	235.2	7.0	8.3	7.9	8.6
2065	232	272.9	259.1	233.6	6.9	8.5	8.2	8.9
2066	225	220.8	199.7	189.8	6.8	8.0	7.5	8.4

2067	342.8	354.6	346.2	274.9	7.4	8.8	8.5	8.9
2068	306.1	328.8	303.7	248.3	7.4	9.0	8.6	9.1
2069	272.4	278.6	256.3	227.9	7.2	8.5	8.1	8.9
2070	283.6	288	259	241.3	7.2	8.6	8.3	9.1
2071	278.8	284.2	269.7	241.5	7.2	8.4	8.0	8.6
2072	316.2	318.9	288.9	248.6	7.2	8.5	8.0	8.7
2073	348.8	377.6	354.2	312.1	7.5	8.9	8.5	9.2
2074	295.6	364.6	339.2	289.7	7.3	8.9	8.6	9.3
2075	353.1	393.5	351.3	321.2	7.6	9.3	8.9	9.6
2076	384.8	406.2	367.9	298.3	7.7	9.2	8.8	9.2
2077	337.5	380.2	358.1	288.1	7.4	8.9	8.6	8.9
2078	355	365.1	331.3	276.7	7.6	8.9	8.6	9.0
2079	335.3	329.1	300.3	243.8	7.5	8.8	8.3	8.8
2080	359.5	369.5	347.4	283.8	7.6	9.0	8.7	9.0
2081	268.5	302.6	279.7	251.3	7.1	8.5	8.1	8.9
2082	279.4	277.1	253.6	219.1	7.1	8.4	8.1	8.6
2083	390	415.2	389.6	310.9	7.8	9.3	8.9	9.3
2084	315.4	350.6	326.7	281.9	7.4	8.9	8.6	9.2
2085	406.4	435.1	403.6	323.4	7.9	9.7	9.4	9.8
2086	364.9	415.6	397.6	328	7.5	9.1	8.7	9.3
2087	368.2	366.9	348	291.2	7.7	9.2	8.8	9.5
2088	340.8	330.1	293.4	255.8	7.4	8.7	8.2	8.8
2089	341.6	383.6	371.2	303.2	7.5	9.1	8.8	9.5
2090	342.3	378.1	344.8	289.2	7.5	9.1	8.8	9.2
2091	350	401.7	372.4	292.2	7.4	9.2	8.8	9.2
2092	307.4	334.7	303.4	261.8	7.4	8.9	8.6	9.2
2093	425.7	448.7	418.2	347.5	8.0	9.6	9.2	9.6
2094	375.7	408.2	385.2	313.8	7.7	9.4	9.0	9.6
2095	386.6	424.1	404.2	314.6	7.8	9.5	9.1	9.4
2096	393.6	410.4	376.7	316.3	7.8	9.3	9.0	9.4
2097	348.6	348.7	316	295.7	7.5	8.9	8.5	9.3
2098	383.7	400.8	380.2	321	7.8	9.5	9.2	9.7
2099	388.5	402	381.3	297.7	7.8	9.3	9.0	9.5

Table 61: Kenya Climate Hazard Index (wsdi, cdd) by four county

year	Nyandarua wsdi (day)	Kiambu wsdi (day)	Nairobi wsdi (day)	Machakos wsdi (day)	Nyandarua cdd(day)	Kiambu cdd(day)	Nairobi cdd(day)	Machakos cdd(day)
1976	0	0	0	0	26.3	33	34.5	49.4
1977	0.1	0.2	0.3	0.2	29.8	37.4	37.8	54.4
1978	0.6	0.7	0.7	0.5	28.4	33.9	34.9	47.8
1979	0.6	0.7	0.7	0.9	31.5	39.1	41.2	55.5
1980	2.1	2	2	1.8	27.4	35.3	38.1	53.8
1981	1.1	1.1	1.1	1.1	27.1	35	36.6	52.3
1982	0.6	0.7	0.8	0.3	27.8	40.3	42.2	57.8
1983	0	0	0	0	29.5	38.1	39.5	57.7
1984	0.5	0.4	0.4	0.4	30.1	36.7	39.3	51.3
1985	2.4	2.4	2.7	2.1	32	39.6	41.9	53.7
1986	1	1.1	1.3	1.2	30.8	36.9	38.5	54.4
1987	0	0	0	0	29.9	35.9	37.7	54.1
1988	0.1	0.2	0.1	0.2	29.6	35.7	37.7	49.8
1989	1.1	0.8	0.8	1	29	38.3	39.1	57.1
1990	0.5	0.5	0.5	0.6	29.2	39.7	42.1	58.1
1991	0.2	0.2	0.3	0.5	28	36.5	37.3	56.9
1992	0.6	1.3	1.4	0.7	31.5	37.3	38.7	52.4
1993	0.7	1.1	1.2	1	29	36.5	38	54.7
1994	0	0	0	0	28.2	34	35	50.9
1995	0.4	0.4	0.5	0.6	28.2	35.6	37	56.2
1996	0.5	0.6	0.7	0.6	27.6	34	35.5	51.3
1997	0.3	0.2	0.2	0.4	30.3	38.3	39.7	58.3
1998	0.2	0.3	0.3	0.3	23.4	30.9	32.6	47.3
1999	0	0.1	0.1	0	27.6	35.1	36.7	54.7
2000	0.1	0.3	0.4	0.4	29.8	41.7	44.2	61.2
2001	0.3	0	0.1	0	24.2	38.7	41.2	58.4
2002	0.4	0.3	0.3	0.2	26.6	34.2	36	48
2003	1.5	1.9	2	1.9	28.4	36.4	37.7	54.7
2004	0.2	0.2	0.2	0.6	28	33.6	34.8	49.1
2005	1.2	1.6	1.5	2.1	29.2	42.8	44.9	65.3
2010	0.2	0.8	1.2	1.1	26.7	37.5	40.1	55
2011	3.5	3.1	2.9	2.7	25.9	36.4	37.8	53.9
2012	1.5	1.5	1.4	1.6	31.9	40.7	42.3	58.1

2013	2.4	1.4	1.4	0.8	32.5	39.5	40.6	56.3
2014	2.8	2.5	2.5	2.5	30.1	39.3	41.8	56.8
2015	1.9	1.2	1.2	0.5	23.1	34.4	36.5	50.4
2016	1.7	1.6	1.7	1.4	27	35.2	36.8	53.9
2017	1.4	1.5	1.6	1.3	28.6	34.5	36.6	50.6
2018	0.4	0.3	0.2	0.6	24.1	33.3	35.9	47.3
2019	3.1	3	3.3	2.5	29.8	38.8	40.7	55.1
2020	8.4	5.9	5.2	4.8	29.5	41.1	43.5	56.3
2021	3.6	3.2	3.3	3.3	31.5	38.6	40.6	57.2
2022	3.7	3.9	3.9	3.6	26.1	35.2	36.2	53.5
2023	2	1.8	1.8	2	25.5	38.4	41.1	59.3
2024	4.5	5.8	5.8	5.9	27.9	37.9	40.2	56.1
2025	4.7	4.9	4.8	4.3	27.1	36.5	37.5	57
2026	3.8	5.2	5.8	4.9	28.3	40	42.3	60.3
2027	2.6	3.8	4.2	4.2	23.8	35	37.4	57.2
2028	2.6	2.5	2.7	1.9	22.7	33.4	34.9	51.3
2029	4.7	5.2	5.2	5.1	25.3	37.6	39.6	57.4
2030	4.3	4.9	5.2	4.4	28.1	36.1	37.5	54.7
2031	3.7	3.3	3.4	3	26.2	39.1	41.7	58.5
2032	7.4	7.8	8	5.6	27.2	37.3	38.9	53.2
2033	4.4	4.9	5.1	4.8	30.9	38.5	41.4	54.7
2034	5.5	5.6	5.8	5.3	25.2	35.1	37.1	55.2
2035	7.3	8.9	9.6	9.5	30.4	40	40.9	58.4
2036	5.6	5.6	5.7	6.1	25.7	37.4	40.2	55.3
2037	5	5.6	5.4	5.3	26.1	37.6	39.9	54.4
2038	6.4	5.7	5.7	4.4	23.5	35.3	37.2	53.4
2039	5.8	5	4.9	4.8	28.1	39.9	42.8	60.7
2040	5.6	5.5	5.6	5.6	29.3	41.1	42.7	60.7
2041	6.7	6.1	6.1	5.4	26	35.5	36.9	53.6
2042	8.1	8.2	8.4	7.1	28.5	35.8	36.5	54
2043	9.9	9.4	9.1	7.7	27.5	36.8	38.4	53.3
2044	7.5	8.6	9	8.6	25.8	39.4	41.1	58
2045	5.2	6.1	6.3	6.3	24	35.2	38.1	53.6
2046	7.6	7.3	7	7.3	23.5	35.3	36.5	57.3
2047	7.7	7.9	7.9	7.6	28.1	40.6	42.7	59.3
2048	9.5	10.3	10.5	9.9	26.9	36.1	37.6	55.4

2049	6.1	5.6	5.8	5.4	24.6	36.7	37.7	60.1
2050	8.3	9.2	9.5	9.5	24.8	37.3	40.3	55.9
2051	11.8	11.3	11.2	10.5	24.1	36.6	39	54
2052	7.3	7.8	8.1	7.6	28.9	37.3	37.6	58.1
2053	15.6	16.1	16.7	17	25.5	38.3	40	57.9
2054	12	10.1	9.5	8.3	25.8	34.4	36	49.4
2055	12.4	10.7	10.8	10.3	25.1	37.2	39.6	59.7
2056	12.8	10.9	10.2	10.7	25.9	35.1	37.2	52.8
2057	10	11.9	11.4	10.6	26.6	40.3	42.6	59
2058	13.6	11.3	10.7	10.4	28.4	39.7	41	60.3
2059	15.2	16.1	15.7	17.2	26.2	36.7	37.4	53.5
2060	15.6	15.9	15.7	15	26.5	37.3	39.5	53.5
2061	13.2	12.7	12.7	12	23	33.3	35.5	51.2
2062	11.6	13.2	13.3	12.1	26	38.3	40.3	55.6
2063	8.6	10.4	10.4	10.6	24.7	39.6	40.7	58.1
2064	13.2	12.4	12.8	10.8	26	37.5	39.3	56.6
2065	13.4	11.6	11.5	11.5	23.8	38.1	40.1	57.6
2066	15.1	13.9	14	14.1	25.7	33.2	34.1	50.8
2067	12.4	12.5	12.4	11.3	24.5	36	37.9	53
2068	11.5	11.6	11.2	11.1	25.3	34.6	36.2	50.2
2069	21.8	21	20.9	19.3	27.7	39.5	41.4	60.4
2070	18.8	19.3	20	18	23.4	36.1	38.4	55.9
2071	20	17.9	17.9	17.9	23.1	34.3	36.5	50.7
2072	21.3	21.6	21.4	20.8	24.5	39.8	41.1	63.4
2073	13.5	12.5	12.2	14	24.1	34.4	36.2	51.1
2074	15.4	14.5	14.4	14.5	25	35.6	37.1	54.2
2075	16.6	15.6	15.6	15.6	25.8	35.9	36.3	55.7
2076	18.9	18.1	18.1	17.6	26.6	39.9	43.4	56.9
2077	27.1	24.3	24	23.7	27.5	39	41.2	59.2
2078	25.8	24.3	23.7	24.5	24.7	35.9	37.1	56.4
2079	18.5	17.4	17.5	17.2	24	36.9	39.2	56.4
2080	29.1	28.9	28.9	27.8	22.4	36	38.5	54.6
2081	22.1	23	22.7	22.7	24.8	38.6	41	58.3
2082	23.7	26.1	26.8	26.5	27.7	39.9	41.8	58.2
2083	18.7	20.5	20.8	20.4	23	36.3	38.2	58
2084	21.6	20.6	20.4	20.2	29	37.4	38.8	55.8

2085	23.1	23.2	23.1	23.3	28	42.1	44	58.6
2086	26.8	23.4	23.2	21	24.1	36.5	38.7	56.3
2087	17.8	17.4	18.5	15.8	23.3	40.4	43.9	59.2
2088	20.3	18.4	18.6	18.2	26.4	34	35	51.9
2089	24.7	21.9	21.5	21.3	25.4	35.8	38.5	52.6
2090	22.4	21.1	21.4	20.6	24.7	33.5	35.4	49.2
2091	20.1	20.2	20	19.5	22.4	34.9	37.7	52.7
2092	31	31.5	31.5	30.1	26.5	40.2	43.1	58.6
2093	23.4	26.3	27.1	27.1	24.4	37	39.5	55.9
2094	19	22	22.3	23	29.1	38.8	40.8	57.8
2095	29.2	27.3	27.4	26.3	26.1	38.2	39.8	56.1
2096	30.4	32.2	32.6	31.8	25	33.8	35.6	51.8
2097	25.2	25.7	26.1	25.6	28	40.2	41.7	60.6
2098	29.8	26.1	25.3	24.7	22.7	32.9	34.5	53.3
2099	23.7	22.4	22.8	20.4	26.2	35	37.5	52.1
2010	1.4	1.4	1.5	1.4	28.5	41.4	43.9	60.4
2011	1	1.1	1.2	0.6	30.6	38.9	40.6	56
2012	1.4	1.6	1.7	1.5	31.8	41.6	42.9	58.9
2013	0.8	0.9	0.9	0.9	25.6	36.5	38.8	54.3
2014	0.8	0.9	0.9	1	24.4	37.2	39.6	56
2015	0.6	0.2	0.2	0.2	28.4	38.9	40.4	55.9
2016	0.4	0.2	0.2	0.1	28.9	38.5	40.2	54.1
2017	0.1	0.2	0.3	0.5	27.1	36.7	37.6	55.6
2018	0.7	0.3	0.2	0.2	28.1	36.8	38.4	55.3
2019	0.3	0.5	0.5	0.6	28.4	38	40	56.3
2020	0.9	0.5	0.6	0.2	28	39.2	40.7	60.9
2021	0.3	0.2	0.2	0.4	26.9	36.6	37.5	56.2
2022	0.8	0.6	0.7	0.4	28.5	36.3	37.6	52.3
2023	3	4.1	4.4	4.1	27	36.6	38.7	55.5
2024	2.9	2.9	2.9	2.7	30.5	40.6	42.1	61.9
2025	0	0.3	0.3	1	27.9	39.4	40.8	58
2026	2.1	2	1.8	1.9	28.8	36	37.6	53.1
2027	1.4	1	0.9	0.9	26.6	36.3	37.4	56.6
2028	0.7	1	1.1	1.1	26.9	36.5	38.3	54.4
2029	0.7	0.9	0.8	1	27.4	36.4	37.8	55.5
2030	1.4	1	0.8	1	30.6	39.8	42	57.8

2031	3	2.7	2.8	1.4	25.6	35.8	38	53.5
2032	0.5	0.3	0.1	1.1	28.6	40.1	42.4	61.6
2033	1.8	2.2	2.5	2.4	27.8	38	39.2	58.2
2034	2.4	2.5	2.4	2.2	25.7	33	33.9	50.9
2035	0.5	0.6	0.7	0.7	25.4	35.5	37.2	54.1
2036	1.5	0.9	0.8	0.9	23.6	36.3	38.1	54.4
2037	3.1	3.3	3.7	3.8	26.3	34.6	35.9	53.4
2038	0.6	0.5	0.5	0.8	26.7	38.2	41.1	55.6
2039	1.7	1.4	1.5	1.5	25.5	36.8	38.2	57.4
2040	2.5	2.4	2.5	2.3	25.4	36.5	38.1	57
2041	1.7	1.7	2	1.7	28.8	38.4	40.4	58.5
2042	3.3	3.2	3.5	2.7	29.9	38.7	40	56.1
2043	3.6	3.4	3.5	2.8	29	39.5	42.2	59.2
2044	1.5	1.9	2.2	2.2	25.1	34.8	37	54.2
2045	1.8	1.7	1.6	1.7	26.2	37.8	40.5	54.5
2046	1.7	1.6	1.8	1.7	28	37.1	38	54.5
2047	2.8	3.2	3.2	3.8	24.4	34.9	36.4	54.7
2048	2.8	2.6	2.6	3	26.9	35.3	35.3	52.9
2049	3.1	3.4	3.6	3.4	27.6	38.8	39.5	59.8
2050	2.6	3.1	3.2	2.9	26.8	33.4	33.9	50.7
2051	4.5	4	3.8	4.5	27.2	39.5	40.9	61.4
2052	4.4	4.8	4.6	4.2	25.7	37	37.4	58.1
2053	6.8	6.2	5.6	6	27.1	37.4	39.1	58.9
2054	4.4	5	5.1	3.9	26.6	38.6	39.9	57.8
2055	9.5	9.5	9.6	8.5	27.5	38.7	40.8	58.4
2056	3.7	3.2	3.3	2.1	24.3	41.3	42.8	63.7
2057	6.6	6	6.1	4.9	24.4	38	41.8	52.1
2058	9.7	10	10.2	9.3	26.2	38.5	40	59.4
2059	7.9	8.2	7.9	9.1	27.1	37	38.1	57.4
2060	8.9	9.5	9.8	8	27.1	35	36.2	51.5
2061	5.9	5.9	5.7	5.2	23.9	35.9	37.5	55.4
2062	7.6	7.9	7.7	7.3	23.4	34.8	35.9	55.2
2063	8.6	8	7.9	7.3	26.4	36.5	38.5	51.7
2064	7.8	8.4	8.7	8.7	25.1	38.4	41.3	56.4
2065	12.6	11.2	11.4	10.4	24.8	43.9	46.6	67.2
2066	12.2	10.5	10.4	8.9	25.9	41.5	42.8	60.1

2067	11.9	11.8	11.8	11.5	24.9	35.5	38.3	52.2
2068	14.7	14.1	13.2	14.5	29.2	40.6	41.5	59
2069	18.9	19.4	19.6	19	29.4	39.7	41.5	60.7
2070	17.2	17.3	17.8	15.8	25.5	41.3	42.2	63
2071	14.3	14.1	13.8	14.2	24	36.1	37.6	53.4
2072	21.1	21.3	21.3	20.6	26.7	44	47.9	62
2073	15.5	14.9	14.3	14.8	24	38.3	39.3	58.3
2074	18.8	19.7	19.8	20.2	25.9	37.4	39.4	54.5
2075	24.6	25.2	25.4	22.9	23.5	37.8	39.8	57.8
2076	23.3	24.7	25.9	22.7	23.3	33.4	34.8	50.2
2077	27.6	24.8	24.4	21.4	25.1	41.1	43.8	62.9
2078	28.9	28.2	28.1	26.2	25.2	37.4	38.9	60.2
2079	27.7	29.7	30.2	29.7	24.7	41	43.4	65.1
2080	26.5	28.5	29.6	28.9	26.6	38.5	41.3	55.8
2081	35.8	34.3	34.3	32.6	25.2	38.6	39.3	58.4
2082	41.4	43.4	43.1	43.5	25.6	40	43	63.9
2083	27.1	23.2	22.7	23	24.1	36.3	36.9	53.8
2084	43.1	43.3	43.7	42.5	25.4	38	39.3	58.5
2085	39.5	39.5	39.3	39.8	24.4	38.1	41	55.8
2086	46.6	44.5	43.3	41.3	23.5	41.1	43.2	62.1
2087	52.2	49.9	49.5	48.3	25.6	37.3	39.2	57.1
2088	51.4	50.1	50	46.9	26.6	42.1	43.8	65
2089	49.9	50.7	51	52.2	26.1	39	40.8	53.6
2090	55.3	51.9	51.2	51.7	26.4	37.9	39.7	59.2
2091	65.5	59.4	59.8	60.6	25	40	41.9	63.8
2092	77.7	72.1	71.5	69.8	24.6	40.6	43	62.4
2093	75.1	75.7	75.7	77.4	27	42.6	45.3	58.8
2094	71.8	69.4	68.8	69.5	23.6	40.6	42.7	62.4
2095	60.5	57.6	57.9	60	26.6	44.7	48.3	66.8
2096	78	74.2	74.3	75.6	25	36.9	39.3	54.8
2097	97.3	94.6	93.6	95.6	25.3	44.8	48.8	66.1
2098	87.7	84.4	84.4	83.2	27.8	42	43.9	61.9
2099	93.8	94.3	94.2	94.4	24.4	41.1	43.4	61.3

Annex 2. Kenya Exposure and Vulnerability Index

Table 62: Basins, Forests, and Parks (Wiesmann et al., 2016)

County	Share of parks in county*	Parks in county (km^2)	Share of forests in county*	Forests in county (km^2)	Main basin in which county is located
Nyandarua	7.00%	0	16.10%	522	Rift Valley Basin
Kiambu	0.00%	0	16.40%	416	Athi River Basin
Nairobi	7.70%	53	4.90%	34	Athi River Basin
Machakos	0.40%	27	0.40%	22	Athi River Basin
Makueni	13.10%	1046	1.50%	123	Athi River Basin

* in terms of land area

Table 63: Accessibility and Transport (Wiesmann et al., 2016)

County	Average travel time to nearest city (min)*	Share of surface area within time distance of 2 hours	Share of surface area outside time distance of 6 hours
Nyandarua	249	26.00%	18.10%
Kiambu	187	53.40%	18.40%
Nairobi	30	96.10%	0.00%
Machakos	167	38.20%	5.50%
Makueni	314	10.40%	35.50%

* Average of all 1x1-km squares in county

Table 64: Population Density (Wiesmann et al., 2016)

County	Population density (people/km^2)	Rank	Total population*	Surface area (land area, excluding waterbodies; km^2)
Nyandarua	182	24	589.6	3,242
Kiambu	630	6	1,603.40	2,543
Nairobi	4,429	1	3,078.90	695
Machakos	175	26	1,085.60	6,212
Makueni	109	29	874.4	8,024

* in thousands

Table 65: Population Density (Wiesmann et al., 2016)

County	Population density (people/km^2)	Rank	Total population*	Surface area (land area, excluding waterbodies; km^2)
Nyandarua	182	24	589.6	3,242
Kiambu	630	6	1,603.40	2,543
Nairobi	4,429	1	3,078.90	695
Machakos	175	26	1,085.60	6,212
Makueni	109	29	874.4	8,024

* in thousands

Table 66: Total Fertility Rate, Maternal Mortality Rate, and Child Mortality Rate (Wiesmann et al., 2016)

County	Total fertility rate	Maternal mortality rate	Child mortality rate	Total number of children under age five*
Nyandarua	3.7	364	60	83.1
Kiambu	3.1	230	58	202.7
Nairobi	3	212	56	393.6
Machakos	3.6	425	56	145.3
Makueni	4.2	400	61	125.5

* in thousands

Table 67: General Sex Ratio (Wiesmann et al., 2016)

County	General sex ratio (females to males)	Total female population*	Total male population*	General sex ratio in urban sub-locations
Nyandarua	1.04	300.9	288.7	1.05
Kiambu	1.02	811.6	791.8	1.02
Nairobi	0.97	1,513.70	1,565.20	0.97
Machakos	1.03	549.7	535.9	0.98
Makueni	1.06	449.7	424.7	1.02

* in thousands

Table 68: The Population Under Age 18 (Wiesmann et al., 2016)

County	Percentage of population under age 18	Rank	Number of people under age 18*	Number of 18- to 64-year-olds*
Nyandarua	50.30%	31	296.5	266.7
Kiambu	40.30%	44	646.7	898.7
Nairobi	35.40%	47	1,091.00	1,953.60
Machakos	46.40%	38	504.1	527.2
Makueni	51.90%	27	454.2	374.9

* in thousands

Table 69: The Population Over Age 64 (Wiesmann et al., 2016)

County	Percentage of population over age 64	Rank	Number of people over age 64*	Number of 18- to 64-year-olds*
Nyandarua	4.50%	12	26.4	266.7
Kiambu	3.60%	22	58	898.7
Nairobi	1.10%	47	34.2	1,953.60
Machakos	5.00%	11	54.3	527.2
Makueni	5.20%	10	45.3	374.9

* in thousands

Table 70: Access to Safe Water Sources (Wiesmann et al., 2016)

County	Percentage of households with access to safe water	Rank	No. of households with access to safe water*	No. of households without access to safe water*	Percentage of households without access to safe water
Nyandarua	59.30%	18	85.3	58.6	40.72
Kiambu	75.90%	3	356.2	113.1	24.10
Nairobi	82.70%	1	814.2	170.8	17.34
Machakos	39.40%	33	104.1	160.4	60.64
Makueni	36.90%	37	68.8	117.7	63.11

* in thousands

Table 71: Access to Improved Sanitation (Wiesmann et al., 2016)

County	Hhs with access to improved sanitation	Rank	No. of hhs with access to improved sanitation*	No. of hhs without access to improved sanitation*	Percentage of Hhs without access to improved sanitation
Nyandarua	74.10%	12	106.6	37.3	25.92
Kiambu	80.50%	6	377.5	91.7	19.54
Nairobi	86.80%	1	855.4	129.6	13.16
Machakos	62.70%	23	166	98.5	37.24
Makueni	56.40%	28	105.1	81.4	43.65

* in thousands

Table 72: Poverty Incidence (Wiesmann et al., 2016)

County	Poverty incidence	Rank	Population living below poverty line*
Nyandarua	38.80%	14	226.2
Kiambu	24.20%	2	387.8
Nairobi	21.80%	1	668.8
Machakos	42.60%	22	462.2
Makueni	60.60%	38	529.2

* in thousands

Table 73: Small-Scale Agriculture and Pastoral Activities (Wiesmann et al., 2016)

County	Perc. of empl. labour force in small-scale agr. and pastoralism	Rank	No. of people in small-scale agr. and pastoralism*	Employed labour force*
Nyandarua	58.00%	1	140.6	242.2
Kiambu	20.10%	41	140.8	698.9
Nairobi	0.00%	47	0	1,481.70
Machakos	19.60%	42	76.4	389.2
Makueni	26.20%	38	66.5	253.6

Table 74: Households Owning Livestock (Wiesmann et al., 2016)

County	Percentage of households owning livestock	Rank	Number of households owning livestock*	Number of households owning cattle*
Nyandarua	62.20%	16	89.5	79.3
Kiambu	28.70%	45	134.7	109.5
Nairobi	1.80%	47	17.4	8.3
Machakos	54.70%	28	144.7	101.1
Makueni	70.20%	9	131	89.3

Annex 3. Kenya Population Prospects

Table 75: Total Population by Country, 1950, 2013, 2025, 2050 AND 2100 (MEDIUM VARIANT) (World Population Prospects The 2012 Revision)

	Population (thousands)				
Country or area	1950	2013	2025	2050	2100
Kenya	6,077	44,354	59,386	97,173	160,423

Table 76: Kenya Population Prospects from 1950-2100

Year	Population (thousands)	Year	Population (thousands)	Year	Population (thousands)	Year	Population (thousands)	Year	Population (thousands)
1950	6,027.68	1980	11,028	2010	39,999.2	2040	81,904.4	2070	125,707
1951	5,691.59	1981	11,668.8	2011	41,248.9	2041	83,395.2	2071	127,071
1952	5,393.99	1982	12,335.7	2012	42,512.6	2042	84,887.6	2072	128,424
1953	5,134.47	1983	13,028.5	2013	43,789.8	2043	86,381.4	2073	129,766
1954	4,912.62	1984	13,746.7	2014	45,080.2	2044	87,876	2074	131,097
1955	4,728.03	1985	14,490	2015	46,383.3	2045	89,371.1	2075	132,417
1956	4,580.3	1986	15,257.8	2016	47,698.7	2046	90,866.3	2076	133,724
1957	4,469.01	1987	16,049.7	2017	49,026.1	2047	92,361.1	2077	135,018
1958	4,393.76	1988	16,865.5	2018	50,364.9	2048	93,855.2	2078	136,299
1959	4,354.14	1989	17,704.6	2019	51,714.9	2049	95,348.1	2079	137,567
1960	4,349.73	1990	18,566.7	2020	53,075.5	2050	96,839.4	2080	138,821
1961	4,380.13	1991	19,451.3	2021	54,446.5	2051	98,328.8	2081	140,061
1962	4,444.94	1992	20,358	2022	55,827.3	2052	99,815.7	2082	141,287
1963	4,543.74	1993	21,286.5	2023	57,217.6	2053	101,300	2083	142,497
1964	4,676.12	1994	22,236.3	2024	58,616.9	2054	102,781	2084	143,691
1965	4,841.67	1995	23,207.1	2025	60,024.9	2055	104,258	2085	144,870
1966	5,039.99	1996	24,198.3	2026	61,441.1	2056	105,732	2086	146,033
1967	5,270.67	1997	25,209.6	2027	62,865.1	2057	107,200	2087	147,179
1968	5,533.3	1998	26,240.6	2028	64,296.6	2058	108,664	2088	148,307
1969	5,827.46	1999	27,290.9	2029	65,735.1	2059	110,123	2089	149,419
1970	6,152.76	2000	28,360	2030	67,180.2	2060	111,576	2090	150,512
1971	6,508.78	2001	29,447.6	2031	68,631.5	2061	113,024	2091	151,587
1972	6,895.11	2002	30,553.3	2032	70,088.6	2062	114,464	2092	152,643
1973	7,311.35	2003	31,676.5	2033	71,551	2063	115,898	2093	153,680
1974	7,757.08	2004	32,817.1	2034	73,018.4	2064	117,324	2094	154,698
1975	8,231.9	2005	33,974.4	2035	74,490.4	2065	118,743	2095	155,695
1976	8,735.4	2006	35,148.2	2036	75,966.5	2066	120,154	2096	156,672
1977	9,267.17	2007	36,338	2037	77,446.4	2067	121,556	2097	157,629
1978	9,826.8	2008	37,543.3	2038	78,929.6	2068	122,949	2098	158,564
1979	10,413.9	2009	38,763.9	2039	80,415.8	2069	124,333	2099	159,478
								2100	160,369

Annex 4. Guideline & Specification on Surface Water and Rainfall Monitoring Station

Introduction

Table 14 and Table 23 have been identified and selected for installation of telemetric systems in four Counties of Kenya. It has defined monitoring equipment be installed to capture hydrological data along various river flows and rainfall.

Installation requirements for each station has been defined in Table 14 and Table 23 indicating what should be installed categorized as follows:

1. Water Level monitoring devices
2. Water quality and water level monitoring devices
3. Data loggers
4. Acoustic Doppler Current Profiler (ADCP)
5. Rainfall gauges

Scope of Work

The Scope of works includes:

1. Conduction of Topographical survey of each station site.
2. Design of layout and logger house and perimeter security fence.
3. Preparation of specifications and Bill of quantities of requirements for each station derived from the matrix.
4. Construction and Installation of the telemetric equipment.
5. Preparation of maintenance program for station.
6. Training

Description of the Work

The work shall mainly consist of the following components:

1. Conducting topographic surveys at the selected sites
2. Procurement and supply of telemetric equipment viz; automatic water level and water quality multi parameter sensors), tools and computers for downloading and processing of logged data.
3. Construction of logger houses, securing them by erecting fences and installation of data loggers/ telemetric equipment (water level pressure transducers and multi parameter water quality sensors)
4. Rehabilitation/repairs of existing stations
5. Branding of the stations
6. Training on, installation, configuration, operation and maintenance of the installed telemetric equipment.
7. Routine service and maintenance of stations for the prescribed period.

Methodology of Work Execution

- **Community Engagement**

To ensure success of any planned project, community sensitization to create awareness and sense of ownership by the local community is very important. This will be achieved through reaching out and proactively engaging with each areas' local administrative leadership. Community sensitization will be then undertaken where benefits to the community arising from the project shall clearly highlighted. Once community engagement is finalized the implementation teams of relevant experts will be adequately prepared and mobilized to the sites.

- **Topographic Survey**

The first activity shall be conducting the topographic survey. To successfully conduct this survey all the relevant survey tools, equipment and accessories will be acquired and provided to experts appropriately facilitated to promptly undertake the exercise.

Figure 68: Total station surveying equipment

This is because all other subsequent works will be designed and executed based/pegged on the results of the topographic survey carried out. This topographic survey shall be carried out only at the side on which the river gauging station is situated.

The survey will involve:

a) Checking condition of existing control points
b) Conducting horizontal control survey by traversing method and vertical control survey by leveling method
c) Spot point survey by a Total Station (TS)
d) Topographic mapping and preparation of topographical map
e) Preparation of topographic survey report

- **Design for construction of logger houses and rehabilitation / installation of concrete staff gauges**
  a) Designing for construction of logger house - Determine the suitable location for the gauge/logger house and ensure that it will be both resistant and resilient to flooding for long period of time based on the topographic survey.

Figure 69: A photo showing a logger house marooned by river flood waters

  b) Preparing design plans for rehabilitation/installation of the staff gauges.
  c) Erecting of a security fence enclosing the logger house.
  d) Design for the installation of the automatic water level and water quality sensors

Figure 70: The proposed data logger firmly fixed on the wall (sample)

Figure 71: A sketch of the proposed plan for installing the water level, water quality sensors and the data logger.

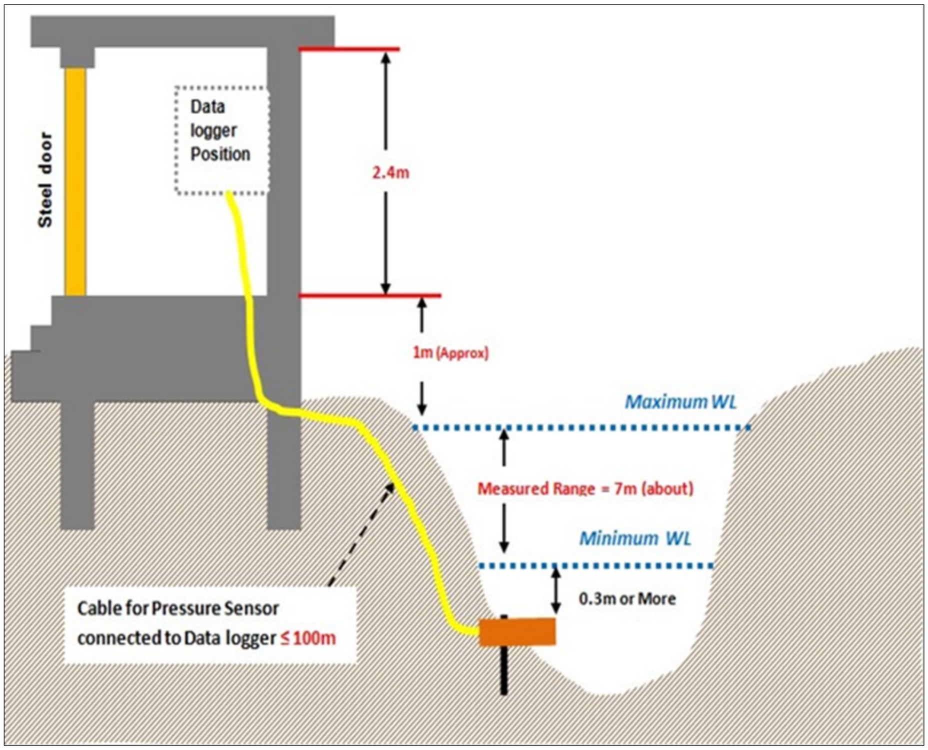


Figure 72: Concrete Post design

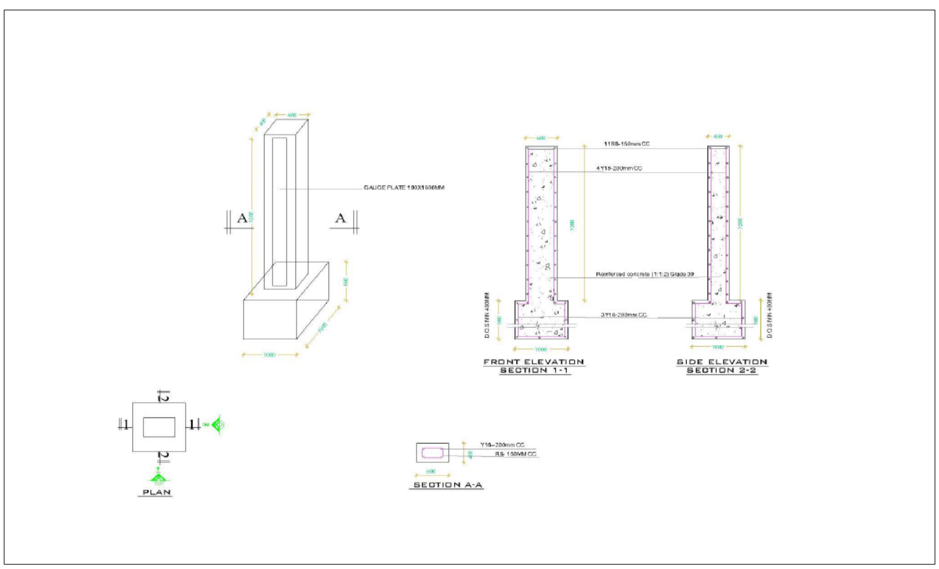


Figure 73: Logger House Plan

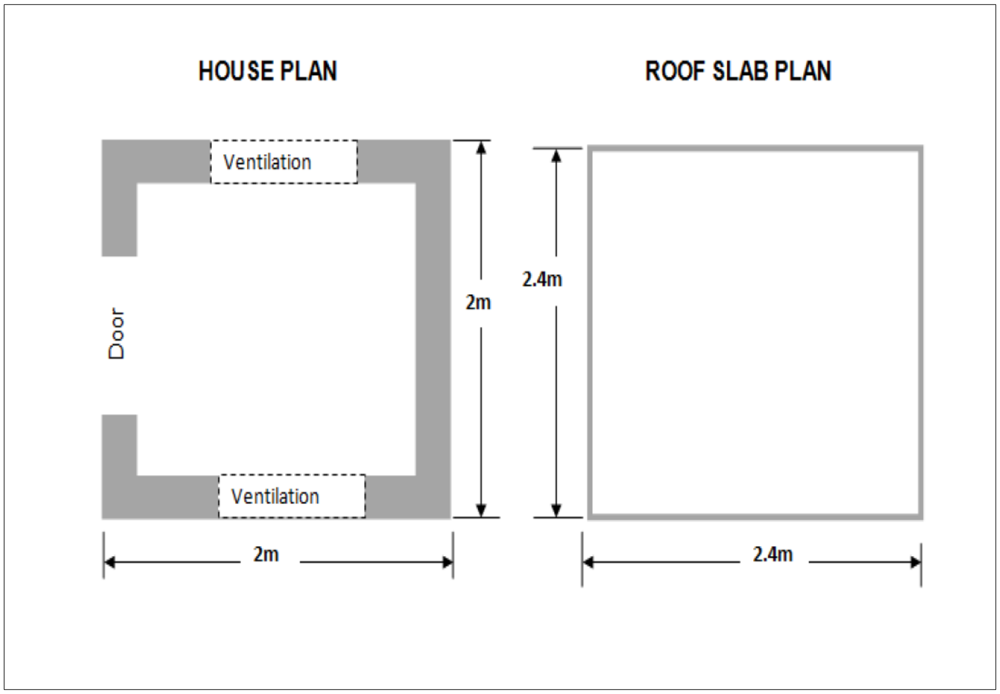


Figure 74: A sketch of the design plan for the proposed trench is shown below

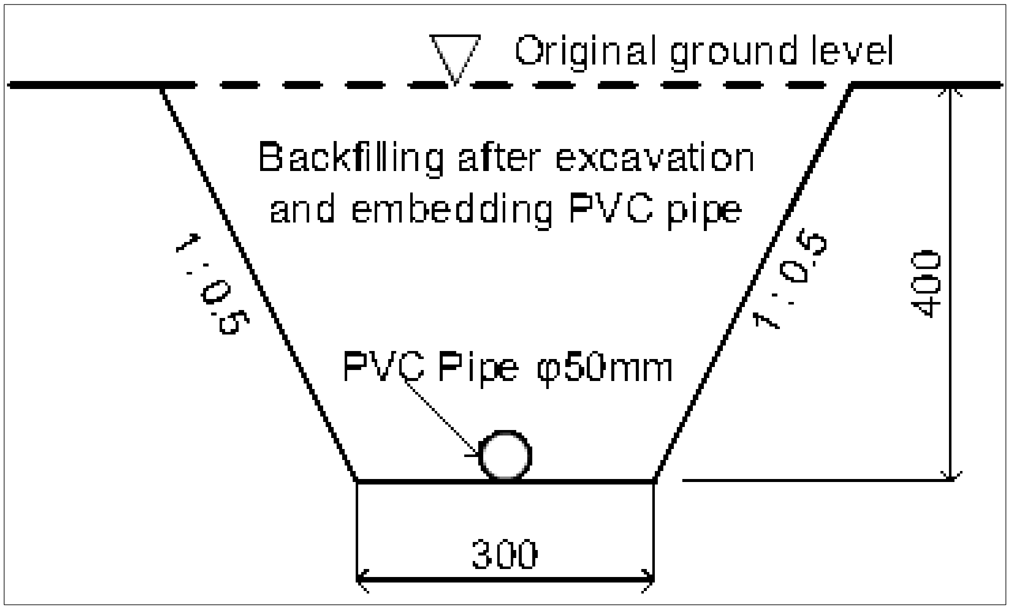
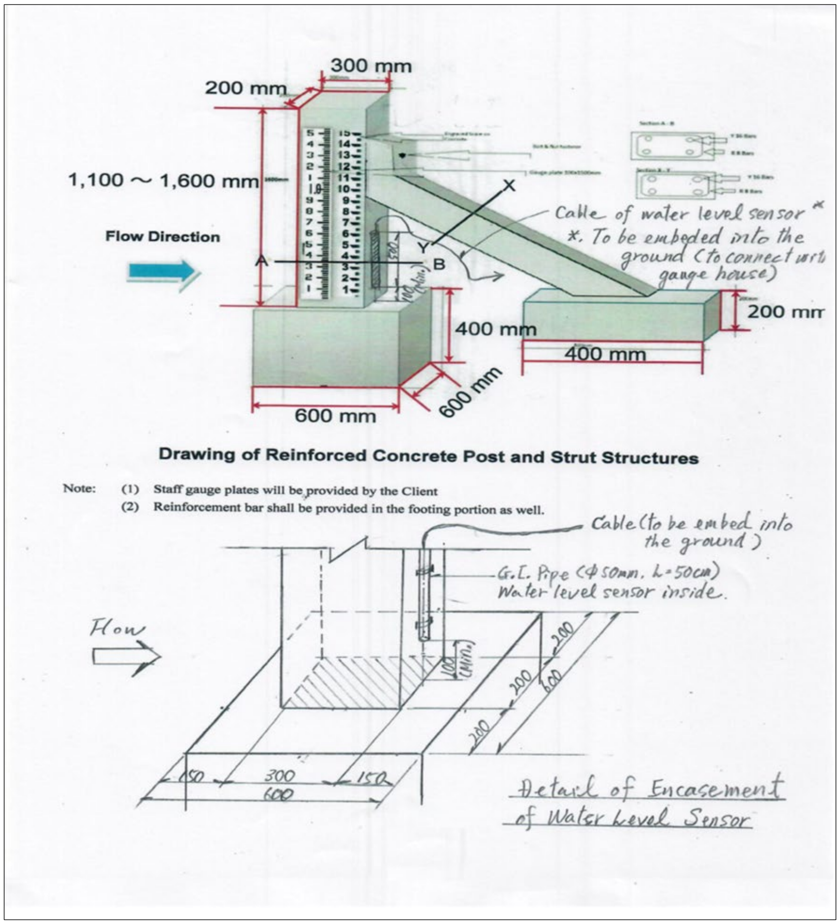


Figure 75: Pressure probe / level probe(left), water quality sensor(right)

Figure 76: Rain gauge (sample)

In order to avoid the washing away of the installed sensors by strong water currents during floods, the sensor housing tubes shall be firmly encased or fixed on to the constructed concrete staff post. The inclusion of the strut might not practically possible.

Figure 77: Encasing of water level sensors for protection



Data logger, shall be much more than a simple data acquisition terminal. Should have high calculation capacity, openness to new programming and ease of management, it is capable of interfacing with the majority of measurement instruments on the market, making it liable for use in any monitoring and alerting application context.

Figure 78: Deployment/Commissioning of the installed and configured sensors (sample)

The data logger has a web interface that allows to:

a) Share all the information collected by the Open Log data logger e.g. graphs, pictures.
b) Execute instantaneous measurement and receive the sampled data in real time.
c) Connect to each of the network's data loggers and configure them in mobility.

Sign boards showing key information of the target gauging stations shall be prepared and appropriately erected at each of the station sites. The material to be used for constructing the sign boards shall be concrete to protect against vandalism

This will shall involve;

a) Designing plan drawings and preparing for installing and setting up of concrete sign boards bearing the desired logo and colors at all the respective sites.
b) All the details of contents to be captured on the constructed sign boards shall be designated, instructed or provided by the client.

The design plan dimensions for the proposed concrete sign board shall be specified.

Figure 79: The concrete sign board finishing and branding

- **Training in the installation, configuration, operation and maintenance of the installed telemetric equipment raining**

After the completion of the installation works a two (2) day training workshop will be organized for both in-house and on-site for operational staff.

Power point presentations will be prepared covering the following modules.

a) Installation of the AWL, AWQ and Rain stations including the setup of the data communication devices

b) Configuring the Data Collection Platform and connection to sensors
c) Description of the telemetric system and protocol.
d) Care and handling of the sensors, DCP and other accessories.
e) On-site field visits, adjusting and downloading data from the field.
f) Preventive maintenance, including field checks and calibration.
g) Common problems and troubleshooting techniques.
h) Calibration methods.

Annex 5. Guideline & Specification on Groundwater Monitoring Well

General Consideration

The well design should be based on the available information with respect to successive hydrogeological units as indicated by the conceptual model. All available geological and geophysical information should be used.

The lithological borehole description based on rock sampling can often be significantly improved if geophysical borehole logging is applied. Especially, the rotary drilling method is applied and materials tend to get to the surface in a mixed and delayed way. The geophysical borehole logs may provide much better indications with respect to the depth of different layers and their permeability.

The diameter of a monitoring well depends on the sampling devices available. A diameter of 6 inch for tube and screen is considered a minimum for water quality sampling if small size equipment is available. A larger diameter will also be necessary for wells that will be used for water supply as well.

Screens must be positioned on the right depths, confronting the aquifer layers. The packing material around the screens should be of the proper size and form a suitable transition zone between aquifer material and slot size of the screen. The slot size of the screens should be designed in such a way that packing material cannot enter the well and only very minor portions of the aquifer material can pass.

Inflow of surface water into a monitoring well, either directly into the well or via the borehole and packing material should be avoided. Proper plugging of the borehole around the well with cement is essential in the upper section above the screen.

The specification as below is a sample and can be changed according to local conditions.

Detail tasks for monitoring well

Detail tasks of the contractor, specification and procedure of borehole construction are presented in this section.

- **Drilling of monitoring well**

  a) If the actual depth of the borehole being drilled justifies any additional depth in the specification, the contractor will request the authorization of the client for such stop or changes to be made
  b) Mud-Rotary & DTH methods are recommended however, the contractor can change the drilling method after discuss with the client.
  c) The drilling diameter is 14 ¼” for the upper soft unconsolidated (alluvial) materials. And then, 10” steel temporary surface casing install to support the upper soft unconsolidated materials from collapse, and drill by 8” to target depth.
  d) The contractor is to ensure that cut samples from the drilling are collected properly at 2 meters intervals as required by the law and can also be taken less than 2 meters intervals when there is change of geologic formation. Then, the lithological description of the samples are described in detail include aquifers.

e) The rig to be deployed must be capable of drilling to at least a depth of 25% beyond the anticipated final depth at the final required diameter.
f) In any case, if the actual characteristic of the well differs from those indicated in the terms of reference, and once the changes have been authorized by the client, a price adjustment may be made according to the final depth of the well, and the unit price rendered by the contractor in his original proposal.
g) The contractor will be required to state the type of polymer to be used, and describe the means by which the selected fluid additive will be mixed. In this regard, please note that direct rotary flush using water based mud as the circulating fluid of bentonite type or naturally biodegradable polymers will not be approved.

- **Water level measurement**

a) The contractor shall always measure the hydrostatic level of the drilled hole before and after a day's drilling work, and will be recorded in daily work logbook.

- **Casing and screen installation**

a) The contractor will supply all casings and screens including outer permanent casings stainless steel plain casing.
b) The well casing installation design will be performed by the geologist assigned at the site from the contractor side and the project manager from the client.
c) The internal diameter of 6 and 5/8 inch PVC blind and screen productive casing are installed in the drilled strata in such a way that the screens put against possible ground water bearing formations.
d) The pipe material, type and dimension shall be as fol1ows:
e) Material : PVC
f) For the blind casing and the screen: Inner diameter of 6 and 5/8 inches
g) Socket type : screw type (outer socket)
h) Pipe length : 6 meter
i) Screen opening ratio : more than 3%
j) Slot size : 0.3 to 1mm horizontal slot
   - Fine sand- 0.3mm;
   - Medium sand- 0.5 mm; and
   - Coarse sand – 1 mm
k) Numbers of slot on the circumference: 6 slots minimum on the circumference
l) When lowering the casings into the drilled hole, a three meter length of bottom plugged blind casing shall precede other casings, for the purpose of sand trapping. In order to set the pipes in the right center of the drilled hole, centralizers shall be attached to every three pieces of casing.
m) Sections of the screen shall be provided in maximum 6 meters length and joined watertight by threaded connections.
n) The length of screen and final depth shall be determined by the client authorized staff on the basis of the nature and the thickness of the water bearing strata. The top of the screen be a minimum of

the lowest expected dynamic water level. In deep confined aquifer with high thickness (> 6m) of water bearing layer, the length of screen shall normally be 60% to 75% of the aquifer thickness. For a thin layer (< 6m), the screen shall be installed to the full depth of the aquifer thickness, unless part of the aquifer layer yields unsuitable water.

o) The blind casing of the same size should protrude 70cm at the ground surface as well head.

- **Gravel packing**

a) The annular space between the borehole wall and the outer surface of the productive PVC casing shall be packed with selected well graded, rounded, clean and hard river gravel of 2-4mm in size, from the bottom of the hole up to 5 meters above the screen. Proper techniques should be used for the accurate placing of this pack to ensure its even placement.

b) The gravel shall be inserted into the borehole by hand using a shovel in order to protect the borehole wall from damage.

- **Well development**

a) After gravel packing is complete, the well will be developed by air-lifting, alternating continuous and surging, lowing and raising the drilling tools until the water purified from sediments and drilling fluids

b) It is recommended that flushing be done for a minimum of 6 hours.

c) Development will be considered complete only when less than 15 ppm of suspended solids remains in the water.

d) Maximum care shall be taken to avoid the physical, chemical, or contamination of water during construction. If the well is contaminated due to contractor’s negligence, the contractor will be obliged to remove the contamination from the well at his own cost.

e) Any casing and/or screen damage during installation and well development shall be the responsibility of the contractor, who shall make the necessary corrections/repairs without additional cost. When well development is completed, the gravel packing will be topped up if it is found settling below the required depth.

- **Pumping test**

a) The contractor will provide all necessary materials for pumping test purpose which are include weirs, pipes, gauges for the proper measurement of discharge rates and water levels and disposal of extracts. The contractor will evacuate all pumped water in such a way that no impoundments are produced at distances less than 200 meters from the borehole

b) The contractor shall conduct steps pumping test at least 2 hours (total: 3 step, at least 6 hours) under the supervision of the client.

c) Immediately after step pumping test, the contractor shall conduct the recovery test until initial static water level (SWL) (at least 2 hours). Where the client or his representative cannot be present at such pumping test, the contractor may continue without him, keeping accurate records of the test in terms of discharge and drawdown. Should the contractor fail to keep such records, the client may order the test to be repeated at no extra cost. The water level measurements shall be taken in accordance with the following schedule or until the initial water, level is recovered:

- Every one (1) minute for the opening ten (10) minutes
- Every two (2) minutes for the period ten (10) minutes to twenty (20) minutes
- Every five (5) minutes for the period twenty (20) minutes to sixty (60) minutes
- Every ten (10) minutes after sixty (60) minutes

d) After the step pumping test, the contractor shall conduct 24 hours continuous pumping test under the supervision of the client. And, the others steps are the same as steps pumping test

e) During the continuous pumping test, the contractor shall follow the standard continuous pumping test procedure

f) The contractor shall measure the water temperature, the electrical conductivity and the pH every 30 minutes during the step pumping test & the continuous pumping test.

g) The contractor shall take suitable countermeasures to prevent flowing backward the discharge water into the testing borehole.

h) The contractor shall furnish and install the necessary pumping equipment capable of pumping or a maximum of 10 ~ 20 l/sec with a static pumping head level 50 meters below ground level but with satisfactory throttling devices so that the discharge may be reduced gradually to required yield.

i) When the continuity of the test is interrupted for a period exceeding 10 minutes due to negligence on the part of the contractor, the client shall order a new test and the interrupted test shall not be paid for. Accidental interruptions may if so agreed upon between the contractor and the client, be compensated for by corresponding extending the time the completion of the test run.

j) After the completion of the test, the contractor shall remove by bailing sand pump or other methods any sands, stones or other foreign materials that may have deposited in the borehole.

k) After finished the pumping test, the well should be capped on the top of the PVC to prevent entrance of any foreign material into the borehole.

- **Water quality analysis in laboratory**

a) The contractor will take two (2) liter samples for laboratory analysis, after completion of test pumping. One sample will be used for each of these tests; bacteriological, physical and chemical analysis, which should be collected in clean, sterilized and properly sealed, protected plastic containers. The samples so collected should reach the authorized Water Testing Laboratories, within six hours from the time of collection from the borehole. The contractor shall be responsible for transporting the water samples to the authorized laboratories to conduct the water quality analysis for agriculture and human use.

- **Additional gravel/sand packing and backfilling**

a) After completion of the pumping test, removal of the test pumping unit and after the last water level recovery observations have been made, the level of the gravel pack will again be checked to see if there is any settlement below the required depth. If it is found below the required depth, it will be topped up to the appropriate level. Therefore, the contractor shall pour additional gravel or sand and backfill the annular space with drill cuttings.

- **Cement sealing & wellhead construction**
  a) About three (3) meters of the annular space near the surface shall be sealed with cement grouting to prevent dirty surface water from entering the well.
  b) A sanitary seal surrounding must be excavated until an adequately firm formation is reached and constructed in C25 (1:2:4) mix concrete with surface dimensions of 1 meter length, 1 meter width and 0.25 meters height. In such a case as a firm formation is not available close to the surface on which the concrete block can rest, the space around the casing up to 1.5 meters below the surface casing must be filled with C25 mix concrete block. The surface/outer permanent casing must protrude 0.45 meters above the concrete block. Then, wellhead construction with concrete including grouting & locking.

- **REPORT**

Progress Report

The contractor shall submit to the client, weekly drilling progress report showing:

a) The depth drilled each day including drilling in meters hour with comments on degree of hardness of materials being penetrated.
b) Depth at which each aquifer bearing zone is encountered and rise and down of water level in different formations.
c) The full details of work carried out in respect of operations which are paid for at hourly rates.
d) The full details of the number of hours worked each day. Three copies of the "Borehole Completion Report" and "Test Pumping Record" should be made by the Contractor and submitted to the client within seven days after completion of borehole.

Final report

The Contractor shall submit the final report to the client following the format given below in a bound report in three hard copies and one electronic copy, before final payment is made.

a) General
b) Geology & geographical features of the drilling site
c) Profile of the borehole including description of the formation
d) Construction and drilling rate logs
e) Water rests (SWL), strikes,
f) Screen and casing arrangement with detail sketch

g) Pumping test and recovery analysis and all required suggestions and recommendations (Submersible pump type, capacity, pump positioning, and other relevant data including hydraulic constant)
h) Water quality data at field level and interpretation of results for using the water for agriculture and human use
i) Water quality laboratory results and interpretation of results for using the water for agriculture and human use
j) Abandoned well data and environmental protection recommendations
k) Photos showing the all drilling progress.

Figure 80: Profile of Monitoring Well

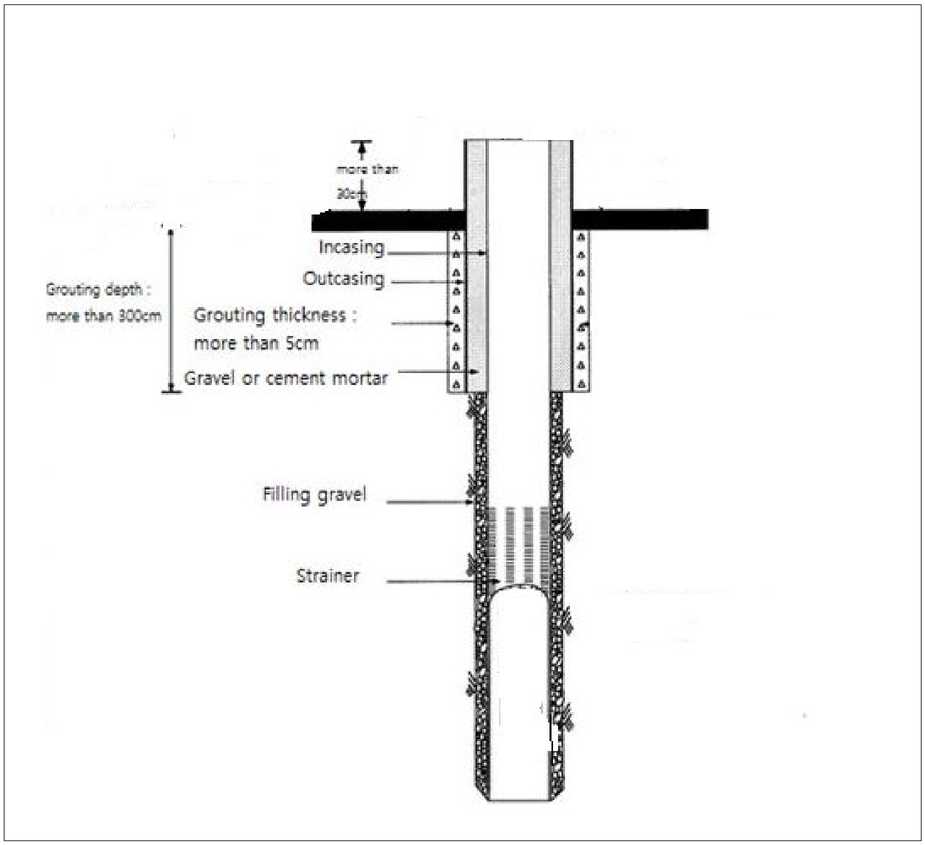
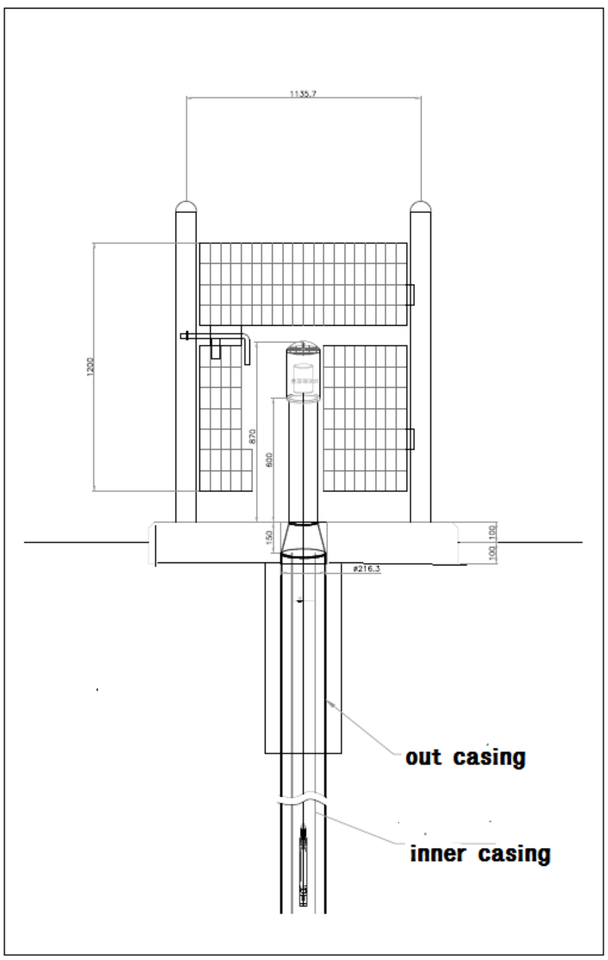
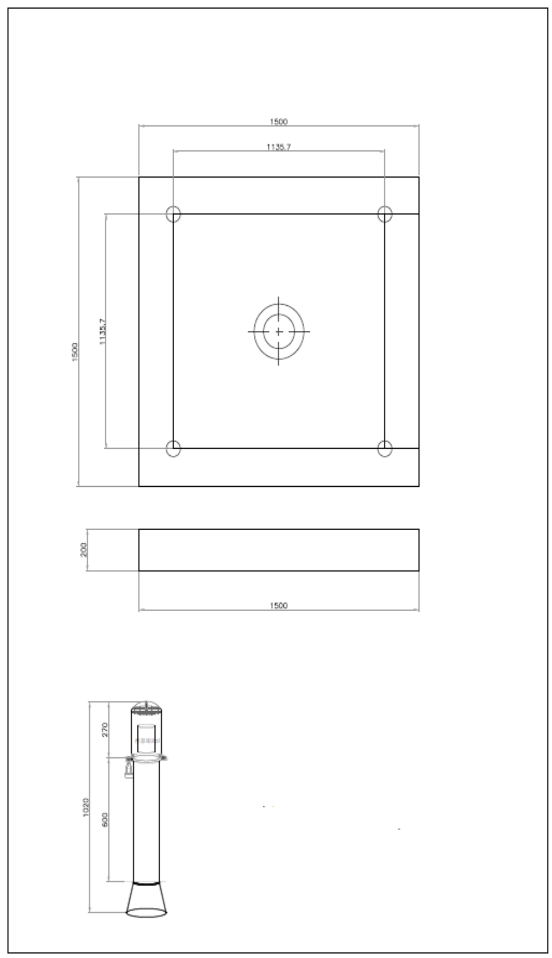


Figure 81: Profile of Protective Facilities

<Front View>



<Floor Plan>



Annex 6. Proposed Training Courses for WRA

	Course	Level	Duration	No of Participants	Institution
1	PhD in Hydrogeology (sandwiched programme)	PHD	4yrs	1	UoN
2	PhD in Geology	PHD	4 yrs	1	UoN
3	PHD in Climate Change Adaptation	PHD	3 Year	1	UoN
4	Masters in Climate Change Adaptation	Masters	2 years	2	UoN
5	Strategic leadership development programme (SLDP)	Certificate	6 weeks	2	KSG
6	Intergrated Water Resource Management (IWRM)	Certificate	4weeks	12	KEWI
7	Inhouse PDB & Mike Basin / Alternative Software	Certificate	4 Weeks	8	To be decided
8	Geographical information systems (GIS) and Remote Sensing	Certificate	3 months	4	RCMRD
9	Windows server 2003/2008	Certificate	1 yr	1	
10	Monitoring of contaminants of emerging concerns	Certificate	4 weeks	4	UoN
11	Gender mainstreaming and conflict management	Certificate	3 month	1	UoN
13	Environmental Law, Policy and Diplomacy	Short - Course	1 month	8	UoN
14	Operation and Maintenance of Automatic Stations	Short - Course	2-weeks	16	[PAD]
	Total			**61**	

Legend

UoN – University of Nairobi

KSG – Kenya School of Government

KEWI – Kenya Water Institute

RCMRD- Regional Centre for Mapping of Resources for Development (RCMRD), Nairobi, Kenya

PAD- Product Accredited Distributor

Annex 7. Institutional Strengthening and Capacity Building Needs for KMD

	Item	Challenges
1	Infrastructure -Observation hardware	- Security and safety (Hardware vandal and damage by animals e.g. monkeys) - Need for adequate spares, batteries sensors etc - Inaccessible areas - need for four wheel drive vehicles, air and sea transport crafts or services
2	Tools	- Lack of maintenance kits Protective clothing and mobile field accommodation equipment
3	Calibration	- Sensors come in different protocols and standards for connection. This makes it very difficult to have a common calibration kit. Need for station type specific calibration kit.
4	Connectivity	-Where data is to be pushed into a server by a data logger, obtaining a static IP address from service providers is very difficult. Cloud services required. -Communication costs support required both in hardware and software to maintain continuous data flow. -Some areas have poor GSM network connectivity for data thus need for other modes of connectivity, Satellite, trunked radio etc. -Need for software updates to conform to emerging technologies
5	Training	There are different trainings required; - First line training (For regular site and sensor cleaning training for AWS care takers in order to maintain the integrity of data. - Second line training (This is for qualified technicians who carry out periodic maintenance) - Data Managers, communicators, analysts, trainers and forecasters training. Inadequate funding to carry out such trainings is a critical Challenge
6	Computers and Software	- Need for computers in some stations and replacement of faulty/obsolete computers - Need for standardized software - Need for antivirus software Data Integration System to converge data from the various observation platforms is lacking. Data observation platforms Real-time monitoring and evaluation system is not available.

Annex 8. Sites of the Access Structures

No	Longitude	Latitude	Altitude	County	Name	Type
1.	-0.871250000	36.598111111	2616	Nyandarua	Kariani	Water pan
2.	-0.892111111	36.567444444	2683	Nyandarua	Githwe	Borehole
3.	-0.865944444	36.560333333	2725	Nyandarua	Kahora	Water pan
4.	-0.828250000	36.576527778	2681	Nyandarua	Mutonyora	Water pan
5.	-0.786916667	36.559388889	2650	Nyandarua	Heni	Water pan
6.	-0.699833333	36.548388889	2516	Nyandarua	Karanja Wanaina	Water pan
7.	-0.717194444	36.573527778	2553	Nyandarua	Wanyeki	Water pan
8.	-0.723777778	36.533138889	2524	Nyandarua	Koinange	Borehole
9.	-0.754972222	36.641222222	2535	Nyandarua	Wachira Waheni	Water pan
10.	-0.798305556	36.614694444	2622	Nyandarua	Mbiru	Water pan
11.	-0.778000000	36.661472222	2504	Nyandarua	Kahungura	Spring
12.	-0.728500000	36.671888889	2525	Nyandarua	Ebrahim Koikai	Water pan
13.	-0.693527778	36.640972222	2597	Nyandarua	Kwa Musa	Water pan
14.	-0.678000000	36.655166667	2703	Nyandarua	Gachuchu Spring	Spring
15.	-0.714805556	36.629861111	2548	Nyandarua	Warungana	Water pan
16.	-0.755444444	36.654972222	2523	Nyandarua	Churiri	Water pan
17.	-1.183583333	36.753000000	1837	Kiambu	Kambara	Spring
18.	-1.184305556	36.751083333	1838	Kiambu	Karia spring	Spring
19.	-1.188888889	36.760388889	1810	Kiambu	Gathiri	Spring
20.	-1.159888889	36.753944444	1939	Kiambu	Ite dam	Water pan
21.	-1.065722222	36.649361111	2317	Kiambu	Romo	Borehole
22.	-1.197916667	36.592250000	2094	Kiambu	Nguirubi	Borehole
23.	-1.207555556	36.570194444	2035	Kiambu	Kiriri	Borehole
24.	-1.142305556	36.785361111	1838	Kiambu	Riara	Catchment
25.	-1.109944444	36.755250000		Kiambu	Kamiti	Water pan
26.	-1.250138889	36.670722222	1969	Kiambu	Kikuyu	Spring
27.	-1.243277778	36.669972222	1970	Kiambu	Rugita	Borehole
28.	-1.242972222	36.670250000	1970	Kiambu	Rungiri	Water pan
29.	-1.071102000	37.012097000		Kiambu	Ndarugu river	Catchment
30.	-1.399305556	37.398055556	1480	Machakos	Musaalani	Water pan
31.	-1.209666667	37.209138889	1496	Machakos	Kwale dam	Water pan
32.	-1.465333333	37.285722222	1998	Machakos	Kailo spring	Spring
33.	-1.434361111	37.319111111	1649	Machakos	Muooni Dam	Water pan
34.	-1.407228000	37.170124000		Machakos	Mithatini Community	Borehole
35.	-1.517371000	37.264830000		Machakos	80 Health Centres	Tanks
36.	-1.493138889	37.513500000	1258	Machakos	Muthutheni dam	Water pan
37.	-1.602972222	37.237083333	1593	Machakos	Kwa Katheke	Water pan
38.	-1.579388889	37.328583333	1448	Machakos	Miwani	Water pan
39.	-1.657888889	37.270750000	1749	Machakos	Muumandu	Water pan
40.	-1.388277778	37.756055556	1112	Machakos	Mekilingi Dam	Water pan
41.	-1.270194444	37.697750000	1125	Machakos	Ikombe sand dam	Sand dam
42.	-1.212111111	37.289166667	1461	Machakos	Kwa Matinga dam	Water pan
43.	-1.436411000	36.994351000		Machakos	Gimu	Borehole

Annex 9. Engineering Drawing of Water Structures

[Submission - 26-3-21\Updated - ARCA Technical report December 2020.pdf]

Annex 10. Stakeholder Consultations

Meeting	Date	Time	Venue	Objective	Participants
Initial GCF meeting at the UNEP	5th December 2017	11:00	UNEP Regional Office for Africa	GCF Project Cooperation	Representatives of UNEP's Africa office and NEMA
Roundtable Discussion	6th December 2017	16:00	Lord Eroll	GCF Project Cooperation	(Korea) Vice-President of Ministry of Environment (Kenya) Director General of NEMA
AE Working Group	7th December 2017	16:00	Ole Serini	Project introduction and Formation of technical working group	NEMA
1st Technical Working Group	9th December 2017	10:00	Machakos County		Water Resources Manager of County Government and WRA
2nd Technical Working Group	11th December 2017	10:00	Nairobi University		A professor of Nairobi University, Representative of WRA
Kick-Off Meeting for 1st Field Mission	12th of March 2018	12:00	NEMA	Report for progress and field mission plan	Ministry of Water and Sanitation, NEMA, WRA
1st Field Consultations	13th~18th March 2018		Nyandarua County	Collecting data and gathering opinions of stakeholders	Nayandarua County Government, Regional offices of WRA and NEMA, KARLO, KMD, Kenya Forest Service, WRUA, Dam Management Committee, NGOs

Wrap-Up Meeting for 1st Field Mission	19th March 2018	14:00	NEMA	Wrap-Up for 1st field survey	NEMA, WRA
Kick-Off Meeting for 2nd Field Mission	2nd July 2018	14:00	NEMA	Report for progress and field mission plan	Ministry of Water and Sanitation, NEMA, WRA, KMD, University of Nairobi
2nd Field Consultations	3rd July 2018		University of Nairobi	Consultation on Training Program for Stakeholders, Capacity building, Development of DSS for water resources management	Prof. Madara Ogot
	4th July 2018	10:00	WRA	Data collection on water related national plan, policy and DB for water resources monitoring	Mr. Canute Mwakamba, Ms.Leah Mukiite
	6th July 2018	10:00	KMD	Data collection on DB for weather monitoring, Cooperation between KMD and WRA	Mr. Peter M. Macharia, John T. Muiruri, Mr. David Muchemi, Mr. Pilip Rhieg, Ms. Lilian Wanyiri
	3rd ~13th July 2018		Nairobi, Kiambu, Nyandarua, Machakos County Government	Field survey on potential stations of surface and ground water monitoring	Water Resources Managers of County Governments
Wrap-Up Meeting for	25th July 2018	10:00	NEMA	Report on stakeholders meeting results, surface and	Ministry of Water and

2nd Field Mission				groundwater monitoring stations survey, capacity building enhancement program, etc.	Sanitation, WRA, NEMA
Workshop	15th October 2018	10:00	NEMA	Consultations on Technical Feasibility Report	NEMA, Local Consultants
Stakeholders Meeting	16th October 2018	10:00	NEMA	Inspection Feasibility Study Results	Ministry of Water and Sanitation, NEMA, WRA