SIMULATION OF WATER RESOURCE USE AND ALLOCATION IN NYANGORES SUB-CATCHMENT OF THE UPPER MARA BASIN, BOMET COUNTY, KENYA

BY

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DECLARATION

This thesis is my original work and has not been presented for a degree or any other award in any other University.

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DEDICATION

I dedicate this Thesis to the Almighty God from whom all blessings and knowledge flow. Without His Providence and Presence I would not have made it this far. Shalom.

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LIST OF ABBREVIATIONS AND ACRONYMS

CAACs	Catchment Area Advisory committees
CAT	Case Analysis Tool
DEM	Digital Elevation Model
DSS	Decision Support Systems
DHS	Danish Hydraulic Institute
DPSIR	Drivers-Pressures-States-Impacts-Responses Framework
E-WFP	European Water Framework Directive
FAO	Food and Agriculture Organization of the United Nations
FGD	Focus Group Discussions
GEF	Global Environment Facility
GIS	Geographical Information System
GoK	Government of Kenya
GPS	Global Positioning System
GWP	Global Water Partnership
IWRM	Integrated Water Resources Management.
JWH	Joke-Waller Hunter Initiative
KENSOTER	Kenya Soil Terrain Classification system
KII	Key Informant Interviews
KNBS	Kenya National Bureau of Statistics
MDGs	Millennium Development Goals
MoALF	Ministry of Agriculture, Livestock and Fisheries
MRB	Mara River Basin
MULINO-DSS system	Multi-Sectoral Integrated and Operational Decision Support
PET	Potential Evapo-Transpiration
PAWD	Partnership for Africa's Water Development Programme
RIBASIM	River Basin Simulation Model
SEI	Stockholm Environment Institute
SCMP	Sub-Catchment Management Plan
WARMA	Water Resources Management Authority
WASREB	Water Services Regulatory Board
WEAP	Water Evaluation and Planning Tool
WBalMo	Water Balance Model
WHO	World Health Organization
WRUAs	Water Resource Users Association

ABSTRACT

Allocation of available water resources to various competing uses is increasingly necessary in basins that experience water scarcity. In the Nyangores sub-catchment, there are currently a number of water abstractors, however, no water allocation plan exists for either the River Nyangores or the entire sub-catchment hence creating room for conflict between upstream and downstream users during periods of water stress. The sub-catchment is significant in that it forms a part of the Mara River basin that supports the Mara and Serengeti ecosystems, a world heritage site. The main objective of this study was to simulate the water resource use and allocation in the sub-catchment for the purposes of planning and management. The study was guided by three specific objectives (i) To identify existing major water sources of the sub-catchment ii) To determine the current demand, supply and quality of water resources in the sub-catchment (iii) Simulate the impact of planning and management options on the future of water use and allocation in the sub-catchment. Water use data for the year 2014 and past hydro-meteorological data for the period 1970 – 2014 was collected from field exercises, the Water Resource Management Authority and the Meteorological department in Nairobi. Datasets on water sources and sinks and their attributes were collected using Geographical Positioning System and processed in ArcGIS 10.1 software to create a spatial database. Descriptive statistics and STATA11 software were used to analyze water quantity and quality data. Water Evaluation and Planning tool was then applied to investigate the hydrology of the Nyangores River to scenarios of increased water demand. Over 90% of the upstream springs and wells were found to be active sources supporting the rural communities. In the downstream arid and semi-arid area, 25% of the springs are completely dry and another 25% are seasonal in nature thereby increasing the dependency on the river Nyangores as a major water source. In overall, the spring flow rates during the measurement campaign lay between 0.1 – 0.25 liters/second. The results also indicate that the Total Dissolved Solids tend to increase in downstream sources, ranging from 40 to 1150 mg/L indicating deteriorating water quality generally. This can be attributed to accumulation of pollutants and increase in sediment load, as the river winds its way downstream. A positive correlation of ($r = 0.47$) was found between discharge rate and a change in altitude. The current annual water demand within the sub-catchment is 27.2 million m^3 of which 24% is being met through improved and protected water sources while 76% is met through informal and unprotected sources which are inefficient to cater for future increases in demand. Under the Reference Scenario, by the year 2030, the WEAP Model predicted an annual total inadequate supply of 8.1 Million m^3 mostly in the dry season. The current annual unmet water demand is 1.3 million m^3 and is experienced at the Irrigation demand site, also significant in the dry seasons of December through February. While monthly unmet domestic demand under High Population Growth was projected to be 1.06 million m^3, by year 2030. However, with Improved Water Conservation Scenario, total water demand is projected to reduce by 24.2% in the same period. The results indicate a definite inadequate water supply for the sub-catchment within the next 15 years. Catchment water conservation measures, informed water works and collective water planning and management must therefore be undertaken by the three county governments that share the sub-catchment to ensure sustainable water supply and demand allocation devoid of conflict among users.

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

The need for water is universal, and without water, life would end. Water is constantly in motion, transient from one place to another and from one state to another, making its sensible planning, control and management a very intricate and complicated task under the best of conditions (Turner *et al*., 2004). Therefore, the convenience of access and use of available water is mainly limited by spatial quantity and quality of supply. Water is also a basic natural resource for socio-economic activities such as industrial production, hydropower production, irrigated agriculture, livestock keeping, mineral processing, tourism, recreation, navigation and transportation (MoWI, 2012).

The global freshwater supply is stored up in the atmosphere, surface water, underground, icecaps and within glaciers. Climate change and climate variability has increasingly and adversely affected the replenishment rate of fresh water resources globally. This has worsened the water scarcity problem especially in Sub-Saharan Africa (UN-WATER, 2010). To decide a nations' freshwater availability, the replenishment rate per annum is taken into account. Kenya is considered as water-scarce (Mogaka *et al*., 2006). A nation is 'water-scarce' if its annual renewable freshwater supplies are less than 1,000 cubic meters per capita and "water-stressed" if its annual renewable freshwater supplies are between 1,000 and 1,700 cubic meters per capita (World Bank, 2004). Approximately, 8.3% of the countries in the world are classified as water-scarce, while 9.8% of the countries are categorized as water-stressed (NWMP, 2013; Mogaka *et al*., 2006)

Water resources management therefore remains a challenge in most catchments and urban centers in Kenya. Water management is undergoing sector reforms occasioned by the operationalization of the Kenya Water Act 2002. The formation of Catchment Area Advisory Committees or CAACs, mean that catchment management is now done at the local level. To be effective in their mandate, the committees need tools such as decision support systems or DSS, to assist them in decision making. Among the difficult decisions is water allocation and use with increasing demand and sometimes, dwindling supplies. The natural freshwater supply for Kenya is limited by an annual renewable supply of only 647 cubic meters per capita, (NWMP, 2013; World Bank, 2000).

The water sector reforms in the Nyangores and most catchments in Kenya are progressive and there is need to drastically transform how water is allocated and used among various users. The major aim of the reforms is to guarantee a progressive equilibrium between efficiency, sustainability and equity in all areas of water provisioning (GoK, 2002). Therefore, modeling of likely scenarios at the catchment level forms a DSS for water managers since there are different water resource developments and variations in supply conditions at any given time. Such models employ an interactive computer based system to analyze water development projects, hydrological data, policy, socio-economic factors and other geo-physical aspects of catchment hydrology to replicates the actual situation.

1.2 Problem Statement and Justification of the Study

The community living in the Nyangores catchment is increasingly facing water scarcity problems. This problem is perpetuated by deforestation within the catchment, soil erosion, unsustainable quarrying and sand harvesting, planting of eucalyptus trees on riparian land and encroachment on riverbank/springs (WRMA, 2011). There is also a rapid population increase within the sub-catchment leading to water conflicts among upstream and downstream users (Kilonzo, 2014). The Upper Mara Basin area experiences high water demand and uneven seasonal distribution of available water, which leads to water scarcity in the dry season (Olang and Kundu, 2011).

Planning for mid-term and long-term water demand and supply is critical for the study area. The projected water supply schemes within the catchment must be implemented based on comprehensive studies and the planning undertaken within the precincts of available scientific and historical information. Over-abstraction upstream might jeopardize the ability of downstream users to meet their own water demand, including those of the greater Masai Mara and Serengeti ecosystems. Building credible water use and allocation scenarios for the future would greatly assist influence water supply and allocation policy options and improve planning and management decisions.

The basis for conducting this study was motivated by the fact that Nyangores sub-catchment is part of the greater Mara River basin, where the Nyangores River feeds into the Mara River. Mara River has been experiencing reduced discharges in recent times, threatening the survival of over 1.1 million people, more than 470 species of birds and 60 species of mammals that depend on it (Mango *et al.*, 2011). According to the Nyangores Water Resource Users Association, WRUA (WRMA, 2011), several studies have been conducted in the Mara Basin but little on water allocation. The land and water conservation measures are weak, leading to more undesirable consequences on water resources than projected. Also, the population in the catchment is growing rapidly, which is intensifying the land-use and land-cover changes. The soils in the sub-catchment are increasingly depleted due to high farming intensities. This directly affects the soil water holding capacity, increases run-off and causes erosion within the area (Shaghude, 2006). To combat these challenges, a proper water planning tool is required. Since some work has previously been done on Integrated Water Resources Management (IWRM) in the sub-catchment, adopting the Water Evaluation and Allocation Plan (WEAP) could augment a common understanding of the source and cause of water supply and demand challenges; as well as explore solution options and alternatives for the greater Upper Mara Basin.

1.3 Research Questions

The study used the following research questions.

i) What are the existing major water sources and sinks for Nyangores Sub-catchment?

ii) What is the present water supply and demand situation in the sub-catchment?

iii) What are the implications of existing water resource planning options on the future of the sub-catchment water resources?

1.4 Research Hypothesis

H1: There is a correlation between available water quantities and demand in the sub-catchment.

H2: There is a balance between the available water supply and demand in the sub-catchment.

H3: Planning and management decisions have a significant effect on future water availability, use and allocation in the sub-catchment.

1.5 Research Objectives

General Objective

The main objective of the study was to simulate the water resource allocation and use in Nyangores Sub-catchment for the purposes of sustainable planning and management decision making.

Specific objectives were;

i) To identify existing major water sources and sinks in Nyangores Sub-Catchment.

ii) To determine the current water supply, demand and quality in the sub-catchment.

iii) To determine the impact of water planning options on the future of water resource use and allocation in the sub-catchment using simulation.

1.6 Significance of the Study

Water resources are an important resource both to human kind and the environment. The community in Nyangores sub-catchment depends on water for its livelihood. The study on water resource use and allocation is critical in ensuring there is development of proper policy and legislation as well as ensure proper management of the available water resources for sustainability. The results of this study offer valuable material that may help in the management of the greater Mara River Basin which is an important lifeline for the

Mara-Serengeti ecosystem. This findings and recommendations will help the Bomet county government and the Bomet Water and Sewerage Company in achieving the Sustainable Development Goal (SDG) number six which pursues the guarantee of available and sustainable management of water and sanitation for all. This will also contribute to the realization of the Kenya vision 2030, as tourism, including in the Masai Mara, is one of the key economic drivers in Kenya.

The Key to identifying appropriate planning options for sustainable water supply in the catchment as well as in other river basins is in water modeling approach. The finding of this modeling study adds information on the state of water resources of the Nyangores Catchment and its current allocation priorities to the county government of Bomet and local water resource user associations. It has availed prior information to different water resource users in the sub-catchment and other related environments to help allocate, use, conserve and manage water resources sustainably.

1.7 Limitations of the Study

The study assumption was that precipitation and Potential Evapotranspiration, PET, were in approximate balance in the sub-catchment. This is never the case because PET can fluctuate depending on several factors such as plant growth stage, percentage of soil cover, solar radiation, humidity, temperature and wind. The study also assumed that water demand expansion for the scenario years 2013 – 2030 was mostly limited to irrigation water use, domestic and livestock consumption which is the core water demand areas expected to register unprecedented growth at the sub-catchment. The field data collection period for water quality and quantity was limited to a period of one year. These data was then corroborated with similar secondary data for previous years available for the area of study to eliminate seasonal biases.

1.8 Operational Definitions of Key Terms

Water Allocation Plan; is a rational and acceptable framework for the abstraction and allocation of the water in a basin or catchment.

Water Users: are persons, associations and institutions that use water within the sub-catchment.

Water Demand Management: is the deliberate introduction of measures that reduce water use rate such as efficient technology or change in water use behavior.

Water Allocation; is the process of apportioning water to various uses and users. It may satisfy the desired quantity for its intended use or not.

Allocation scenarios: these are substituted sets of suppositions that affect water demand.

Water use: Is the actual volume of water getting to the user.

Water abstraction: is the process of removing water from a water resource for an intended use.

Demand site: Is the sum of all the water needed for specific use i.e. domestic water needs. For example, in a domestic demand site such as a family house unit; Showers, Toilets and washing are the sum of the water needed in a house.

Monthly Demand: Is the monthly volume of water required by a demand site as a portion of the amended annual demand.

Monthly supply requirement: The actual volume required from the supply sources. The supply requirement varies the demand to justify for internal reuse, demand side management stratagems for decreasing demand, and internal losses (SEI, 2005).

Demand Site Flows: The volume provided to a demand site from the summation of the inflows from its transmission links.

Transmission Link Flows: Connects the source to a demand site, the volume supplied to the demand site equates the volume withdrawn from the source (i.e., the inflow to the transmission link) less any losses along the link.

Demand Site Return Links; Conveys wastewater from demand sites to endpoints, which may be either wastewater treatment plants or receiving bodies of water. The amount that flows into the link is a fraction of demand site return flow - outflow minus the flow to demand sites for reuse (SEI, 2005).

1.9 Conceptual Model

The water demands in the catchment (figure 1.0) such as domestic consumption, industrial consumption, agriculture and livestock water use are the propelling influences in the system. The water supply in the sub-catchment is based on the catchment hydrology where the water sources identified such as springs, reservoirs and river/stream inflows provide the water needed. The status of the water sources in turn influence the introduction or strengthening of decision variables for both abstraction and conservation or protection of the water resource. Stress factors on the water resources that affect quantity and quality come from the action of soil erosion, deforestation, quantity of water abstracted and the discharge of waste water. Imposition of control and regulation of water use is done using water market tariffs, policies and discharge permits which are the decision variables. These decision variables affect both the demand and the status of water resources in the catchment.

The supply and demand data variables were then modeled in WEAP to build various future scenarios. Such comprised "what if" scenarios and included; What if there is an increase of 5% in the human population growth rate? What if a waste water treatment plant is introduced? What if there is a 50% increase in irrigated land? What if water conservation program is introduced? These scenarios were then entered into the modeling system and repeated cyclically in a loop till the specific outcome was met.

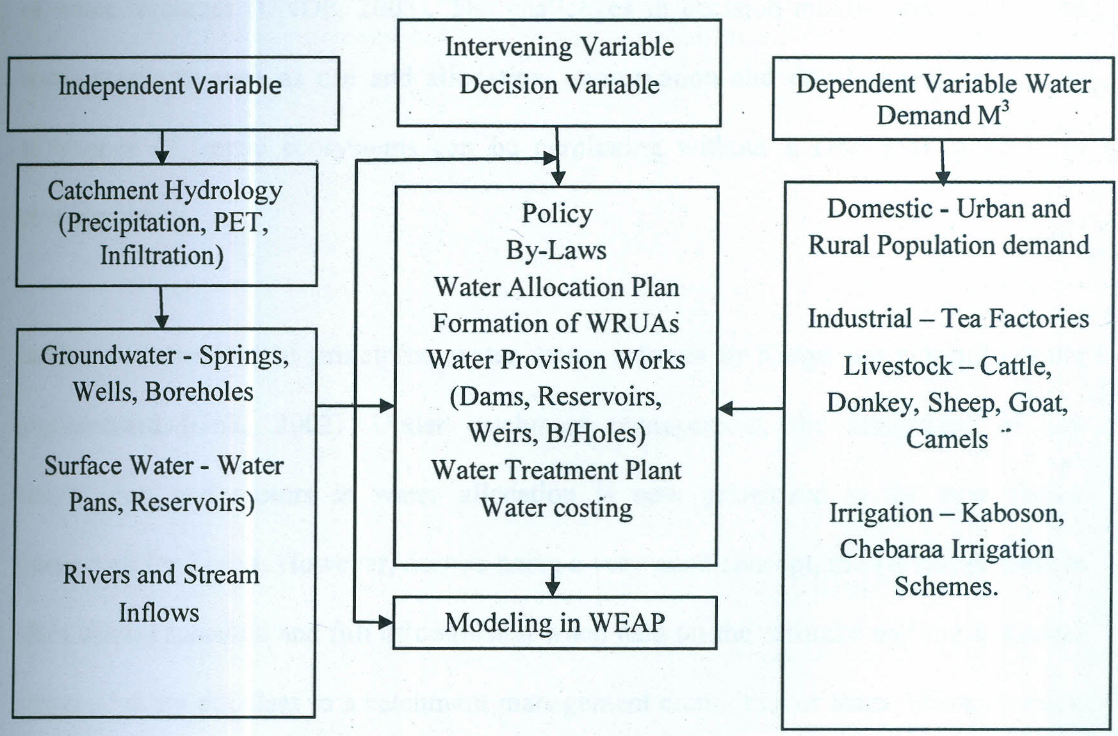

Figure 1.0: Conceptual Model (Adapted from Akivaga, 2010)

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Water resources planning is no longer a preserve of engineering deliberations, instead, it is progressively becoming an integral part of an intricate, multi-disciplinary research that combines a variety of individuals and institutions with different interests, technical awareness, and precedence. Therefore, with this backdrop, effective IWRM models require appropriate planning that can simplify the convoluted issues that can arise (IFAD, 2012; Loucks, 1995). In the context of socio-economic and environmental goals, IWRM is seen as an orderly process for the sustainable development, allocation and monitoring of water resources (UNDP, 2005). The challenges in decision making associated with water resources such as use and allocation, conservation and development as well as sustenance of fragile ecosystems can be perplexing without a DSS tool to assist in creating clarity.

In line with the IWRM principles, water sector reforms in Kenya are currently being implemented (GoK, 2002). Under catchment management, the integration of key stakeholders and sectors in water allocation is now prioritized in the new policy framework for Kenya. However, despite being a very good concept, the IWRM process is often behind schedule and full of confusion when data on the resource and metaphysical interactions are not clear to a catchment management committee or team. There is hence need to form a DSS for water managers at the catchment level by using scientific means to advance understanding of likely scenarios. Such modeling can be attained through;

ground water flow models, water balance models and economic water use models (Alfarra, 2004).

2.2 Water Resource Allocation

Many countries are faced with the challenge of sustainably allocating limited water resources for competing users (Conway *et al.*, 2009; Speed *et al.*, 2013). This is because population growth and increased income are escalating the demand for water (Freebairn, 2011; Smith *et al.*, 2010), thus resulting in inadequate water supply. In East Africa, many river basins are facing water allocation challenges, for example, in the Upper Ewaso Ng'iro basin, Mutiga et al., (2010) noted acute water shortage to the downstream communities. Consequently, this variation of timing and quantity of water, impacts water demand leading to conflicts (Ghinassi *et al.,* 2007).

In the article 'Water for agriculture in Africa', the FAO (2004) offer that in the river basins, several criteria must be considered before water allocation is done. The criterion is based on the tractability in the allocation of the supply system and the equity in the allocation process. It can also consider the use and availability of river water. A framework that has been adopted for the allocation and abstraction of water resources in a basin is the Water Allocation Plan, WAP. A Water Allocation Plan attempts to address the inherent tension in a water resource limiting situation between the need to protect the environment and basic human rights of access to the water resources and consumptive use of the resource for economic development (WRMA, 2011). However, nowadays, for effective water allocation, integrated water management modeling methods that evaluate water allocation capabilities of the river systems are essential (Mounir *et al.,* 2011). Therefore, among the essential integrated water management tools used is the WEAP Model.

WEAP is an integrated water management model for evaluation of water use and allocation (SEI, 2012). It controls the allocation of available water to satisfy the different water needs of different users (Mounir *et al.,* 2011). The model was chosen for this study because of its two principal utilities namely; simulation of natural hydrological processes such as run-off, infiltration and evapotranspiration to enable assessment of the availability of water within a sub-catchment and, simulation of human activities to allow the assessment of the impact of water use. It uses a wide range of hydrological data, demographic data and meteorological data to project and reproduce water demand and allocation (Yates *et al.*, 2005).

According to latest studies, WEAP has been applied in several basins to calculate water demand and allocation. For instance, to evaluate water resource development based on an equilibrium scenario of the current demand, Mutiga *et al.*, (2010) used WEAP in the upper Ewaso Ng'iro basin, Kenya. They simulated water use for domestic, livestock, irrigation and wildlife sectors. They found that abstraction of water for irrigation purposes results in excessive water abstraction upstream hence leading to conflicts downstream.

On the other hand, Ndiiri (2011) used WEAP to analyze the impacts of possible water demands on the water resources of the Mara catchment using a scenario analysis approach. She found that the implementation of the Environmental Reserve flow, an in-stream requirement to guarantee the health of the riverine ecosystems, would increase the shortages for domestic and irrigation water use and other sectors. Therefore, this study also considered the use of WEAP model to examine water demand and allocation among various users in the Nyangores sub-catchment.

2.3 Strategies for Mitigating Water Demand and Allocation Disparities.

Any activity, practice, technology, law or policy that has the ability to reduce water use can be considered as a demand management or water conservation strategy (Dziegielewski, 2011). Therefore, strategies for water demand and allocation management among users to enhance water use efficiency involve managerial, mechanical and policy aspects. Consequently, Celio (2009) and Kadigi *et al.*, (2012) offered that the development of policies that encourage proper water resource management can address the challenges of effective management and allocation of available water resources. Caponera (2007) observed that these laws must be devised and applied to permit water allocation while attaining the needed demand and social goals. Also, Calzadilla *et al.*, (2011) conducted a study on water scarcity and the impact of improved water management in the world; they explored the degree to which upgrades in the water management would be economically valuable and the volume of water savings that could be achieved for the world as a whole. Additionally, a related study by Gersfelt (2007) in Egypt concluded that contemplation of policy tools can be used to achieve an effectual allocation of water to various users in developing countries. However, the implementation of policy to manage water demand and allocation is determined by economical and political matters (Freebairn, 2011).

According to the water policy guidelines for sustainable management of water resources by the Organization for Economic Cooperation and Development (OECD, 2010) water policy development should consider the following criteria. Policies need to consider the intricacy and heterogeneity of water resources and the linkages between quantity and quality. They should also be modified to include more demand aspects and a greater integration of policy across sectors such as agriculture, energy and the environment.

Water Resource Users Associations, WRUAs, are vital for reducing conflict related to water allocation and have been suggested by various scholars (Mutiga *et al*., 2010; Veldwisch, 2010; Inocencio *et al*., 2007). Mutiga *et al*., (2010) asserts that the formation of WRUAs in Upper Ewaso Ngiro North basin, Kenya as it incorporates ideas from different stakeholders who can easily solve water related conflicts. The associations also enhance user's involvement and participation in designing and implementing development of water use goals for the basin. In addition, WRUAs boost water management, water use efficiency, and coordinate water distribution and collects water charges and fees from members to improve water services and infrastructure (Wang *et al*., 2010).

According to Zhang (2013) water pricing has also been shown to be an efficient tool in controlling water use and allocation. Water prices can cover both the costs of supplying water or reflect the real water resource value as well as water scarcity (Komakech, 2012). Freebairn (2011) suggested that efficient allocation of water among different uses and users requires application of the standard economic principle, pricing of water, across the different uses and users. This idea corroborates the findings of Matekole (2003) from his study on factors influencing water management in Georgia. He found that economic measures such as the cost of water are accompanied by reduced volume of water use. Agreeably, Brandes *et al.*, (2011) also noted that increasing water price greatly expands the potential for demand management.

2.4 Water Demand Management

Water management is a decisive activity that targets to advance the status of water resources (Claudia, 2007). Water demand management on the other hand is defined with five elements: (1) decreasing the volume or quality of water necessary to accomplish a particular chore; (2) accomplish the chore with less water or with water of low quality by varying the nature of the task; (3) decreasing losses in movement from source through use to disposal; (4) Change the time of use to off-peak periods; and (5) increasing the flexibility of the system to operate during periods of water scarcity. This definition is appropriate users in both developed and developing countries. It also depicts how objectives of better water use efficiency are interconnected with those of equity, environmental protection and public participation. Collectively, these objectives make water demand management less a set of techniques than a concept of governance (David, 2006)

In small catchments like Nyangores catchment, the degradation in water quality and water quantity is expected to increase as an impact of increased water demand. This impact is amplified by population increase and economic growth. Climate change and climate variability is expected to further aggravate this situation (Lamia *et al*, 2015).

2.5 Water Quality

In small rural communities and in large urban areas, the World Health Organization, WHO, has established guidelines on how to handle the quality of water supplies. It also appreciates that very rigid standards cannot be used across the world. Therefore a range of guideline values for more than 60 parameters have been elaborated. Most nations, including Kenya, have their own guidelines which vary from place to place depending on the local situation (FAO, 2016).

Qualitative and quantitative measurements are needed from time to time to constantly monitor the quality of water from the various sources of supply. Water pH, hardness and presence of a select group of chemical parameters, highly toxic chemicals and biological oxygen demand, BOD, are often estimated. For portable water, WHO and the Water services Regulatory Board, recommends a pH range of 6.5 - 8.5 (WASREB, 2008). It is an indicator of comparative acidity or alkalinity of water. Values of 9.5 and above denote high alkalinity while values of 3 and below suggest acidity. Low pH values help in effective chlorination but trigger problems with corrosion (WHO, 2014). Total Dissolved Solid (TDS) measurements provide a rapid indication of the quantity of dissolved substances in the water. However, this measurement does not provide specific quantity values for the different individual solvents in the water. The Kenyan government recommends a TDS value of 1500 mg/l for drinking water (WASREB, 2008).

2.6 Geographical Information System

A geographic information system (GIS) incorporates hardware, software, and data for obtaining, handling, evaluating, and presenting all forms of geographically referenced data (Schultz, 1993). GIS allows us to see, assess, question, infer, and envision data in many ways that reveal relationships, patterns, and leanings in the form of maps, globes, reports, and charts. Olang (2009) observes that the use of GIS in hydrology and water management is based on data about the area for which hydrologic processes are to describe. Critical hydrologic information includes; time series of historical rainfall and streamflow data, drainage network, land use, elevation and hydrogeology. Spatial hydrologic information is the basis for water management planning, both for use and protection of water resources and the environment (McKinney and Cai, 2002).

2.7 River Basin Simulation Models

The bio-physical and the socio-economic landscapes shape the management of water resources, therefore an effective IWRM model must address these two distinct systems (Yates *et al.*, 2005). Factors in the bio-physical system include; land cover, surface water hydrology, climate, groundwater hydrology, topography, soils, ecosystems and water quality. On the other hand, socio-economic management systems are driven largely by human demand for water. They shape how available water is stored, allocated, and delivered within or outside of a basin or catchment. To simulate water development and management policies in river basins, several programs exist. Some of the programs include enhancements that trade a detailed depiction of functional policies. Stakeholder involvement exercises in model building and simulations may find these programs essential (Akivaga *et al*, 2010).

The models include: River Basin Simulation Model or RIBASIM, MIKE Basin, Water Balance Model (WBalMo), Multi-Sectoral, Integrated and Operational Decision Support System (MULINO- DSS) and Water Evaluation and Planning System (WEAP). These programs are discussed briefly to discuss their data requirements and their limitations if any. They are commercially offered DSSs' and have been utilized on various basins for studies or management (Martijn *et al*, 2010).

The RIBASIM is used for investigating the performance of river basins under diverse hydrological conditions. The model utilizes a user-friendly, graphically, GIS-oriented interface, to enable the user to analyze different actions related to infrastructure, demand management and the output in terms of water quantity and water quality (Loucks, 2005). It has recently been applied in the upper Nile to describe the water distribution coupled to a hydrological model to form the Nile Hydrological simulation Model (Martijn *et al.*, 2010).

MIKE Basin is designed to address water allocation, conjunctive use, reservoir operation and water quality issues (Christensen, 2006). It pairs ArcGIS with hydrologic modeling to provide basin-scale solutions, where the emphasis is on both simulation and conception in both space and time; hence it is perfect for building understanding and consensus (DHI, 2006).

Water Balance Model, WBalMO, is a product of Wasy Limited in Germany and is an interactive simulation system for river-basin management. It models run-off and precipitation and balances it with monthly water use requirements and reservoir storage changes (Christensen, 2006). It has been applied to characterize management standards for river basins, design reservoir systems and their operating policies, and perform environmental impact studies for development projects (DHI, 2003).

The European Union water management project known as RTD created MULINO-DSS with the aim of developing a decision support system to assist water authorities in the management of water resources. Expressly, it aimed to improve the quality of decision making and seeking to achieve a truly integrated approach to river basin management. The tool helped enact a new European water policy and objectives together with local regulations (Giupponi and Cogan, 2002; Giupponi and Cogan, 2003).

2.8 Water Evaluation and Planning Tool

The Water Evaluation and Planning System Version 21 (WEAP21) is an IWRM model that through watershed-scale hydrologic processes, seamlessly integrates water supplies generated with a water management model driven by water demands and environmental requirements (SEI, 2013). It prioritizes demand and supply preferences, which are then used to solve the challenges of water allocation. It presents procedures that can be used to evaluate a range of issues experienced by water planners through a scenario-based approach. These issues include watershed condition, ecosystem needs, climate variability and change, anticipated demands, operational objectives, regulations and available infrastructure (Yates *et al.*, 2005).

Some of the basins in Kenya in which WEAP tool has been used with good results include Ewaso Nyiro river basin, Perkerra River in Baringo and Tana River in Kitui. The same model was herein adopted in the study of the Nyangores sub-catchment in Kenya.

2.9 WEAP Scenarios

Scenarios in WEAP explore how a system would respond to different conditions or settings e.g. new technologies, population changes, new policies or climate change (SEI, 2013). The simulated scenario results are then contrasted against the reference or business as usual scenario to assess their impact on the water system. It is important to note that all scenarios are based on the current account year "business as usual account" as the reference period.

2.10 Research gap

This study provides a comprehensive mapping and quantification of major water sources in the Nyangores sub-catchment. Previous studies, especially those conducted by the Water Resources Management Authority (WRMA, 2011) have focused on the river, rainfall and a quantification of borehole water abstraction. In terms of planning for future water use, the LVBC (2013) conducted a study that estimated the available waters from communal water points throughout the Mara basin using population data. However, this ran the risk of assuming that the water points are evenly distributed and are of similar quantity and quality of supply. In trying to understand the hydrology of the Mara basin, Mango *et al* (2011) explored the impact of land use and climate change on the hydrology of the Mara basin. However, the study did not capture the data necessary for planning for the impacts of increased or reduced water demand situations in the sub-catchment.

CHAPTER THREE: MATERIALS AND METHODS

3.1 The Study Area

3.1.1 Location

The Nyangores sub-catchment of Upper Mara basin is located 250 Kilometres South West of Nairobi, covers an area of approximately 933 Square Kilometres, and lies between Latitude 34°59′E and 35°52′E and Longitude 0°22′S and 1°13′S (Figure 3. 1). The study area falls within the three counties of Bomet, Narok and Nakuru in the former Rift Valley province. There are four major administrative units in the catchment area, namely, Nyangores, Tenwek, Sigor and Kaboson divisions (KNBS, 2009).

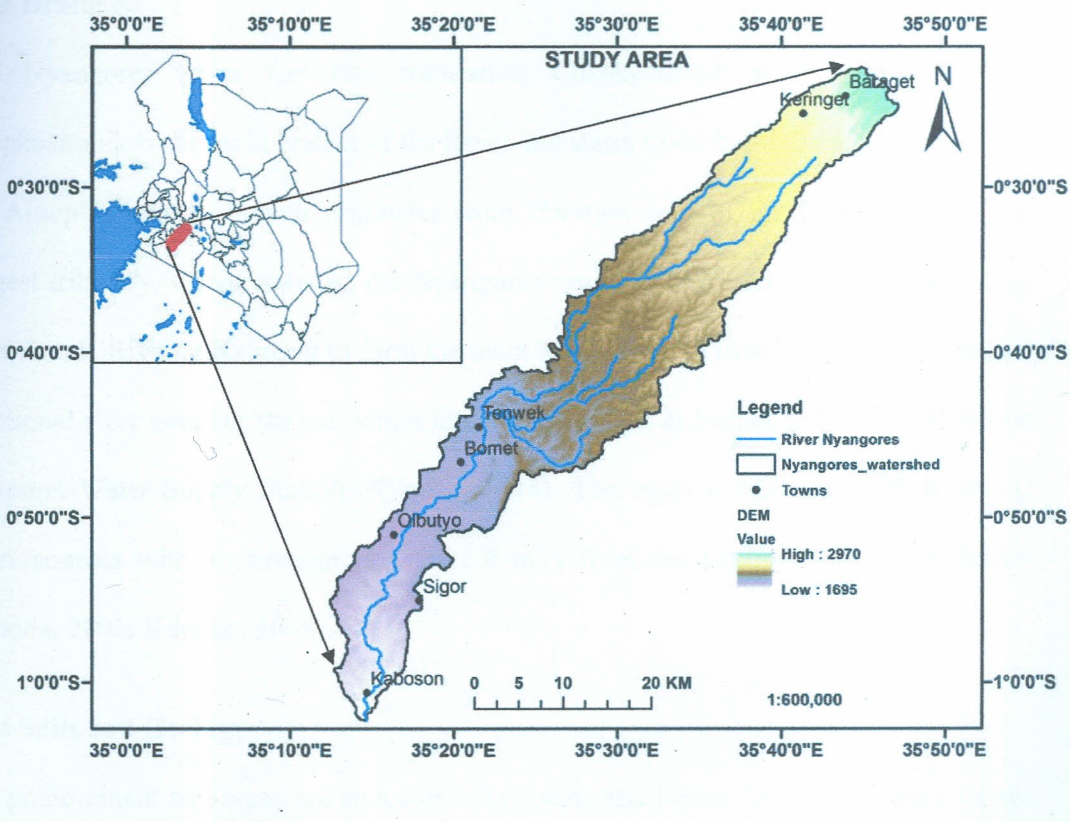

Figure 3.1: Map of Nyangores Sub-catchment (Source; Wimmer *et al.*, 2015)

3.1.2 Climate

The altitudes within the sub-catchment range between 2951m around the Mau Escarpment to 1706m downstream in Kaboson. It is largely hilly in topography with 50% of the total area above 2202m a.s.l. (Dessu and Melesse, 2012). The amount of precipitation varies according to these altitudes. The most rainfall is experienced in the Mau Escarpment with a mean annual of between 1,000 and 1,750 mm. The rainfall pattern is bi-modal, with the long rains starting in mid-March to June with a peak in April, while the short rains are experienced between the months of September and December. Average temperature in the sub-catchment is 17.5 °C (Kilonzo, 2014).

3.1.3 Drainage

The Nyangores River has two tributaries; Chepkositonik and Ainop'ngetunyek. Chepkositonik is the main branch of the River and starts from the Mau escarpment, while the Ainop'ngetunyek branch originates from Bararget area of the Forest. Along the longest tributary, Chepkositonik, the Nyangores runs approximately 94 Kilometres then joins Amala River at Kaboson to form the main Mara River (Krhoda, 2001). There is one functional river gauging station within the sub-catchment at Bomet and a rainfall station at Bomet Water Supply Station (Kilonzo, 2014). The basin is endowed with plenty of water sources with an average flow of 8.6 m^3/s from the Gauging Station at Bomet (Krhoda, 2001; Kilonzo, 2014).

3.1.4 Soils and Geology

The predominant soil types are andosols, clay loams and loams. Underlying the area are undifferentiated pyroclastic materials comprising mainly of poorly consolidated volcanic tuffs and volcanic ashes, which are extensive in the area and are regularly changed into clay in the upper Mau. A plain is found in the southern part of the area and entails an accumulation of sub-aerial volcanic ashes which were later slightly dissected by shallow water routes (Mbuvi and Njeru, 1977).

3.1.5 Land Use

The major land use/covers in the Nyangores River Basin include closed forest, tea in the upper mountain slopes, and subsistence farmland. Other minor land use and land cover classes include shrub-land, tree savannah and grasslands. In the last 15 years, all the land use/covers have experienced some change except the water bodies. Closed forests have decreased by 23% due to forest clearing for tea and/or as timber harvests, which have increased opened land by 82% and reduced natural vegetation (Kiragu, 2009).

3.1.6 Demography and Administrative Units.

Nyangores sub catchment is part of the Mara Basin which is home to 1.1 million people whose main engagement is farming and pastoralism. Bomet town is the main urban centre within the sub-catchment with about 95,000 residents (KNBS, 2011). Other urban centers include Silibwet Township, Sigor, Merigi, Keringet and Kiptagich trading centers which are also rapidly growing into towns. The rest of the population lives in rural areas, with a very high percentage - up to 64% - being below the poverty line. Nyangores sub catchment covers Bomet, Nakuru and Narok counties. The populations of the nineteen wards in the three Counties that overlap the catchment area were recorded in the 2009 Census to have a combined population of 566,153 with an average density of 625 persons per Square Kilometer (KNBS, 2009). Based on the growth rate of 2.8 %, the current total population of the residents within Nyangores drainage basin is estimated to be approximately 290,278 persons (KNBS, 2011).

3.1.7 Socio-Economic Activities

Crop farming remains the dominant economic activity to the majority of the population despite the diversity in spatial extent and land use. About 62% of the households are smallholder farmers, with livestock keeping as the second dominant activity, yet agriculture occupies about 28% of the available arable land. The main crops are tea, maize, potatoes, beans, coffee and pyrethrum. The Nyangores Sub catchment also supports farmer livelihoods, some hunters and gatherers in the forested catchment areas, and other people who directly or indirectly rely on tourism. The use of forest resources also remains an important source of livelihoods to the people in the highlands (WRMA, 2011).

3.2 Research Design

The study used purposive sampling design and the descriptive survey design. Descriptive survey was used to describe the existing water use situation of water supply, water demand, water allocation and strategies used to minimize water allocation disparities. Purposive sampling design was used to determine water sources for on-site field measurements of water quality and discharge rates. In this way the flow trends of springs and the river Nyangores were determined. Data on stream-flow measurements were used in WEAP model calibration and validation. The socio-economic data was collected using a questionnaire and key informant interviews and observation guide. WEAP Model was used to investigate water demand and allocation trends in the sub-catchment. The results were then interpreted and represented in tables, frequencies, and percentages from which inferential were drawn to build scenarios for future water use and planning. The findings were then validated and confirmed with similar empirical works for accuracy and reliability of outcomes.

3.3 Geographical Information System

Spatial data was collected using *Garmin Etrex* 20 *and* 30 GPS equipment and uploaded onto ArcGIS version 10.1 software for spatial analysis and mapping so as to meet the objective one of the study.

3.4 WEAP for Water Allocation

WEAP was used for Simulation of water resources systems and trade-off analysis (Yates *et al.*, 2005, Sieber and Purkey, 2013). The approach to simulation comprised of (i) building water supply and demand network schematics, and populating the model objects with data gathered from field visits and observations, experiments, key informant interviews and utility reporting, (ii) calibrating the model against existing system performance - the calibrated models are referred to as 'reference models' henceforth - and (iii) developing and running projections for future scenarios that are of key interest to each utility. Projections were developed specific to each utility, and represented specific combinations of scenarios and management options (Mehta *et al.*, 2013).

3.5 Modeling Equations for Simulation of Water Use and Allocation

The model performance was evaluated using standard statistics as described by Sieber and Purkey (2011); Mean error (ME), mean square error (MSE) and model coefficient of efficiency (EF).

$$E_Q = Q_M - Q_o \quad \text{(Model residual)} \quad \ldots\ldots\ldots\ldots \text{Equation 3.1}$$

$$ME = \bar{E}_Q = \sum_{i=1}^{n} \frac{Q_m(i) - Q_o(i)}{n} = \sum_{i=1}^{n} \frac{E_Q(i)}{n} \quad \ldots\ldots\ldots\ldots \text{Equation 3.2}$$

$$MSE = \sum_{i=1}^{n} \frac{(Q_m(i) - Q_o(i))^2}{n} = \sum_{i=1}^{n} \frac{(E_Q(i))^2}{n} \quad \ldots\ldots\ldots\ldots \text{Equation 3.3}$$

$$EF = \left[1 - \frac{\sum_{i=1}^{n}(Q_m(i) - Q_o(i))2}{\sum_{i=1}^{n}(Q_o(i) - \overline{Q_o})}\right] = \left[1 - \frac{MSE}{S_{Q_o}^2}\right] \quad \ldots\ldots\ldots\ldots \text{Equation 3.4}$$

Where;

Q_o= Observed flow

Q_m= Simulated flow

ME = Mean Error

MSE = Mean Squared Error

EF = Model Efficiency Coefficient

n = The number of data points

s = Variance (squared standard deviation)

The ME and MSE reflects the bias or systematic deviation in the model results and the random error after correction. Their magnitudes highly depend on the flow magnitude, and thus on the river under study. The model efficiency (EF) as provided by Nash and Sutcliffe (1970), is a dimensionless and scaled version of the MSE for which the values range between 0 and 1 (0 or 1 for a perfect model) which gives a much clearer evaluation of the model results and performance (Nash and Sutcliffe, 1970).

3.5.1 Annual Water Demand and Monthly Supply Requirement Calculations

The WEAP user guide by the Stockholm Environmental Institute outlines how the WEAP model calculates Annual Water Demand, Monthly Water Demand and Monthly supply requirements (SEI, 2005).

Annual demand $_{DS} = \sum_{Br}$ (Total Activity level$_{Br}$X Water Use Rate$_{Br}$)

Monthly Demand $_{DS,m}$=MonthlyVariationFraction$_{DS,m}$ X AdjustedAnnualDemand$_{DS}$

MonthlySupplyRequirement$_{DS,m}$ = (MonthlyDemand$_{DS,m}$ X (1-ReuseRate$_{DS}$) X

(1-DSMSavings$_{DS}$)) / (1-LossRate$_{DS}$).. (*See Appendix 8*).

3.5.2 Inflows and Outflows of Water:

This step computed water inflows to and outflows from every node and link in the WEAP system for a given month. This included calculating withdrawals from supply sources to meet demand. A linear program (LP) was used to maximize satisfaction of requirements for demand sites, in-stream flows, demand priorities, supply preferences, mass balance and other constraints. Mass balance equations are the foundation of WEAP's monthly water accounting; total inflows equal total outflows, net of any change in storage (in reservoirs, aquifers and catchment soil moisture).

3.5.3 Calculation of Irrigation Scheme Water Requirement

The irrigation crop water requirement for WEAP was calculated by using the reference evapotranspiration (ET_o) and effective Precipitation (P_{eff}) method as provided in FAO irrigation paper 56 (FAO, 2002). This method, known as the Simple Rainfall-Runoff Coėfficient Method was chosen for the study because it uses crop coefficients to calculate Evapo-transpiration. The method has also successfully been used by various scholars in the calculation of irrigation water requirement in many basins (Ndiiri, 2011; Mutiga *et al.*, 2010).

3.5.4 Rainfall-Runoff Coefficient Method - Based on FAO Crop Requirement

This method was used as it utilizes crop coefficients to calculate evapotranspiration. The remainder of the precipitation that cannot evaporate and transpire by crops and soils was simulated to be runoff to the river. According to De Laat *et al.*, (1996), the generic water balance equation for a catchment is given by;

$$(P-E)*A-Q = \Delta S/\Delta t,$$

Where: P = precipitation, E = evaporation, A = area, Q = discharge and $\Delta S/\Delta t$ = change in storage over time.

Spaans (2001) argues that the hydrological cycle water balance is based on the principle of continuity and /or laws of conservation of mass and provides the following equation to represent the hydrological water balance for a catchment;

$$P + R + B - F - E - T - O = \Delta S$$

(Where P = precipitation, R = runoff, B = subsurface flow, F = infiltration, E = evaporation, T = transpiration, O= outflow and ΔS = change in storage volume).

However, this equation disregards inter-catchment transfers (Spaans, 2001). Irrigation water requirement was estimated on the basis of crop with the highest water requirement or the crop that occupied the largest area in the irrigation scheme. In this regard, crops of the Solonacea family such as tomatoes were chosen for the purposes of computing crop water requirements.

3.5.5 Calculating of Tropical Livestock Unit Water Requirement

The Tropical Livestock Unit Water Requirement was calculated according to the formula proposed by Heady (1975). The total livestock population within the sub-catchment was converted to Tropical Livestock Units, TLU, using the Food and Agriculture Organizations recommended formula; 1 Tropical Livestock Unit = 1 adult cow of 300 Kg. *Appendix 1* provides further weighted estimates for TLU conversions.

3.6 Calibration

WEAP incorporates a link to the Parameter Estimation Tool (PEST). This allows the user to computerize the procedure of matching WEAP results to historical observations and modifying model parameters to improve its accuracy. PEST was used to help calibrate stream-flow, run-off and infiltration as well as to set ranges for annual water consumption per capita (Doherty and Hunt, 2009). Other variables calibrated with PEST to assist in simulating catchment hydrology are provided in Table 3.1.

Table 3.1: Calibration Parameters/ Variables and Plausible Ranges

SN	Instance	Variable/ Parameter	Range (Unit)
1	Settlement	Annual Activity level Consumption	40 - 120 (m^3/cap*annum) 0 - 30 (%)
2	Watershed	Precipitation[1] ETref[2] Kcf[3] Effective Precipitation	0.7 – 1.3 0.7 – 1.3 0.5 – 1.5 0.5 – 1.0
3	Run-off and infiltration	Run-off fraction to Ground water (GW)	10 – 90
4	Stream flow	Flow rate in m^3	0.5 – 40 m^3/s

Source; Sieber and Purkey, 2013

3.6.1 Stream-flow Calibration;

The Stream-flow calibration was done using the River Nyangores gauging station at Bomet. The PEST was used to compare stream-flow gauge data entered, with stream-flow results for the node immediately upstream of the Bomet gauge (Doherty and Johnson, 2003). Availability of consistent historical hydrological data made the building of a representative calibrated model easier (Mehta *et al.,* 2013).

3.6.2 Scenario Simulation

Simulation makes it possible to forecast and evaluate "what if" scenarios as well as water policies such as water conservation plans, demand projections, hydrologic changes, new infrastructure and fluctuations in allocations (Raskin *et al.,* 1992; Yates *et al.,*2005).

The WEAP model was applied by simulating recent base year or 'business as usual' account, for which water availability and demand were determined. This information was obtained from field observations and water users/stakeholders in the basin through group discussions and individual interviews conducted during fieldwork campaigns. The model was configured for the whole of the Nyangores sub-catchment. The information was then used to simulate alternative scenarios to assess the impacts of different development and management options. This was possible since the model has the ability to optimize water use in the catchment using an interactive linear programming algorithm with the objective of maximizing the water delivered to demand sites according to a set of user-defined rules (Sieber and Purkey, 2013).

The application was defined by time frame, spatial boundaries, system components and configuration of the problem. The Current Account, which is the calibration step of the model, provided the actual water demand, resources and supplies for the system. Scenarios built on the current account enabled the exploration of the impact of alternative policies, technological advancements and other factors on future water availability, demand, supply and hydrology. During the study, WEAP analysis was underpinned on the available data for the entire sub-catchment. Table 3.2 shows various datasets gathered across the sub-catchment and was required for populating the WEAP model.

Table 3.2: Datasets gathered for WEAP tool.

SN	Variable	Description (Monthly/Daily Water Demand M^3)
1	Urban and Rural population requirement	Rural and Urban water Consumption
2	Livestock requirement	Intake per livestock unit
3	Irrigation	Water demand Per crop type/ Ha
4	Factories/ industries	Daily water use
5	Population of catchment	Annual water activity
6	Stream-flow data	Nyangores river and tributaries
7	Land use and land cover	Classification and size

Source (SEI, 2005).

3.7 Other Research Instruments

Other than the WEAP model, the study incorporated the use of instruments such as GPS for acquiring spatial datasets, computer, ArcGIS software, satellite imagery (Landsat), Secondary land cover datasets, Maps, Key Informant Interviews (KII) and Focus Group Discussions (Kothari, 2004).

3.8 Data Collection Procedures

Rural water demand data for portable water collected for domestic use, in litres, was collected for two hours every morning, between 6 am and 8 am at identified major water sources. For livestock water requirements, secondary data on livestock units; goats, sheep, cattle, donkey and camels, and their daily water consumption index was acquired from the local Ministry of Agriculture, Livestock and Fisheries offices in Bomet town. The average discharge for spring water was calculated using a calibrated 20 litre bucket and a stop watch. The rate in litres per second was then converted into Cubic Metres per Second. The municipal/ piped household water, industrial and irrigation water was quantified by checking the water billing documents and irrigation design capacity respectively. Rate of river and stream flow data was collected from the Water Resource Users Association in Silibwet and from Water Resource Management Authority offices in Kericho, being collected from gauging stations along the river. The Borehole pump capacity and the hours of operation were used to determine the rate of abstraction for each borehole in the sub-catchment. These daily water demand and supply data was then converted to monthly figures and used to determine the current water use scenario of the catchment.

According to WRMA (2011), Six types of water sources exist in the Bomet County, namely, Wells, Protected springs 30, Dams 1, Permanent River 1, Streams 2 and Ponds 50. Households that harvest rainwater using roofs are 750, while households with piped water are 1200. A further 1500 Households use portable water. The types of water demand sites that exist in the sub-catchment include domestic, livestock, irrigation, municipal and industrial water demand, which includes Tea Factories. The sample size was derived as given in Yamane (1973) to get the sample size for the Wells, ponds, springs and boreholes that were sampled in this study.

The Yamane formula is given by;-

$$n=N/1+N(e)^2$$

(Where n=required sample size, N=population size, e=desired level of precision given as; 1- precision, where the desired precision level was 95%). Where (e) was calculated as (1-0.95) = 0.05. Therefore, the substituted values were; $n=30/1+30(1-0.95)^2 = 27$. This sampling size procedure was done to ensure even distribution of sample points across the catchment as well as to avoid biased results. The resultant sample figures were then spread equally across the three zones in the sub-catchment; upper catchment, mid-catchment and lower catchment. Using purposive sampling and with the assistance of the WRUAs, the water resources were selected depending on permanency, seasonality and proximity to the Nyangores River. Water infrastructure and allocation information was obtained through Key Informant Interviews and review of documents from WRUAs, WRMA, NEMA, WWF Upper Mara basin Program offices and the Bomet county government office in charge of Water, Environment and Natural Resources. Secondary data such as climate data, soil classification data, Landscape data including vegetative cover and land use data, was collected as GIS files from Meteorological department, FAO Africover data and United States Geological Survey website respectively.

3.9 Water Quality

Using a Conductivity Metre at select water collection and abstraction points, rapid measurements on water quality were conducted. Water quality parameters such as pH, Total Dissolved Solids (TDS) and Electrical conductivity (EC) were selected because they are a quick and relatively reliable indicator of water quality which can be ascertained on site. Comprehensive water quality tests may require more sophisticated and expensive equipment, a laboratory and extended time periods (Sidneit *et al.*, 1992). It was imperative to take these basic measurements so as to roughly gauge the suitability of the quality of the mapped water resources for domestic use within the catchment. The overall turbidity of the water and the local conditions were also visually assessed to understand if the water quality was influenced by local environmental conditions.

Two types of GPS were used to obtain the spatial locations of water sources for comparison purposes. These were Garmin *Etrex 20* and Garmin *Etrex 30*. The acquired spatial locations were subsequently mapped using ArcGIS software. For this study, particularly, ArcGIS version 10.1 was selected for use because of its availability at the University. The spatial datasets collected was first projected using the Universal Transverse Mercator (UTM), World Geodetic System (WGS)-1984. This projection system was preferred because it represents a true to scale transformation of areas around the equator while minimizing distortions laterally along the latitude (Olang *et al*, 2011). These were later mapped and linked to the attribute table using the extension Shapefile, *Shp*. Other GIS data such as catchment boundary, river network and administrative centers within the catchment were acquired from secondary sources such as the United States Geological Survey Site, USGS (Wimmer *et al.*, 2015).

3.10 Data Analysis

3.10.1 Descriptive Statistics Analysis

The study used descriptive statistics to arrive at simple assessments of percentages, mean, frequencies, standard deviation and tabulation. This was accomplished by the use of Excel and STATA 11. Descriptive measurements were used to understand the distribution of water resources across the sub-catchment, the characteristic and status of the water resource, the impact of altitude on the quantity of water resources as well as the impact of management decisions on the number and availability of water resources (Rossiter, 2006).

3.10.2 Parametric Test

In this study, protected and non-protected water source was assumed to influence discharge rate and water quality and therefore water demand. For instance, two water quality parameters, pH and TDS were measured in both protected and non-protected sources upstream, midstream and downstream areas and compared with the discharge from the sampled water resource as a continuous dependent variable.

3.10.3 Water Evaluation and Planning Model

The study used the Water Evaluation and Planning tool (WEAP Model) to examine water allocation and demand in the three altitudinal zones of Nyangores sub-catchment. The model was selected ahead of Ribasim and Mike Basin models because of its flexibility and capacity to use a wide range of hydrological, climatic, demographic and socio-economic data to simulate water demand and allocation in a river basin (Sieber and

Purkey, 2013; Yates *et al.*, 2005). It utilizes both primary and secondary spatial datasets and allows simulation of water allocation and demand scenarios. The WEAP model was applied to analyze objective 3 of the study. This objective utilized a majority of the data already acquired for the objectives 1 and 2 of the study. *Table 3.3* describes the data sources used for all the study objectives.

Table 3.3: Datasets required for All Study Objectives

SN	Objective	Data Required	Data Source	Tools & Methods	Description
1	Identify Major Water Resources.	GPS coordinates	Field Mapping	GPS and GIS (ArcGIS 10.1), Structured Interviews & Focused Group Discussions.	Mapping by spatial locations
2	Determine the Current Water Use Situation	Water Demand and Supply Data Water quality datasets	Field Measurements, Secondary data.	Structured Interviews. Field measurements.	Water use Trend analysis
3	Simulate the Impact of Water Use and Management options on the future of Water Resources	Results from Objective I and II River flow data (discharge), Area under crops (Ha), Crop type, Daily rainfall, crop coefficient, average temperature and Evaporation.	WEAP Model, Results of objective I & II. WRMA, Bomet County Water and Environment Office, Meteorological department (Nairobi).	Water Evaluation and Planning Tool	Scenario Analysis

(Source, Adapted from SEI, 2005)

3.10.4 Effective Precipitation

In their book, Guidelines for computing Crop Water Requirements, Allen *et al.*, (2000) poses that in Kenya and the East African region, effective precipitation is taken to be between 50 – 80%. There are more run-offs in drier areas and farmlands because of limited vegetation cover and less run-off in forested areas because of forest and ground cover. Therefore, WEAP defines Effective precipitation as the percentage of precipitation available for evapotranspiration, ET - the remainder is direct run-off. So in the case of this study, Tea and Forest, Upstream, was taken to have 20% precipitation available for ET, Farmland, Mid-stream, 30% and a combination of Woodland and Grassland, downstream, to have 40% available for ET (Allen *et al.*, 2000).

3.10.5 Processing of the Soil Data

The soil data used in this study was acquired from the Kenya Soil Terrain (KENSOTER) soil classification system, which is a classification system that describes soil types for Kenya. Dataset for Kenya was downloaded and sub-set to an area covering the study area. Such a procedure was important in order to reduce the rigorous work of classifying the whole datasets. In order to reclassify the soil types into local classes for subsequent modeling using WEAP, the classes were accessed by querying and selecting specific soil characteristics based on a soil type methodology of loam, clay, sand and silt.

3.10.6 Defining Study Area in WEAP

On the schematic view of the model, GIS based vector maps of the catchment in the form of shape files were uploaded onto the WEAP area of the Model. The study area geographical boundaries were defined as prompted by WEAP (Sieber and Purkey, 2013). The study area covers a total of 933 Km^2. The catchment was divided into three zones, Upstream, Mid-stream and Downstream so as to assist in the simulation of the catchment system.

3.10.7 Period of Analysis:

The Base year for the study was year 2000 and the last year of scenarios was 2030. The choice of the base year was based on availability of complete and continuous water demand data, climate data, stream flow data and other parameters from which future scenarios could be built (SEI, 2012). Since the base year also serves as the start year, year 2000 was chosen because it was the year with the most upto-date water use information. The year 2030 was chosen to allow for 30 years of projection. It also coincided with the realization of Kenya's Vision 2030 upon which most current development projects are targeted. Using the Expression builder, the Monthly Time-Series Wizard, Yearly Time-Series Wizard and the ReadFromFile Wizard, monthly time step series data was uploaded and entered in WEAP directly or as a Comma Separated Value (CSV) format.

3.10.8 Hydrology Selection

To select hydrology attributes, one can either use historical flow analysis or the water year method. Historical flow analysis was chosen for this study because the method is suitable for when historical flow data is available. Therefore, historical flow from 2000 to 2015 was used in the simulation of scenarios. This was done based on the assumption that past hydrological patterns will be repeated in the future.

3.10.9 Catchment Simulation

For the purposes of this study, the Simple Rainfall-Runoff Coefficient simulation Method was employed. This method was chosen because of the availability of relatively continuous and complete climatic and land cover data necessary to calculate run-off. However, WEAP encompasses several catchment simulation processes. These processes consist of; Irrigation Demands Only Method, Simple Rainfall-Runoff coefficient method - Based on FAO crop Requirement - and Soil Moisture Method.

3.10.10 Land Use and Land Cover Classification

The intersection between sub-catchments and elevation bands constituted a WEAP catchment. The area of each catchment was calculated as well as the percentage of various land cover types within the catchment. The land cover dataset was acquired from the FAO (1998) Africover classification scheme and was reclassified from its original classification scheme into Forest, Tree Plantation, farmland and shrub-land categories in ArcGIS as shown in *Table 3.4*. This was then uploaded onto the WEAP model.

Table 3.4: Processed Land Cover Classification Simplified for the WEAP Model

Sub-catchment zone	Initial Land cover classification (FAO 1998 Africover)	Reclassification of land cover for WEAP
Upstream	Closed woody vegetation	Tree plantations
	Forest plantations	
	Tree plantations	
	Forest	Forest
Midstream	Herbaceous crops	Farmland
	Shrub crop	
Downstream	Shrub-land	Shrub-land
	Shrub savannah	
	Tree savannah	
	Grassland	

(Sources, FAO Africover, 1998)

Two datasets on the spatial evolution of the land cover area were used, one for the Upper Mara basin for the period 2002 - 2010, and another for the period 1990 – 1999. Both were derived from Landsat images of the United States Geological Survey Map explorer

(USGS). This latter was used to define initial land cover conditions hence the base year conditions. The former was used in simulating land use change and its impact on run-off. The sub-catchment area was split into three sub-portions, upper, mid and downstream portions; runoff from the land cover and rainfall was assessed and added. The initial step was to define the base hydrologic conditions within each portion of sub-catchment. Satellite data was used to determine the allocation of forest cover versus farm land cover and other land use. Then the area within each sub-portion was represented by an alphabetic letter such as A_1, A_2, A_3 or A_4 (Figure 3.2) and is defined in units of Km^2. These total areas were then used to calculate catchment runoff. The study however, did not calculate the difference in Run-off between the changes in land cover area in the period of 1995 versus 2010.

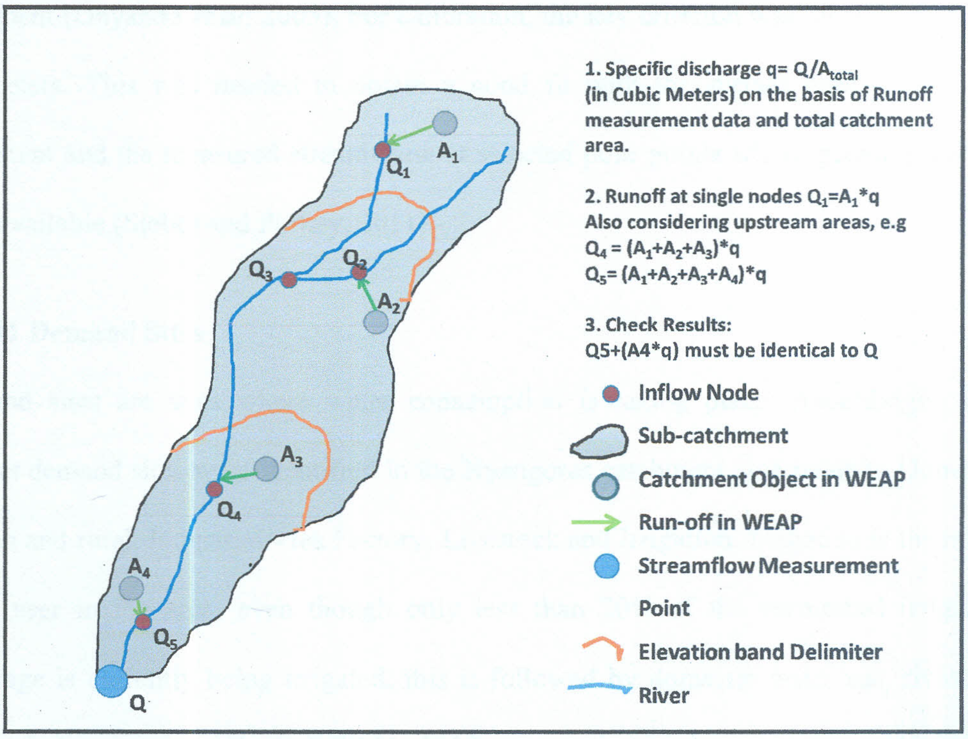

Figure 3.2: Sketch Illustrating Nyangores Sub-Catchment Portions and Elevation Bands

The land cover for the period 1995 was used to provide the baseline land cover area for the base study period in WEAP, which is year 2000. This was done because there is only a 5 year difference between 1995 and 2000, while there is a 10 year difference between year 2000 and 2010. The study assumed the relative land cover change within 5 years is relatively less than the overall land cover change in a 10 year period. However, catchment run-off projection was done using year 2010 land cover size. To determine Surface Runoff at the Sub-catchment Level, the volume of surface runoff within the sub-catchment was calculated for each monthly time step as the sum of the contribution of the runoff coming from the simulation of rainfall-runoff processes in all portions of the sub-catchment (Onyando *et al*, 2005). For calibration, the key criterion was the adjustment of parameters. This was needed to obtain a good fit with the surface area of the sub-catchment and the measured stream-flow at selected pour points where gauging stations were available (Sieber and Purkey, 2011).

3.10.11 Demand Sites

Demand sites are sites where water consumption is taking place. Accordingly, four distinct demand sites were identified in the Nyangores catchment area namely; Domestic - urban and rural, Industrial - tea Factory, Livestock and Irrigation. Irrigation is the major water user in the area, even though only less than 20% of the earmarked irrigation hectarage is currently being irrigated, this is followed by domestic water use, livestock and the Industry consecutively (NEMA, 2009).

3.10.12 Setting Priorities

For this study, demand site priorities in WEAP were set to first fulfill water requirements for Domestic water needs - priority 1, followed by Livestock water needs - priority 2, Irrigation needs, priority 3, and lastly Industrial water requirement, priority 4. Demand priority setting in WEAP assumes the absolute values 1 to 99 (Sieber and Purkey, 2013). WEAP will first allocate water to demand site with the demand priority 1 then 2 or greater. If 2 demand sites have the same priority, WEAP will endeavor to satisfy their water requirements equally. Absolute values have no significance for the priority levels only the relative order matters (Yates *et al.*, 2005).

3.10.13 Scenarios

In this study, scenarios were developed to compare water demand requirements for 30 years (2000-2030). The study considered the following six Scenarios;

3.10.14 Reference Scenario

Also known as the business as usual scenario, this was the base scenario that utilized real time data to help in understanding the best estimates about the studied period (Sieber and Purkey, 2013). The objective of the reference scenario was to help discern the likely occurrences if the current trend continues and to understand the real situation as it is. It sought to identify knowledge gaps in analyzing likely trends and where more information is required (Sieber and Purkey, 2011). The basic model built reflects the reference scenario, which replicates the real situation. The years 2000 – 2014 was used in the calibration of the model and 2015 – 2030 was used in the simulation of future water demand.

3.10.15 Higher Population Growth Rate Scenario, HPG

This scenario was developed to look at the possibility of a Higher Population Growth Rate. According to the national census 2009, the population growth rate for Bomet county is pegged at 2.8% per annum. However, envisioning a higher percentage growth rate of 5%, this scenario tried to cater for an unexpected rise in population which may well be due to among other factors, inter-county migrations leading to higher populations. It was hereby assumed that an increased population leads to increased domestic water use.

3.10.16 Increased Irrigation Area Scenario, IIA

This scenario was chosen for the study because the county government of Bomet, where the majority of the catchment falls, plans to increase the irrigated land area by 100 ha each year for six years, 2013 - 2018. This means adding 600 ha to the current 600 ha under irrigation, hence doubling the irrigated area. Irrigation expansion scenario was assumed because irrigation water demand increases with the increase in irrigated area.

3.10.17 Improved Water Efficiency/Conservation Scenario, IWC

The county government has plans to invest heavily in water harvesting infrastructure for institutions such as schools, colleges and health centers. There are plans to also rehabilitate existing water infrastructure to minimize water loss. This is expected to impact water demand by reducing river and ground-water abstraction (GoK, 2013). The study modelled the future consumption while taking into account 40% increased efficiency due to infrastructure development.

3.10.18 Dry Years Scenario

Using the average low monthly historical precipitation data, the DRY YEARS Scenario was projected. This scenario was informed by the recent climate variability situation which has led to low rainfall levels in the area in comparison to the previous decades.

3.10.19 Model Calibration and Validation

The model was calibrated using a latest base year account for which water accessibility and demand were derived (SEI, 2005). To calibrate the model, precipitation and stream-flow data from 2000-2005 were used to estimate model parameters. This information was gathered from WRMA, the Meteorological Department and Nyangores WRUA through group discussions and individual interviews conducted during the field work. The stability of these parameters were tested in the validation period of 2005 to 2010.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1: Water Sources:

A total of 46 major water sources were identified, mapped and quantified in the Nyangores catchment. These are subdivided as 30 springs, 9 Boreholes/well, 3 Reservoir, 3 water pans, 1 river and 2 streams. Majority of the dams and reservoirs, 90%, are located in the upstream while the rest are found midstream (Figure 4.1). This is because they were excavated in the upper region by the colonial government for irrigation purposes.

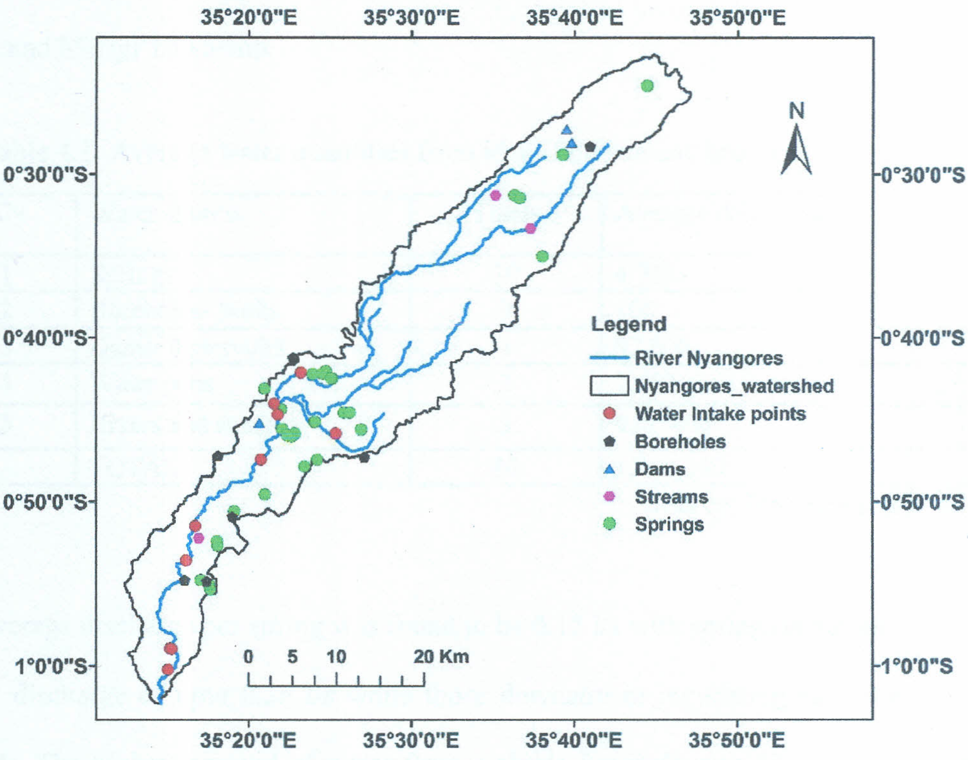

Figure 4.1: Location of Major Water Sources in Nyangores Sub-Catchment

The Upper catchment had 16% of the natural springs because water is often piped to the Tea Farm workers through the organized settlement areas. On the other hand 53% of the springs are located at the center of the catchment which can be attributed to the close proximity of the area to the forest as well as the hilly nature of the landscape which exposes the water holding rocks at frequent intervals. There was also a high population density in the mid-stream area at 578 persons/ Km^2 compared to 459 persons/ Km^2 and 355 persons/ Km^2 in the Upstream and Downstream areas respectively (KNBS, 2011). This high population density midstream can be attributed to the productive nature of the land in this section. This is further justified by the existence and concentration of major agricultural urban centers in the area such as Bomet town, Silibwet Township, Tenwek center and Merigi Township.

Table 4.1: Average water quantities from identified sub-catchment water sources

SN	Water source	Totals	Average daily Quantity M^3/day
1	Springs	30	4,752
2	Boreholes/ Wells	9	108
3	Dams/ Reservoirs	3	97,500
4	Water pans	3	7,500
5	Rivers and streams	3	950, 400
	TOTAL	46	1,060,260

Source; Fieldwork, 2014

The average discharge per spring was found to be 0.15 l/s with springs upstream having a higher discharge of upto 0.25 l/s while those downstream registering values as low as 0.04 l/s. The highest amount of water from a single borehole was 42 m^3/day while the lowest was 9 m^3/day. The largest reservoir was found to contain 97,500m^3/day, while the smallest water pan contained 125m^3/day. The river/stream water quantity was derived from the gauging station (1LA03), on average, the dry season flow values was as low as 1.74 m^3/s and wet season flow values was as high as 30m^3/s.

4.2: Water Sinks

A total of five major water demand sites or water sinks were identified within the catchment (Figure 4.2). These are Tea Factories, Irrigation water demand, Urban domestic water use and Rural domestic water use and Livestock populations water use.

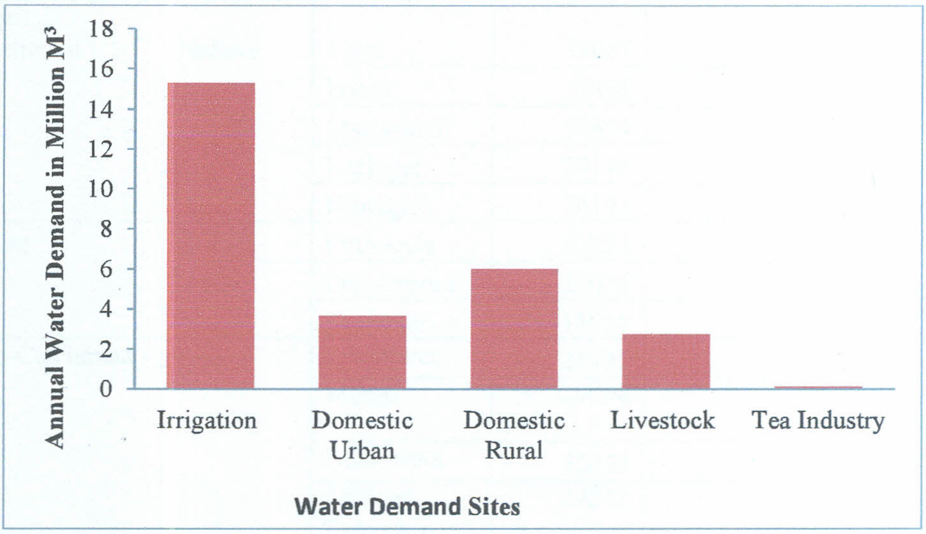

Figure 4.2: Major Water Demand Sites showing Current and Annual water demand.

4.2.1 Domestic Water Consumption

Domestic water consumption in the sub-catchment is driven by both rural and urban household consumption as well as consumption from hotels, schools, churches and offices. This consumption was found to be dependent on the population. Table 4.2 indicates an administrative breakdown of the sub-catchment demography necessary in arriving at the domestic water consumption in the sub-catchment.

Table 4.2: Administrative and Demographic distribution of Nyangores Catchment

Catchment	County	Wards	Population in Wards overlaying catchment boundaries	Population portion in catchment based on population density	%
Upper Catchment	Nakuru	Tinet	39007	19503	28%
		Nyota	39455	4932	
		Mariashoni	12454	2491	
		Keringet	29149	21862	
		Kiptagich	26193	19645	
Forest	Bomet	Embomos	33920	8480	50% (%)
	Narok	Olposimoru	20035	5008	
		Sagamian	15916	7958	
Mid-Catchment	Bomet	Singorwet	21795	7265	
		Merigi	29568	23654	
		Ndaraweta	22059	11029	
		Silibwet Township	27511	22009	
		Nyangores	35420	26565	
		Longisa	28365	7091	
		Kembu	26992	2699	
Lower Catchment	Bomet	Kongasis	29458	7364	22%
		Sigor	32818	16409	
		Chebunyo	34922	11640	
		Siongoroi	61116	20351	
		TOTAL	566153	245955	

(Source: Adapted from, KNBS, 2011)

4.2.2 Factory Water Consumption

The catchment has an evenly distributed number of tea factories, also considered as Industrial sinks considering the favorable agro-climatic and soil properties. There are four tea factories identified in the study area; Namely, Tirgaga, Kapkoros, Kiptagich and Stegro. However, Stegro is yet to commence proper operations. The factory water use is mainly for generating steam in the boilers, cooling and for cleaning purposes at the tea factories. An indication of the water consumption trend at one tea factory is depicted in Table 4.3.

Table 4.3: An industrial Sink, Tirgaga Tea Factory Water Consumption (2013-2014)

Tirgaga Tea Factory: Water Consumption (M^3)			
Month	Year 2013	Year 2014	Average Daily 2013-2014
Jan	2325	2331	75
Feb	2243	2492	85
Mar	2802	2852	91
April	2674	2520	86
May	2728	2883	90
June	2430	3006	91
July	2263	2998	85
Aug	1674	2564	68
Sept	2031	2595	77
Oct	2139	2759	79
Nov	2439	2934	90
Dec	1922	2834	77

(Source, Tirgaga Tea Factory, 2014)

The mean monthly figures showed that there is slightly higher daily water consumption values in the months of March ($91M^3$) and June ($91M^3$) as compared to a relatively low water consumption in the months of January ($75\ M^3$) and August ($68M^3$). The low water use in the month of January indicate reduced tea production due to reduced tea leaves available for picking in the dry months of December and January. However, the low figures in August coincide with the cold season in the area which reduces tea crop productivity. The daily water consumption figures for Tirgaga tea factory for the months of November and December for year 2014 are provided in *Appendix 2.*

4.2.3 Livestock Water Consumption

The total livestock population within the sub-catchment and their Tropical Livestock Units (TLU) indicate that Cattle population comprises 82.3% while camels comprise only 0.004% of the total livestock population (Table 4.4). These TLUs consume an average of 3 Mm^3 of water annually. Most of the livestock, 60%, were found to be in the downstream area of the catchment where they are an important source of livelihood.

Table 4.4: Catchment Livestock Population and their TLU Equivalent (2014).

Livestock type	**Population**	**Tropical Livestock Units (TLU)**	**%**
Cattle	210, 855	210,855	82.3
Shoats (goat and sheep)	135,456	27,091	10.5
Donkey	18, 363	18,363	7.2
Camel	5	11	0.004
Totals	**364, 679**	**256,320**	**100**

(Source, GoK, 2014)

4.3 Distribution of Water Sources in the Sub-Catchment

There is a high concentration, 75% of water sources around the mid and down-stream area, below an altitude of 2300 m (Figure 4.3). The sources in this area also show corresponding low discharge rates, an average of 0.15 litres per second. This could be a factor of a common aquifer whose water is being shared among several sources in the same area. On the other hand, in the upper catchment, at high altitude of 2700 m, there are few major water sources, 25%, but with relatively high water discharge rates, 0.30 l/s. This can be attributed to the topography in the midstream area which highly fluctuates. There is also minimal disturbance and degradation around the water sources upstream as opposed to the other zones hence the high water discharge rates. This is due to factors such as, low numbers of livestock as captured in the Bomet County Fiscal Strategy

Investment Plan (GoK, 2014), which are not enough to degrade and compact the catchment area hence allowing water to flow unabated. The attributes for the water discharge for all the water sources can be found in *Appendix 3*.

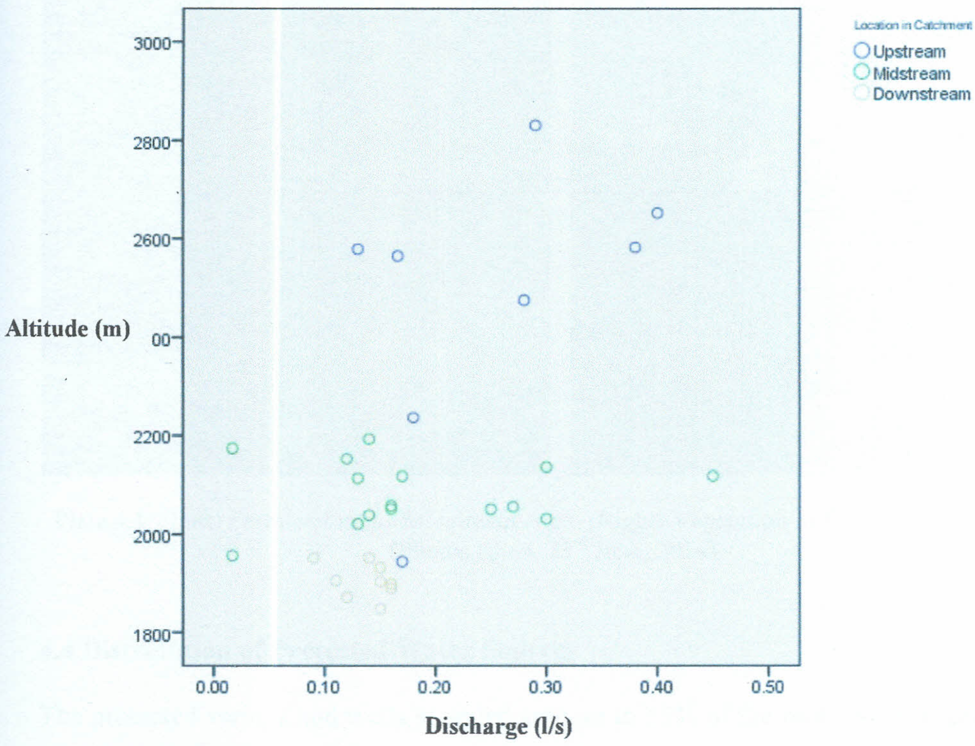

Figure 4.3: Scatter-plot Showing water source Discharge Vs Altitude

According to the report *Exploring Kenyas' Inequality* (KNBS and SID, 2013), the Kenya Bureau of statistics shows that 24% of Bomet county residents use improved water sources such as protected springs, protected wells, boreholes, piped water and rain water collection. While 76% use unimproved sources such as ponds, dam, stream/river, unprotected spring / well and water vendors. In *Plate 4.1* part of the terrain and vegetation is shown that necessitates the availability of diverse sources of water in the sub-catchment. The population in the farmland, which is 50% of the total sub-catchment population, mostly uses spring water and river water while those in shrub-land area uses water pans, river water and boreholes.

Plate 4.1: (Left) Farmland in the Midstream Area; (Right) Vegetation in the Downstream Area, (Photos taken, 23rd June, 2014).

4.4 Distribution of Protected Water Sources

The protected springs and wells sampled amount to 53% of the protected sources, that is, a cement structure, a pipe and or tap has been set up to allow ease of water collection as well as eliminate contamination. On the other hand, 47% springs/wells are not protected. This indicates that there is a gradual effort by various agencies, mostly non-governmental organizations and WRMA in the area to secure major water sources from contamination and increase rate of flow.

4.4: Water Intake and Supply Points

A total of 8 major water intake points were identified in the mid and downstream areas of the sub-catchment. It was noted that none of these sources was based upstream. This can be attributed to the consistent need to provide water downstream because there is a relative lack of water resources or unreliability of available sources in the downstream area other than the Nyangores River. The downstream area is characterized by low erratic annual rainfall of 500 mm to 750 mm; high temperature ranges of 14° to 34° Celsius, and this exhibits in the scattered, thorny and woody vegetation common in the area (Krhoda, 2001)

Table 4.5: Major Water Intake Points along River Nyangores

Code	Water supply station	Latitude	Longitude	Design Capacity (m^3/s)	Current Daily Production (m^3/s)
1	KABOSON MISSION HOSP. INTAKE	-1.00357	35.25147	500	445.5
2	KABOSON/CHEBARAA IRRIGATION	-0.98264	35.25533	44697	3300
3	MOGOMBET COMMUNITY WS	-0.73299	35.3602	1300	1300
3	OLBUTYO WATER SUPPLY	-0.85782	35.27924	1200	800
4	STEGRO TEA FACTORY SUPPLY	-0.76367	35.423	110	100
5	KAPCHELUCH COMMUNITY WATER	-0.70174	35.38725	180	70.5
6	TENWEK MISSION HOSPITAL	-0.753	35.345	150	118
7	BOMET WATER SUPPLY & TREATMENT	-0.701	35.353	1200	700
8	CHEPALUNGU WATER SUPPLY	-0.85396	35.2779	1200	600

Source: Fieldwork, 2014

Additionally, the 8 major urban centers and 18 institutions are located in mid and downstream areas. It is also where the bulk of the population resides relative to the rest of the catchment. At altitude of 2300 m and below, there is an increase in dry conditions hence serious need to supplement water requirements by pumping river water to institutions and Urban Centres (Figure 4.4). All the intake points are located mid-stream and downstream and abstracting their water from the River Nyangores and its tributaries. Some of the Institutions that require major water supply include Tenwek Hospital, Tenwek Secondary School, Sigor Secondary School, Kaboson Mission Hospital, Kaboson Girls and Sigor Sub-County offices. The Chebaraa-Kaboson Irrigation scheme also has its intake at Kaboson area.

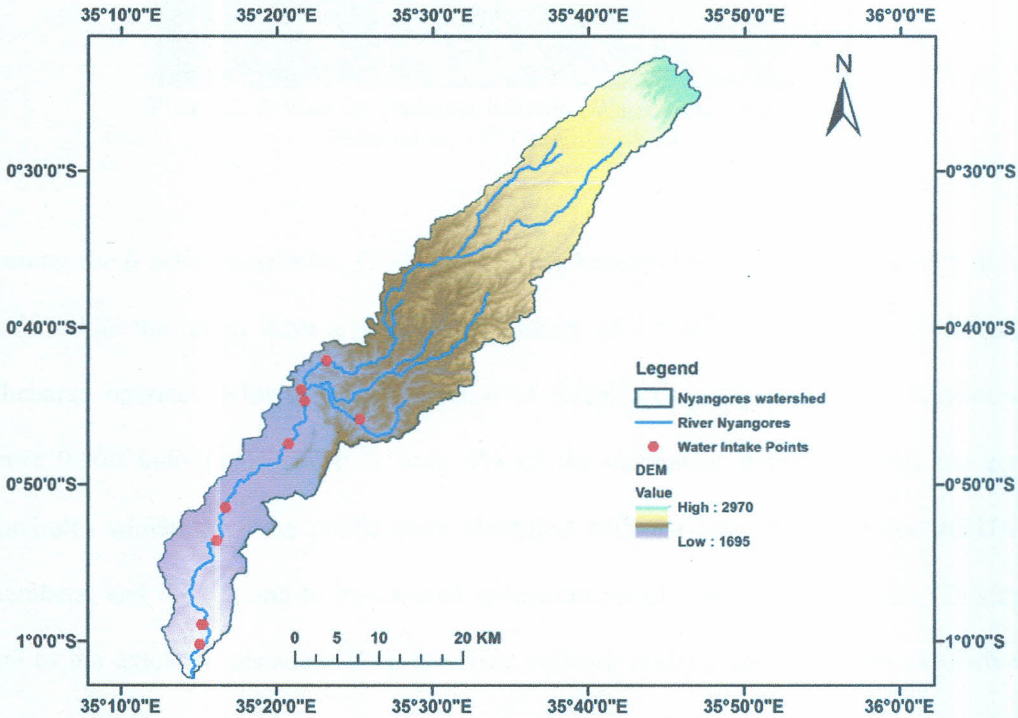

Figure 4.4: Location of Major Water Intake Points

Plate 4.2: A Weir for Chebaraa Irrigation Water Intake at Kaboson
Photo taken, 17th December 2014

Among the 6 active boreholes, Chebaraa and Kapkesosio have the largest capacity at 3 m^3/hr while the others have a production capacity of 1.5 m^3/hr (Table 4.6). However, Chebaraa operates below capacity because of dilapidated equipment. The boreholes serve 9,500 individuals which is only 4% of the catchment population. All the six boreholes which serve the public were identified with the help of Nyangores WRUA members, and were found to be situated at institutions of learning or churches. This is due to the extended distances from the river network making abstraction an expensive exercise. Sinking and maintenance of boreholes is also a relatively affordable exercise for most institutions.

Table 4.6: Groundwater Use Situation; Borehole Attributes

Code	Borehole	Depth (m)	Capacity (Cubic Meters/Hr)	Hrs of operation	Year Established	Target Population
1	Itembe Borehole	130	1.5	8hrs	2011	600
2	Tegat Borehole	150	1.5	8hrs	2014	5000
3	Ndaraweta Borehole	200	2	6hrs	1972	800
4	Chebaraa Borehole	142	3	<2hrs	1945	1200
5	Kapkesosio Borehole	180	3	<2hrs	2014	1000
6	Sigor School	150	1.5	8hrs	1990's	900

Source; Fieldwork, 2014

4.3: Spring Water Quality

The Water sources sampled for water quality were springs and they revealed a positive correlation coefficient (0.78) between altitude and water quality. Most of the springs sampled were mid-stream as this is the area with the highest number of spring water users (Figure 4.5). However a complete water quality attribute table is provided in *Appendix 3*

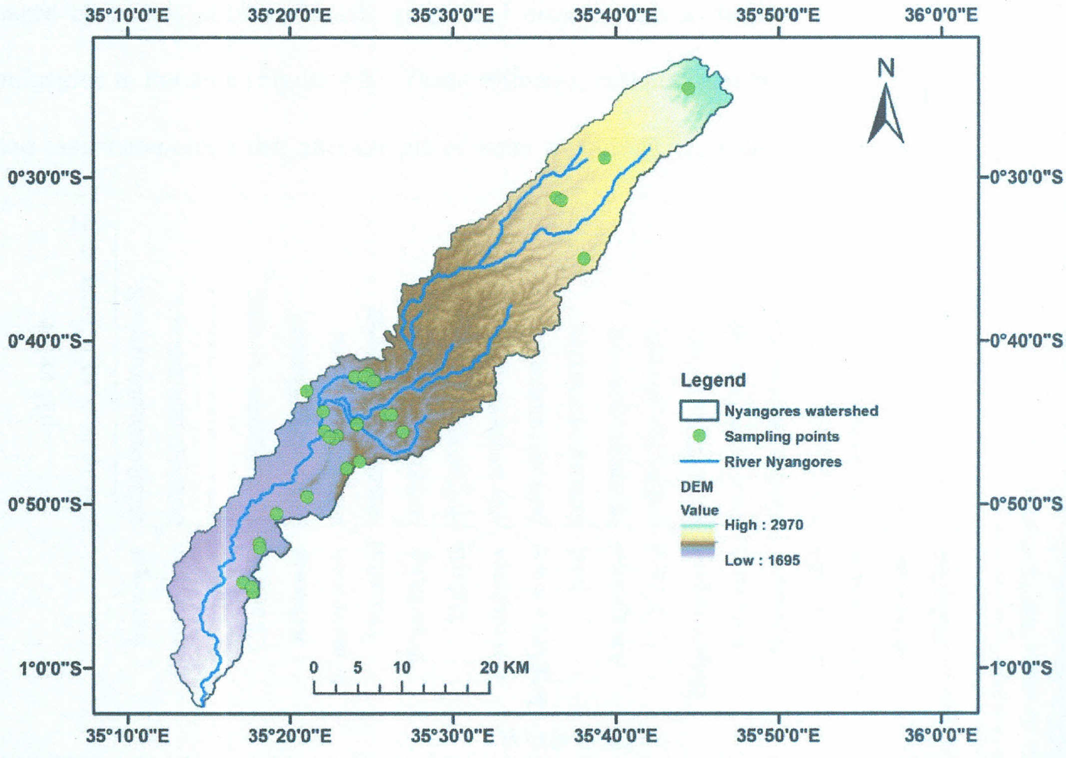

Figure 4.5: Spatial location of the water quality sampling points.

4.3.1 pH Analysis

Altitude decreases from 2800 m.a.s.l at Bararget forest to 1731 m.a.s.l at Kaboson (*Appendix 3*), the pH becomes more erratic and goes below pH 6.5 at Olbutyo and above pH 8.5 at Itembe (Figure 4.6). These values are beyond the pH (6.5 – 8.5) allowable zone for drinking water sources in Kenya (GoK, 2006). The high pH at Itembe maybe attributed to presence of soil minerals in the area that produce sodium carbonate (Na_2CO_3) and sodium bicarbonate (Na_2HCO_3) upon weathering thereby contributing to the high alkaline levels. While the low pH and the fluctuating values could be attributed to the use of various farm based inputs such as fertilizer, pesticides, herbicides and home based chemicals such as bleach, soaps and disinfectants as well as effluents from tea industries in the area (Figure 4.6). These effluents, residues and wastes contribute acidic and basic compounds that alter the pH of water as altitude decreases in the catchment.

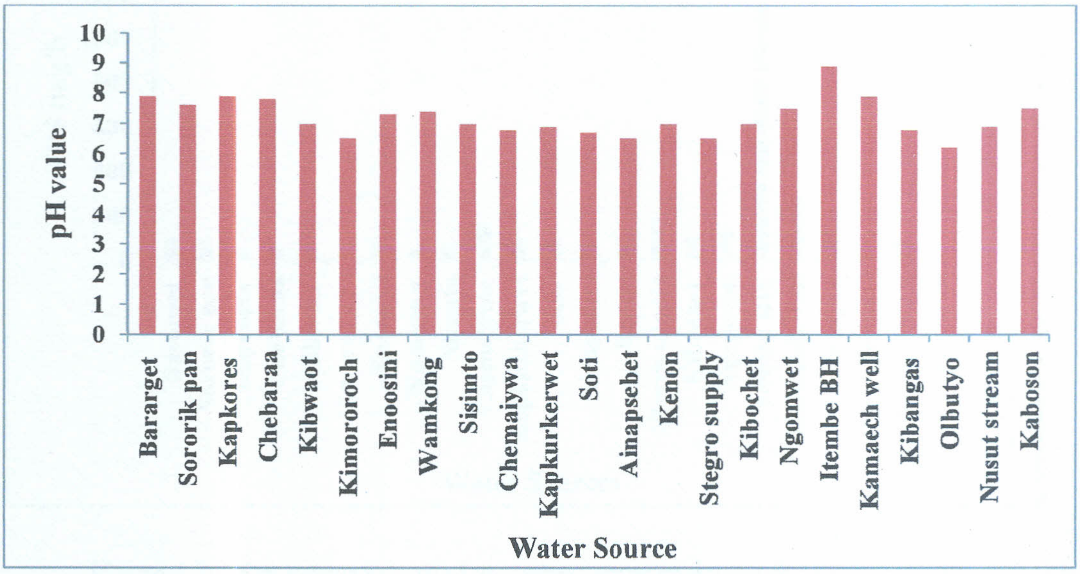

Figure 4.6: Mean pH at various sources recorded during the study period (February 2014 to January 2015)

4.3.2 Total Dissolved Solids

The Total Dissolved Solids trend in the catchment indicate an increase from 50 mg/L at Kapkores (2582m) to 250 mg/L at Kibangas (1800m) with the reducing altitude (Figure 4.7). This can be attributed to soil erosion, the accumulation of fertilizers, domestic waste, industrial effluents, animal wastes and other pollutants as the river courses downstream.

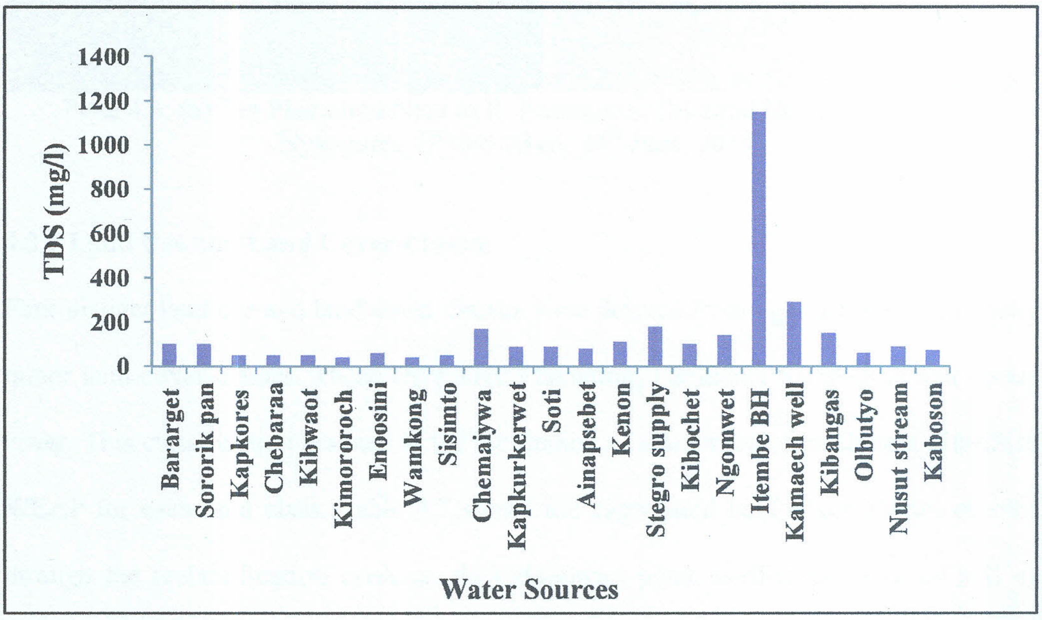

Figure 4.7: TDS values recorded at various sources during the study period (February 2014 – January 2015)

The recommended distance between farm and river is 15 m (GoK, 1999). However, this is not observed in some parts of the catchment such as near Kenon point (plate 4.3). Sand, rock and ballast harvesting is also a common phenomenon around the mid and downstream areas of Tenwek, Olbutyo and Kaboson areas (Plate 4.3). These activities contribute to increased TDS values as altitude decreases.

(a) (b)

Plate 4.3: (a) Tea Plantation Next to R. Nyangores, (b) Sand harvesting Near R. Nyangores. (Photo taken; 14th June, 2014)

4.3.3 Land Use and Land Cover Classes

Four distinct land use and land cover classes were derived from aggregation of the many minor land cover classes. These were Tree Plantation, Farmland, Shrub-land and Forest cover. This classification assisted in the facilitation of simulation of catchment run-off in WEAP for each land class. Table 4.7 shows the aggregated land cover classes derived through the reclassification exercise, their dominant plant coefficient value as well as average rainfall in each land class type. According to the FAO irrigation and Drainage Paper 56, the land class with the highest crop Coefficient (Kc) value was Farmland, at Kc 1.04 due to the increasing population in need of settlement and farm land for subsistence farming (FAO, 1998). While the least was shrub-land at Kc 0.3 which can be attributed to the scattered and limited vegetation cover interspersed with relatively dry pastureland.

Table 4.7: Aggregated Sub-Catchment Land Cover Classes and their sizes.

SN	Land Cover Type	Area (Sq. Km)	Kc Value	Average Monthly Rainfall
1	Forest	261.5	0.9	112.3
2	Farmland	280.4	1.04	110.4
3	Tree Plantation	199.2	0.9	98.3
4	Shrub-land	191.9	0.3	94.8

(Source, Adapted from FAO Irrigation and Drainage Paper 56, 1998)

Percentage land cover change shows that the largest change between 1995 and 2010 was Forest Plantation cover which reduced by 45% while the greatest increase was Forest cover at 29% over the same period (Table 4.8).

Table 4.8: Percentage Land cover change, 1995 – 2010

SN	Land Cover	Area 1995 (Km^2)	Area 2010 (Km^2)	Percentage Change in Cover
1	Forest	261.5	269.8	3%
2	Forest Plantation	199.2	90.9	-45%
3	Farmland	280.4	362.2	29%
4	Shrub-land	191.9	210.2	9%

(Source, Author 2015)

Kilonzo (2014) found out that the major land use/covers in the Nyangores River Basin include closed forest, tea in the upper mountain slopes, and agricultural land. Data for the entire Mara River Basin indicate that, by year 2000, the rangelands/ Shrub-land had been reduced by 24% to only 7,245 Square Kilometres due to encroachment by agriculture, whose area has increased by 55%. Similarly, work done by Kiragu (2009) show that except for the water body, all the other land use/covers have undergone change in the last 15 years. The natural vegetation has been declining as closed forests reduced by 23% due to forest clearing for tea and/or as timber harvests, which have increased opened land by 82% (Figure 4.8)

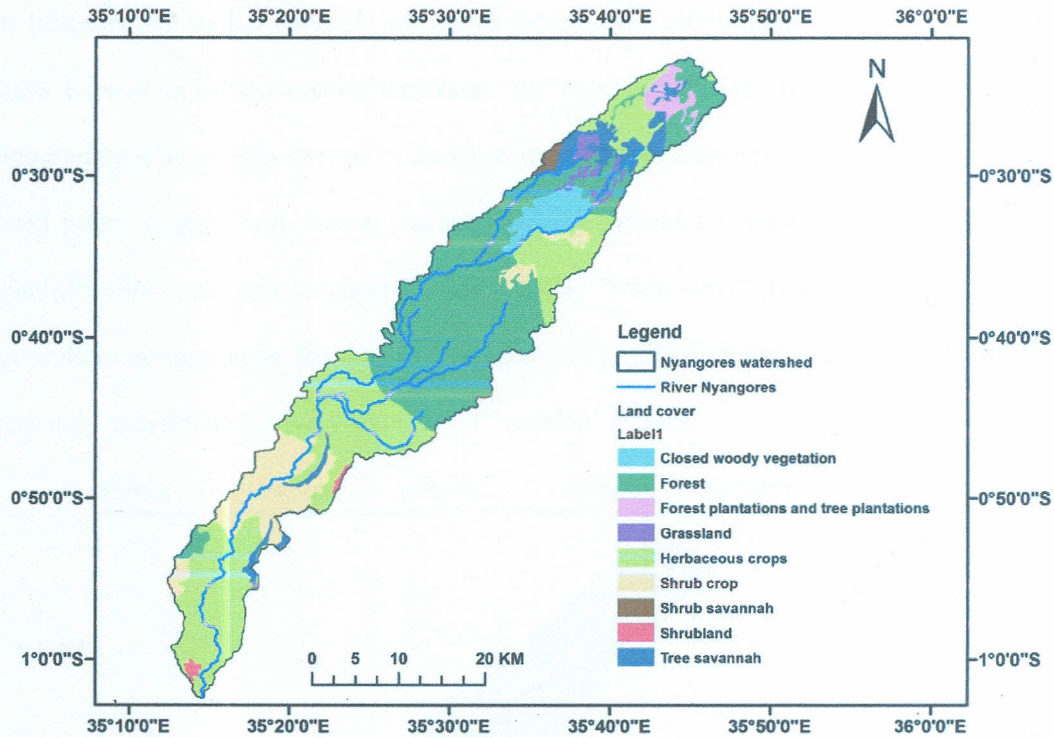

Figure 4.8: FAO Land Cover Map for Nyangores Sub-catchment

(Source; Ngeno, 2015: Waveren, 1995)

4.3.4 Soil Cover Classes

According to Krhoda (2001), the local geology, topography and rainfall determine the types and distribution of soils for the Nyangores sub-catchment. The soils fit into three broad categories, namely, the mountains, plains and swamps. The mountains have rich volcanic soils suitable for intensive agricultural production including wheat, barley and zero grazing. The soils include the shallow but well-drained dark-brown volcanic soils

Ando-calcaric and Humic-nitosols) found on mountains and escarpments. On the hills and minor escarpments, shallow and excessively drained dark-reddish brown soils such as lithosols and mollic andosols are found (Mati *et al*, 2008). These soils are prone to sheet erosion and mass wasting processes and have never been cultivated before. The imperfectly drained grey-brown to dark-brown soils are found on the plateaus and high level plains (Figure 4.9). These plateaux and high plains are imperfectly drained and conducive for grass and sorghum (Krhoda, 2001). While developing the suitability for agriculture nomenclature for the area, Jaetzold *et al.,* (2006) found that the soils within the study area fall under "very suitable" or "suitable" classes.

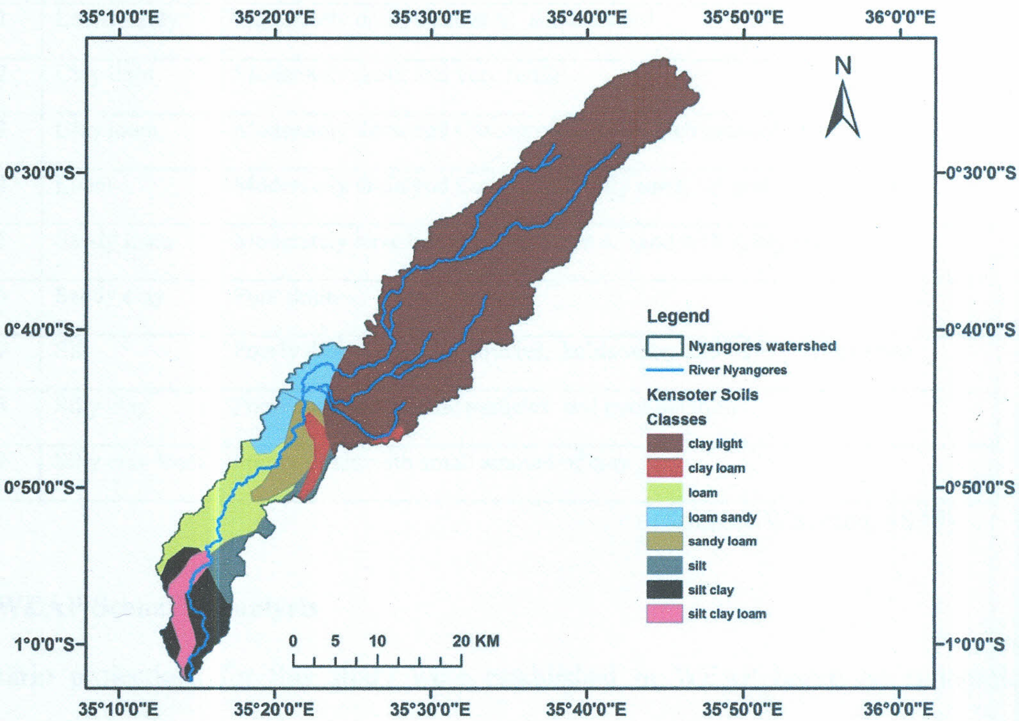

Figure 4.9: A Map of classified KENSOTER Soil Classes
(Source; Ng'eno 2015; Waveren, 1995)

The downstream area was found to have silt clay loam soils as well as silt clay soil properties which poorly drains and hence stagnant ponds and pools of water were a common water source for animals. The mid and upper catchment areas have clay light soils which are moderately drained and fertile. This is the area that is covered with dense Mau forest and tea plantations as land use options. The Kensoter soil classification system in figure 4.9 is further elaborated in Table 4.9.

Table 4.9: KENSOTER Soil Classification

SN	Soil type	Description
1	Loam sandy	Moderately drain Consist of silt and sand
2	Clay light	Moderately drain and very fertile
3	Clay loam	Moderately drain and Consist of clay and high amount of silt
4	Loam	Moderately drain and Consist of mostly sand, silt and small amount of clay
5	Sandy loam	Moderately have high concentration of sand with gritty feel
6	Sandy clay	Poor drain
7	Silt	Poorly drain with fine particles, holds water and have poor aeration
8	Silty clay	Poorly drain with fine particles and poor aeration
9	Silty clay loam	Poorly drain with small amount of clay

(Source; Waveren, 1995)

4.4 WEAP Scenario Analysis

Scenario projections for this study were established in WEAP based on economic, demographic, hydrological, and technological trends starting from a "reference" or "business-as-usual" point. For example, it was observed that increasing human and livestock populations, caused a significant increase in water demand and hence an increase in unmet water demand if no appropriate measures are put in place to offset the effect. Six different scenarios were constructed reflecting alternative paths for future water resources development in the area. These scenarios included Improved Water Conservation (IWC), Higher Population Growth Rate scenario (HPG), Irrigation expansion scenario (IIA), DRY YEARS Scenario, Land Use and Land Cover Change scenario (LULCC) (Table 4.10).

Table 4.10: Selected Scenarios for WEAP study

Scenario	Abbreviation for WEAP	Objective	Informing policy
Reference	Ref	To Provide trend based on current situation	Current water demand and supply situation
Increased Irrigation Area	IIA	To simulate conditions of Increased food security in the County by increasing Irrigation area by 100Ha each year	The Bomet County Strategic Investment plan (2013-2018)
Improved Water Conservati on	IWC	Determine Improved Water Use Efficiency and Water Supply Network Efficiency conditions	Bomet County Strategic Investment Plan (2013-2018)
Higher Population Growth Rate	HPG	To project a higher population growth rate based on the Upper Average National Rate of 5% p.a.	Based on the Upper Average National population growth rate, census 2009
Land Use change	LULCC	Simulate a scenario that incorporates changes in land use and land use practices	Based on land use and land cover change trends of 1995-2010
Dry Years	DRY YEARS	To depict a worst case scenario in precipitation/stream-flow values	Based on low historical precipitation and stream flow values

(Source; Author, 2015)

4.4.1: Model Calibration and Validation Results

Hydrological calibration and validation was achieved by comparing the simulated and observed monthly flows for the gauging station at Bomet (ILA03) (Figure 4.11). The calibration parameters were River length, catchment area measured in ArcGIS 10.3, annual precipitation for Bomet weather station. The regression coefficient (R^2) 0.78 was obtained during calibration between Observed and Simulated flows and a regression coefficient of (R^2) 0.81 for the validation period (Table 4.11).

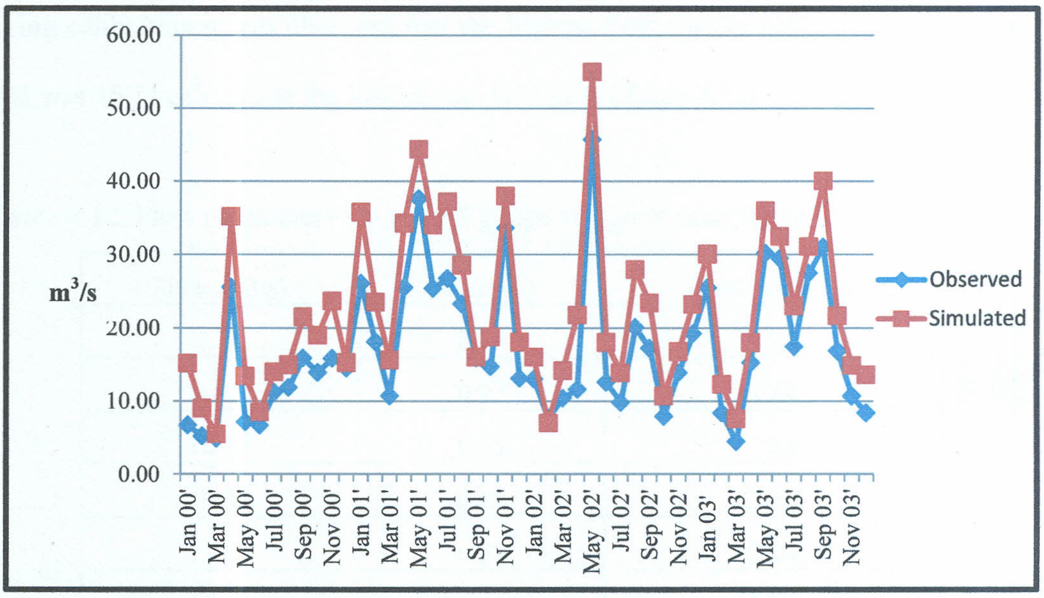

Figure 4.10: Observed and Simulated Stream flow for Nyangores River

Table 4.11; Observed and simulated Stream-flow during calibration and validation

Observed and Simulated Streamflow During Calibration					
Period	R. Gauging station	River	Mean flow m^3/s		Regression Coefficient (R^2)
			Observed	Simulated	
2000-2005	1LA03	Nyangores	7.31	10.33	0.78
Observed and Simulated Streamflow During Validation					
Period	R. Gauging Station	River	Mean flow m^3/s		Regression Coefficient (R^2)
			Observed	Simulated	
2006-2010	1LA03	Nyangores	11.10	11.55	0.81

During calibration it was observed that the highest flow for the calibration period 2000-2005 was 15.14 m^3/s while the lowest was 1.74 m^3/s (Table 4.12).

Table 4.12: Flow parameters for 1LA03 gauge at Bomet used for calibration of WEAP

Flow (m3/s)	Stage (m)	River width (m)
1.74	0.29	14.4
2.98	0.37	19.4
10.15	0.55	20.8
10.99	0.58	20.95
13.54	0.67	22.4
15.14	0.71	23.6

4.5 Water Demand

For the ease of presenting the water demand scenarios using the Weap Model, both urban and rural domestic water demand were quantified separately then combined under each section of the catchment into three main sites; *Kiptagich* to represent domestic upstream consumption, *Bomet* for the mid-catchment and *Chepalungu* for downstream domestic consumption. This was done because the domestic demand for urban consumption was found to be scattered into several but smaller urban centers across the sub-catchment with negligible demand figures that could be aggregated without undermining the allocation equation.

4.5.1 Reference Scenario

In the period leading upto 2030, the total water demand for year 2025 is expected to be 37.9 million cubic meters (mM^3). The largest share of this demand is expected to be consumed by Domestic demand, 37.8 mM^3, followed by Irrigation at 13.4 mM^3. Specifically, domestic water consumption at Bomet town and environs, with the current population growth is expected to be 10.2 mM^3, for Chepalungu and environs 4.3 mM^3, Kiptagich and environs 5.3 mM^3 while Livestock consumption shall stand at 4.6 mM^3. While, the lowest consumption is expected to be that of the industrial water use, 0.1 mM^3. By the year 2030, total domestic water consumption will stand at 44.2 mM^3 while irrigation shall have the second largest share of 15.3 mM^3. Under the current national population growth rate of 2.8% p.a., the population growth is expected to raise the total annual demand from the current 27.2 mM^3 per year to 44.3 mM^3 by 2030, a 61.4% increase in consumption (Figure 4.11).

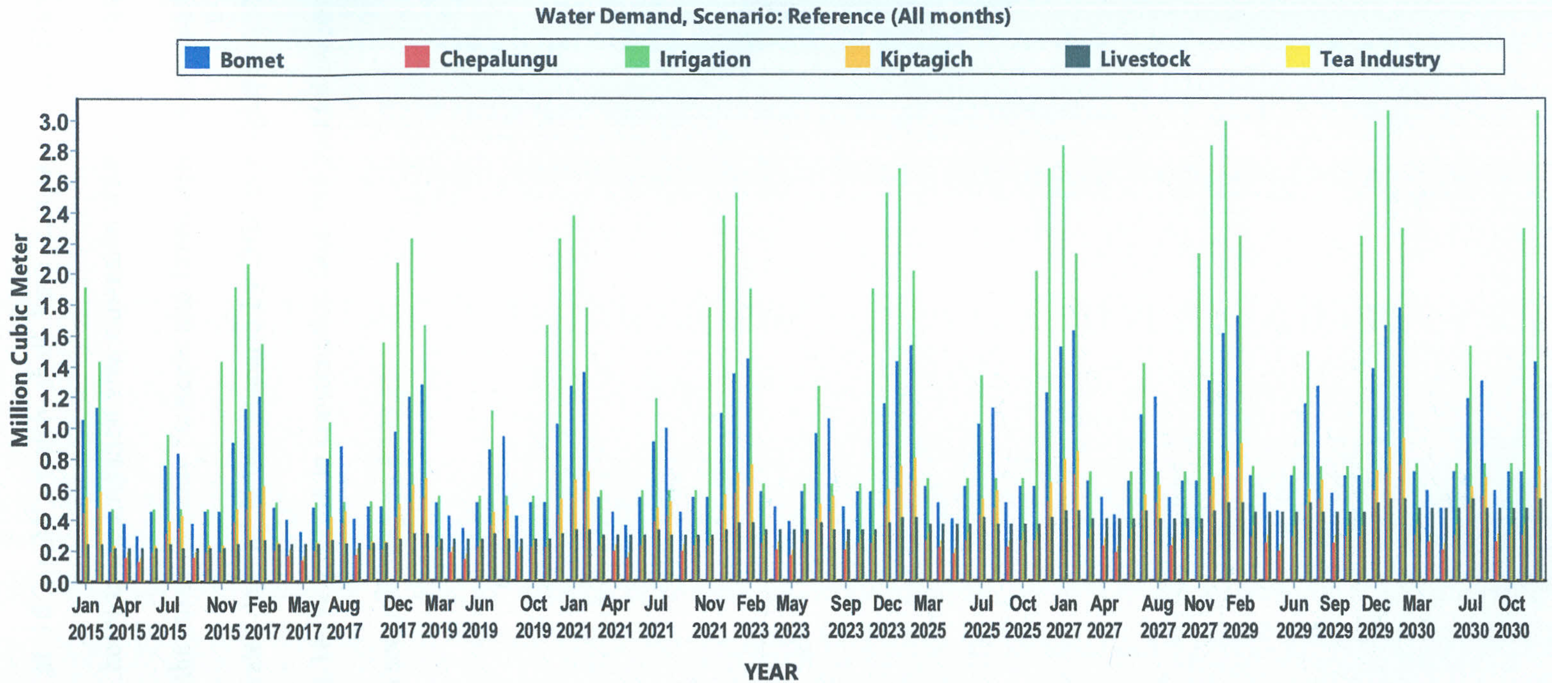

Figure 4.11: Water Demand Scenario, Reference (All Months)

4.5.2: Water Demand Scenario, Higher Population Growth

Under the Higher Population Growth Scenario (HPG) of 5% p.a., the model projects Bomet water consumption at 2030 shall be 34 mM^3, followed by Kiptagich (Upstream) domestic water demand at 16.2 mM^3, which shall have surpassed irrigation water requirement, at 15.3mM^3, because the irrigation area expansion would have stagnated at year 2018 as proposed in the Bomet County Strategic and Investment Development Plan (GoK, 2013). The total water demand in this scenario by 2030 is projected to be 86.5 mM^3. This is a significant 184% increase in consumption from the current demand 30.4 mM^3 under the same HPG scenario (Figure 4.12).

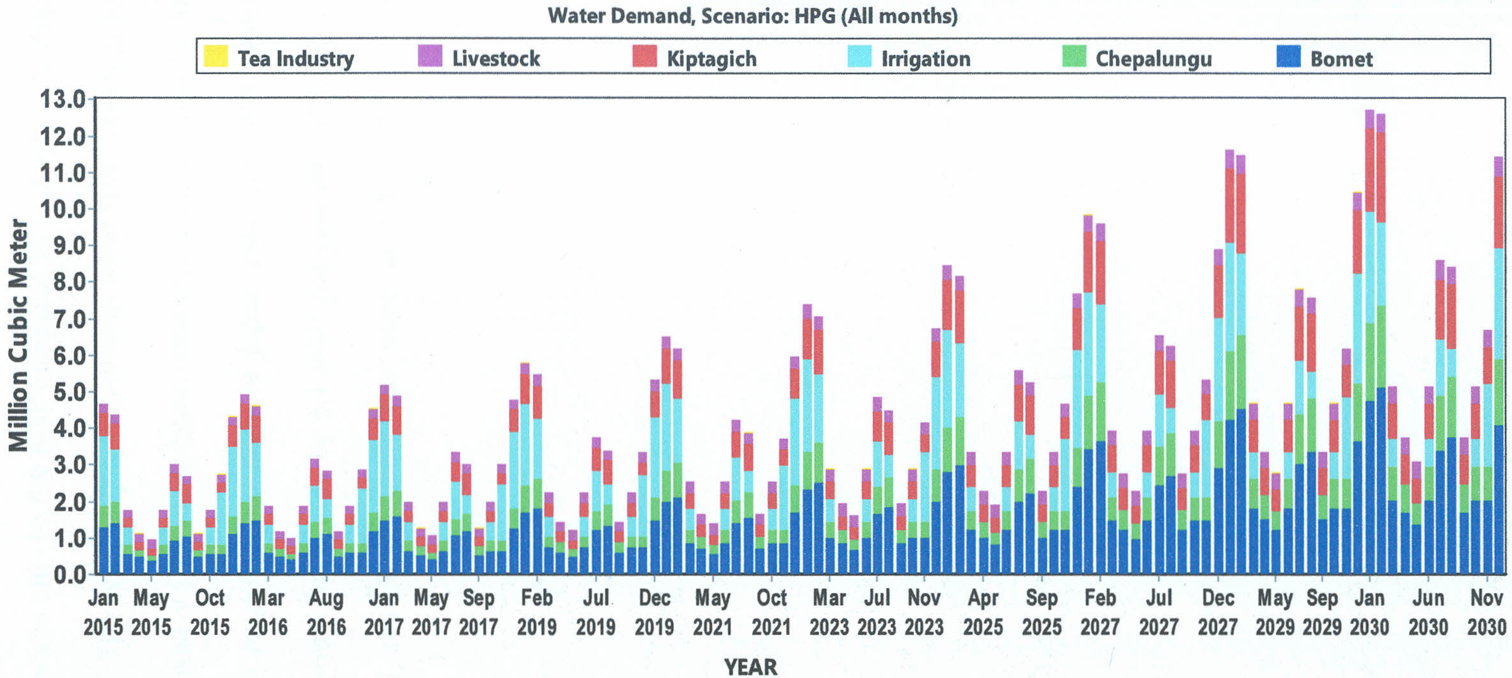

Figure 4.12: Water Demand, Scenario: HPG

4.5.3 Water Demand, Scenario: Improved Water Conservation

The introduction of water conservation measures, IWC, would greatly reduce the overall water requirements per year. For instance, by year 2030, the annual domestic water demand for Bomet town would only be 9.9 mM^3 compared to 11.8 mM^3 observed in the business as usual scenario. This is actually a 19% drop in water loss/ consumption due to the introduction of improved water conservation measures such as reduced leakages, automatic taps as well as proper maintenance of piped water networks. Specifically, irrigation water demand would be reduced by 6.1 mM^3 per year by 2030, and livestock water consumption shall remain relatively the same at 5.9 mM^3 (Figure 4.13)

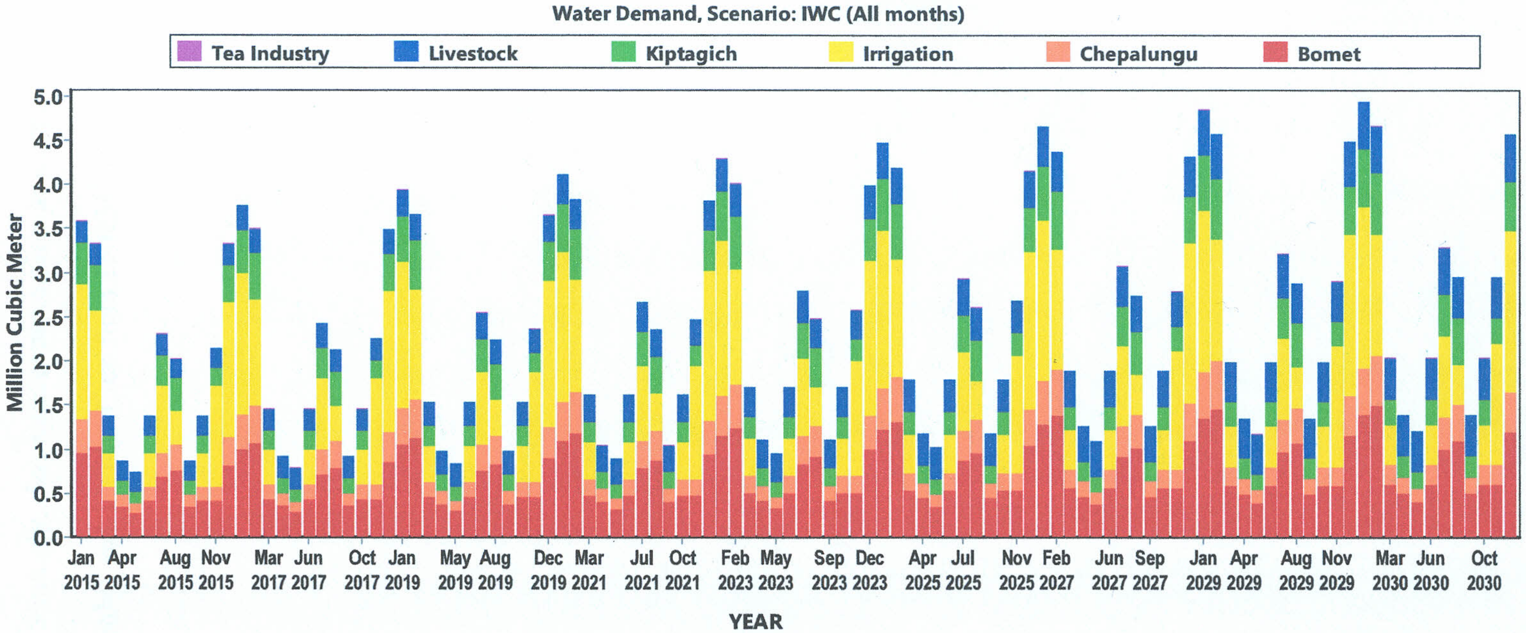

Figure 4.13: Water Demand under Improved Water Conservation

4.5.4 Water Demand, HPG Relative to IWC

The comparison of Bomet domestic water consumption under HPG scenario with IWC scenario registers a reduced water demand value of 24.1 mM^3, by year 2030 compared to 34 mM3 without IWC. Similarly, domestic consumption at Chepalungu and Kiptagich areas is reduced to 11.2 mM^3 and 11.5 mM^3 up from 15 mM^3 and 16.2 mM^3 respectively (Figure 4.14)

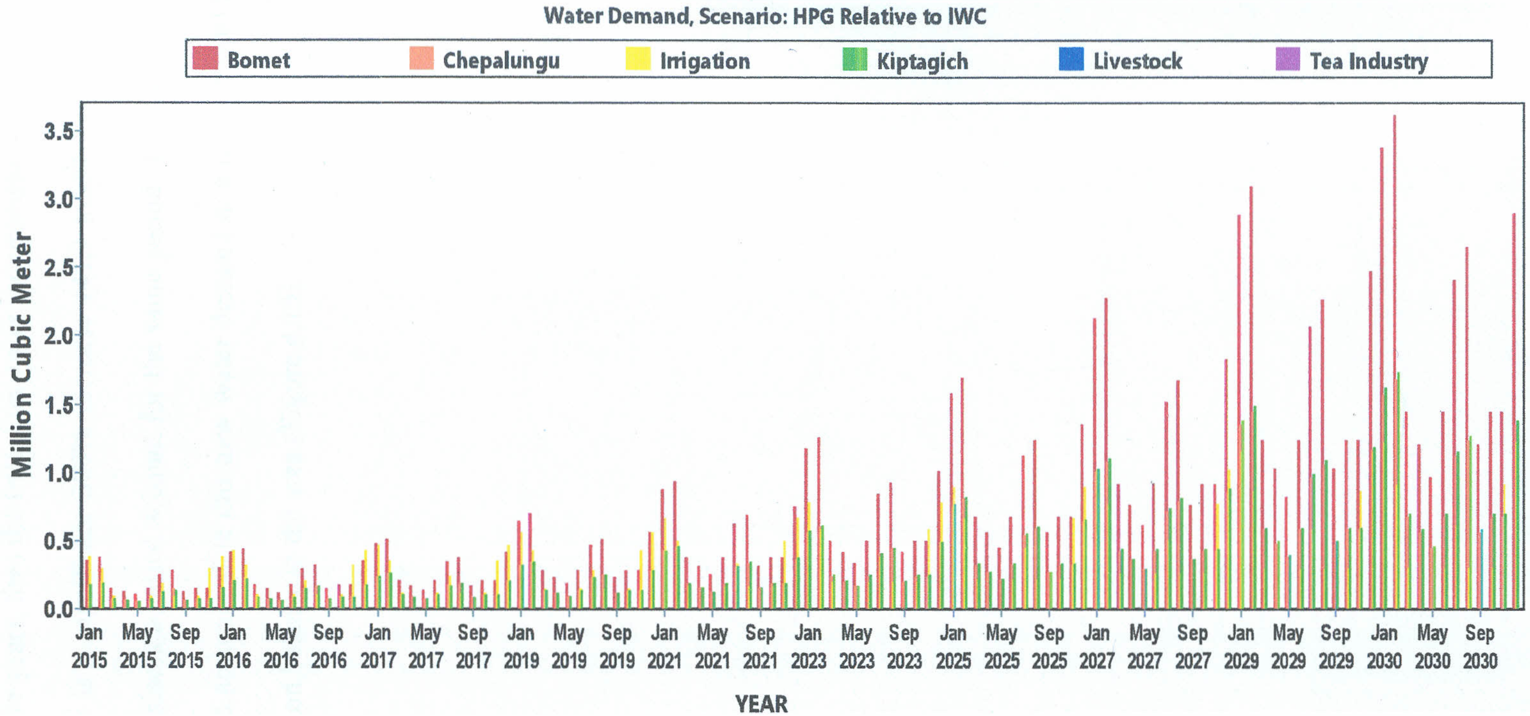

Figure 4.14: Water Demand, Scenario: HPG Relative to IWC

4.5.5 Water Demand, Scenario Increased Irrigation Area

If the county government goes ahead with its plan to increase irrigation area by 100 ha per year for the next five years, then the irrigation water requirement by 2030 is projected to be 61.2 mM^3. This is a significant 300% increase (45.9 mM^3) from the 15.3mM^3 projected under the business as usual account for the same period. This means measures must be put in place to accommodate this new water demand in a manner that does not upset the water allocation balance in the area (Figure 4.15).

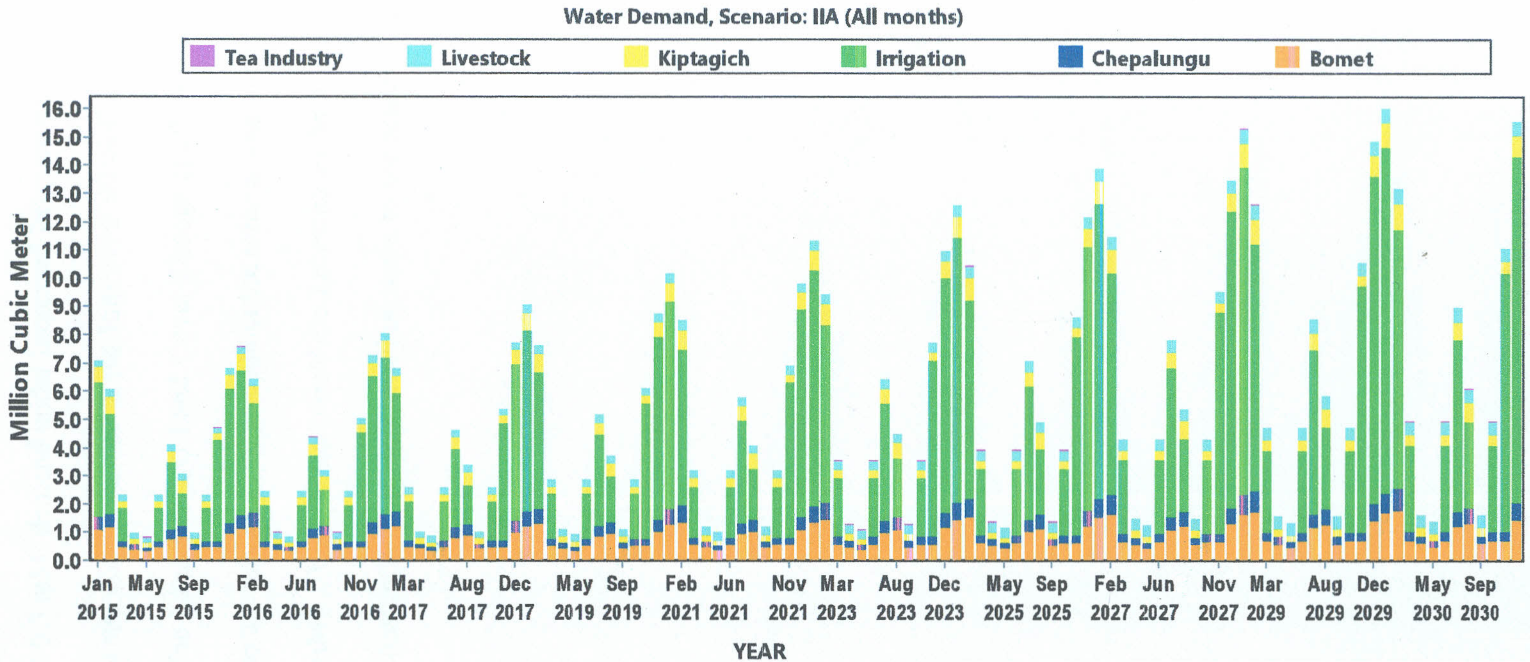

Figure 4.15: Water Demand, Scenario: IIA

4.5.6 Water Demand, All Scenarios

This scenario drew comparisons between all scenarios. The annual water demand projection for year 2030 with a Higher Population Growth rate scenario (HPG) is 86.5 mM^3 compared to the 90.3 mM^3 demand under Increased Irrigated area (IIA). In the same period the amount of water consumed due to the Improved Water Conservation practices (IWC) is 33.5 mM^3. The Land Use and Land Cover Change (LULCC) scenario and the DRY YEARS scenarios are projected to have about the same amount of demand which is expected to be 44.4 mM^3. These values could be necessitated by the reduced run-off hence reduced water consumption as well as adjustments to the scarcity periods (Figure 4.16).

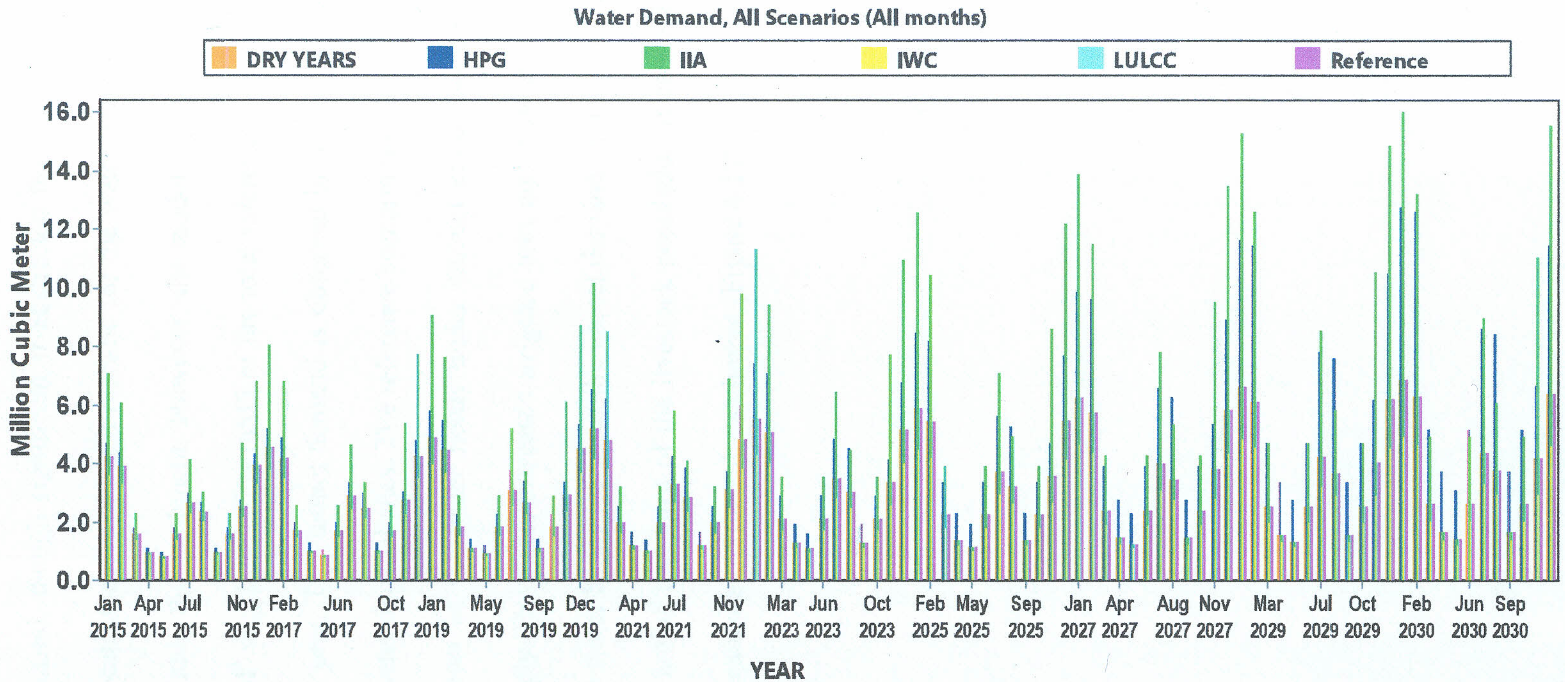

Figure 4.16: Water demand under All Scenarios

4.6 Unmet Demand;

4.6.1 Reference Scenario

The domestic unmet demand for the reference scenario is not registered by the model because the domestic demand, though significant if abstracted from a single point, is hereby spread across the catchment, making it realistic for the water needs to be met in portions by the supply within the catchment. However, the model registers total unmet figure for 2030 at 8.1 mM^3 which is 18.2% mM3 of the total reference scenario demand (44.3 mM^3) for the same year. This unmet demand is observed in irrigation (5.4 mM^3) and livestock (2.7mM^3) water demand sites. The reference scenario unmet water demand status by 2030 means most of the water needs under current circumstances will be covered by available supply. However, increased irrigated area and increasing livestock population demands more water hence increases the unmet demand overtime for the two demand sites. It is worth noting that most of the livestock population is concentrated in the Shrub-land or downstream area of the sub-catchment (Figure 4.17).

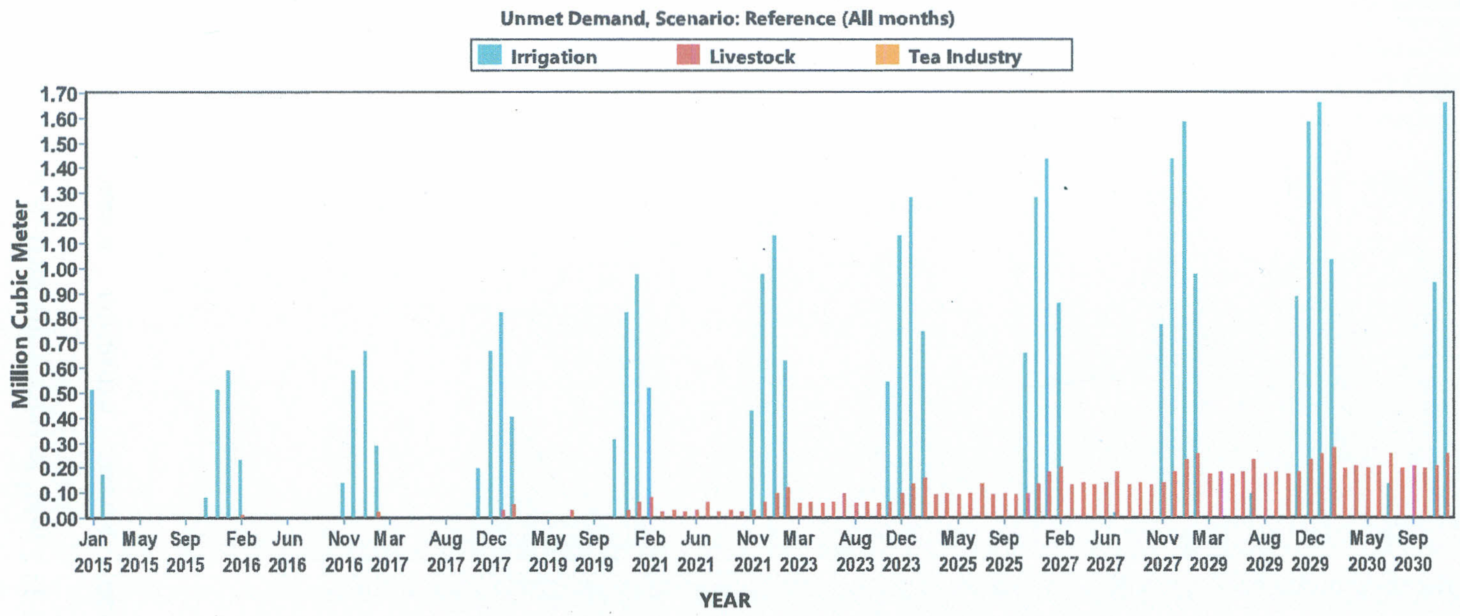

Figure 4.17: Unmet demand, Scenario: Reference (All Months)

4.6.2 Unmet Demand; All Scenarios

The WEAP model, under all scenarios, projects that by 2030, the highest unmet demand would be under the IIA scenario, 51.5 mM^3, as the expanded irrigation area, from 2013 to 2018, would require additional 39.2 mM^3 to sufficiently meet its requirements, up from the current 12.3 mM^3under similar expansion scenario (Figure 4.18).

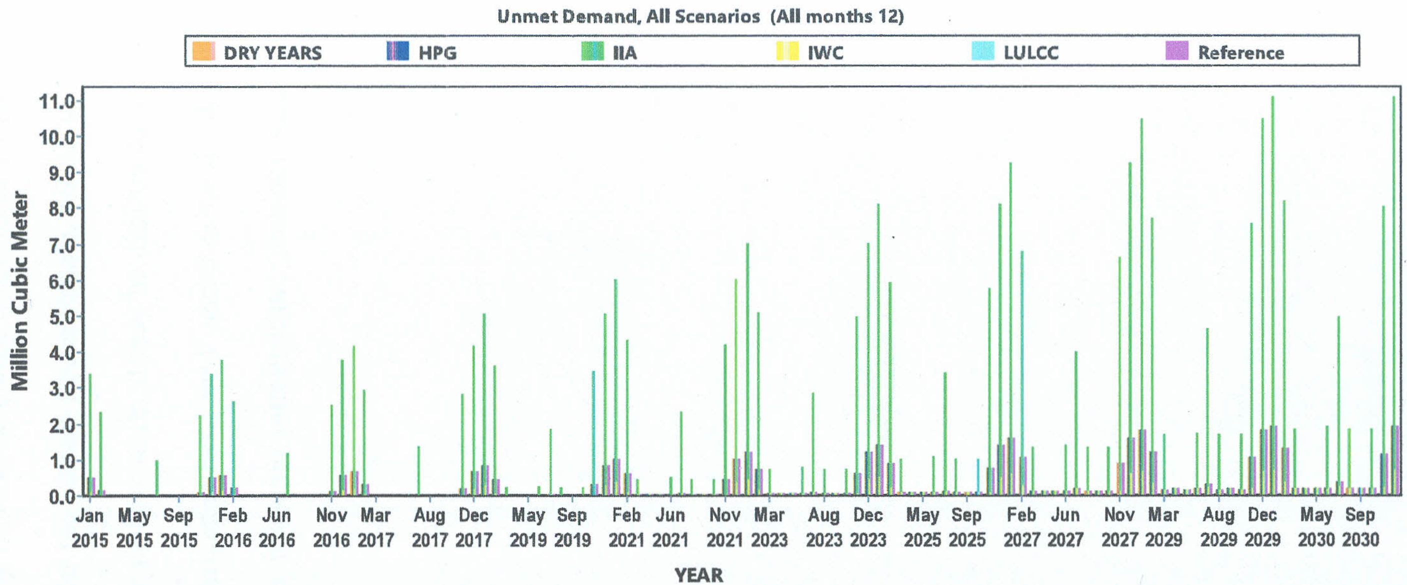

Figure 4.18: Unmet demand under All Scenario

4.6.3 Unmet Demand Relative to Improved Water Conservation

Unmet demand under the improved water conservation program only livestock requirement shows relatively remarkable unmet water needs for livestock at 2.7 mM^3 in 2030. This is because under the current circumstances, where animals drink from the river or open water pans or shallow wells, it may be difficult to institute and quantify a water use efficiency plan. Irrigation has 1 mM^3 unmet demand, which means that a 40% efficiency improvement on irrigation infrastructure provides significant reductions in water use. (Figure 4.19).

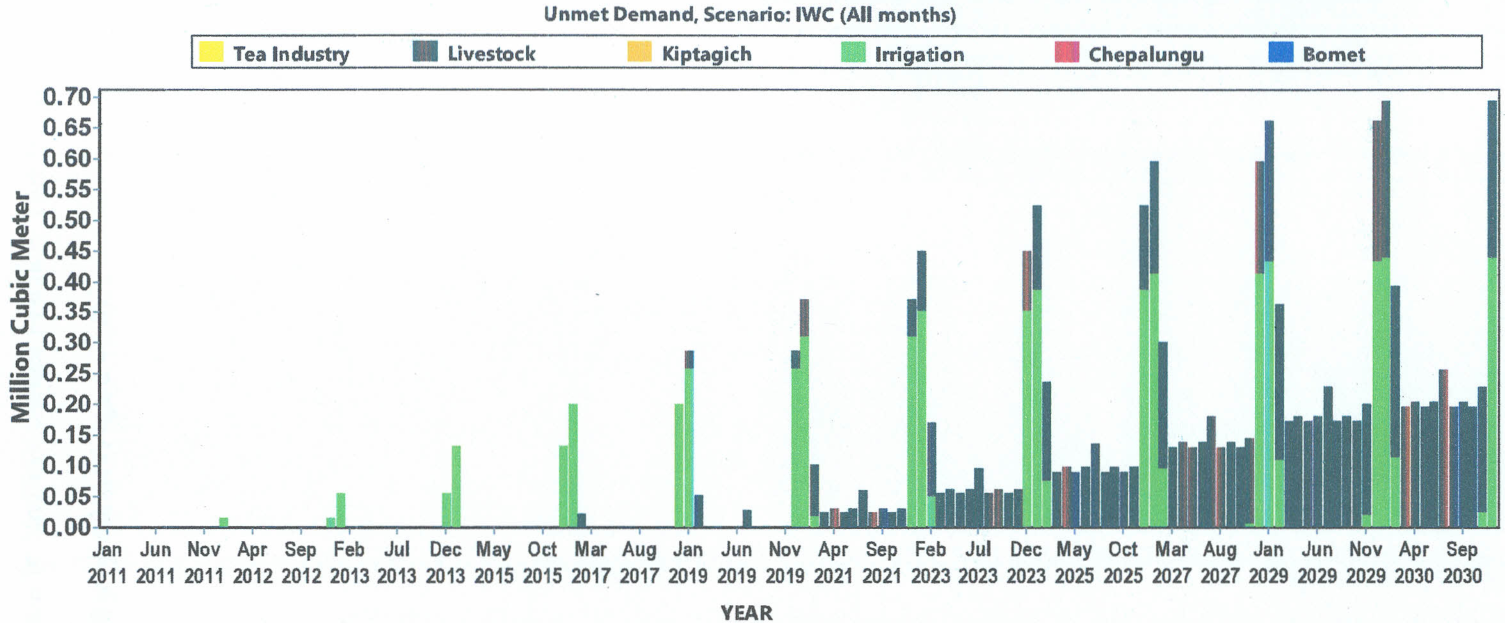

Figure 4.19: Unmet demand relative to Improved Water Conservation, IWC

4.6.4: Unmet Demand, Scenario: LULCC (All Months)

WEAP shows a marked unmet irrigation demand at 5.4 mM^3especially under LULCC. The area under irrigation increases to 1100 Ha from the current 500 Ha by the year 2018. This is a massive 120% increase in land use change practice. This therefore leads us to the unmet demand seen in 2030 projections (Figure 4.20).

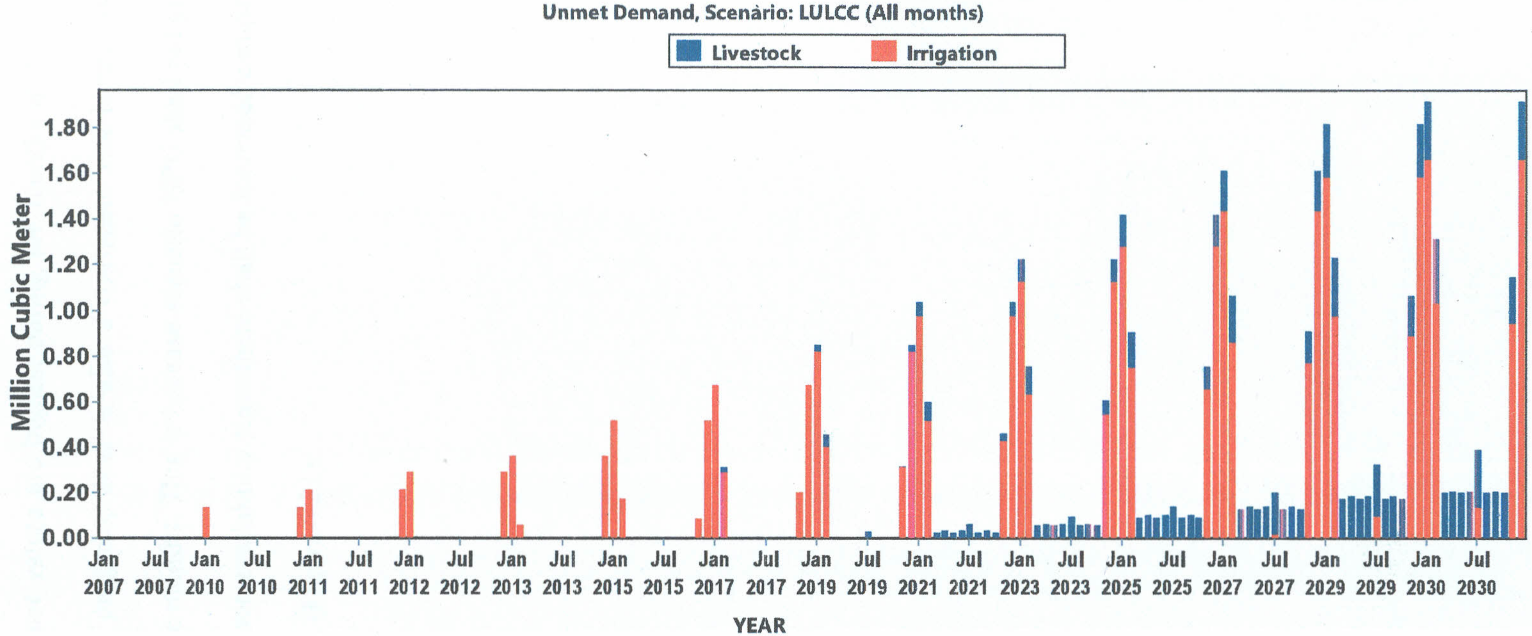

Figure 4.20: Unmet Demand, Scenario: LULCC (All Months)

4.6.5: Unmet Demand, Scenario HPG

Under the higher population growth rate of 5%, domestic unmet requirement for Bomet shall be 0.8 mM^3, while Chepalungu area and Kiptagich areas will register equal figures of 0.4 mM^3. These unmet values are highest during the months of November through February. As the years progress, there is also a consistent rise in the level of Unmet demand in those specific months. This is because scenario HPG shall put pressure on the drier season water resource availability since there shall be increased competition for less water in the dry season. (Figure 4.21).

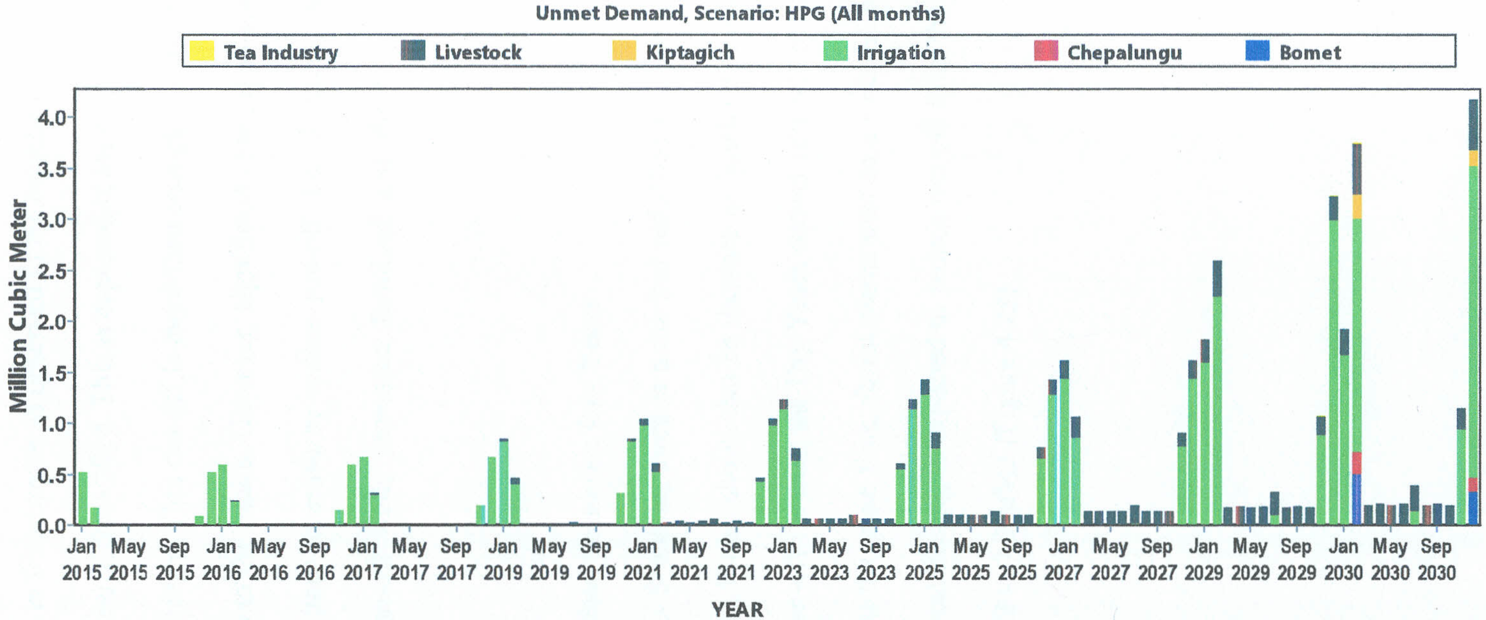

Figure 4.21: Unmet Demand, Scenario HPG (All Months)

4.6.6: Run-off from Precipitation; LULCC

The total run-off from precipitation as at year 2015 stands at 964 mM^3, by 2030, this figure rises slightly to 975.3 mM^3. The increase is due to expansions in farmland and shrub-land areas and reduction in forest cover as observed in the established trend in land use and land cover change of year 1995 – 2010. This is captured in the discussion of table 3.5 on percentage land cover change. This run-off is more than enough to cater for water demand needs both now and into the future. However, significant changes in land cover and land use practices may either increase or reduce run-off. For instance, increased forest cover would reduce run-off while increased farmland and shrub-land tend to increase run-off (Figure 4.22).

4.6.7 Run-off from Precipitation; Scenario: Dry Years

In the Dry Years – All Months Scenario, there is a marked reduction in surface run-off due to the reduced precipitation. It also shows that an increase in farmland as a land-use option leads to an increase in run-off i.e. from the Dry Years current scenario of 7.5 to the scenario 2030 of 26.7 mM3. At the same time, forest plantations as a land-use practice, which is increasing in the sub-catchment, is expected to reduce run-off from the current Dry Year Scenario of 40.2 mM3 to 7.5 mM3 (Figure 4.23).

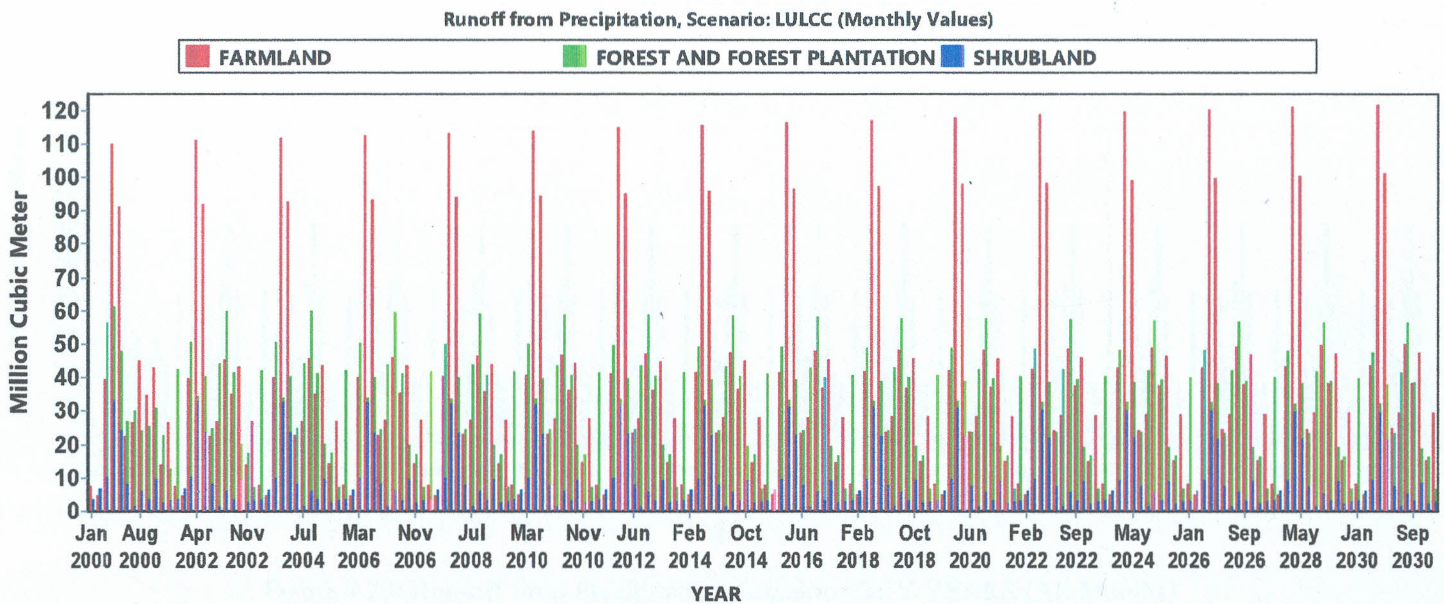

Figure 4.22: Run-off from Precipitation, Scenario: LULCC

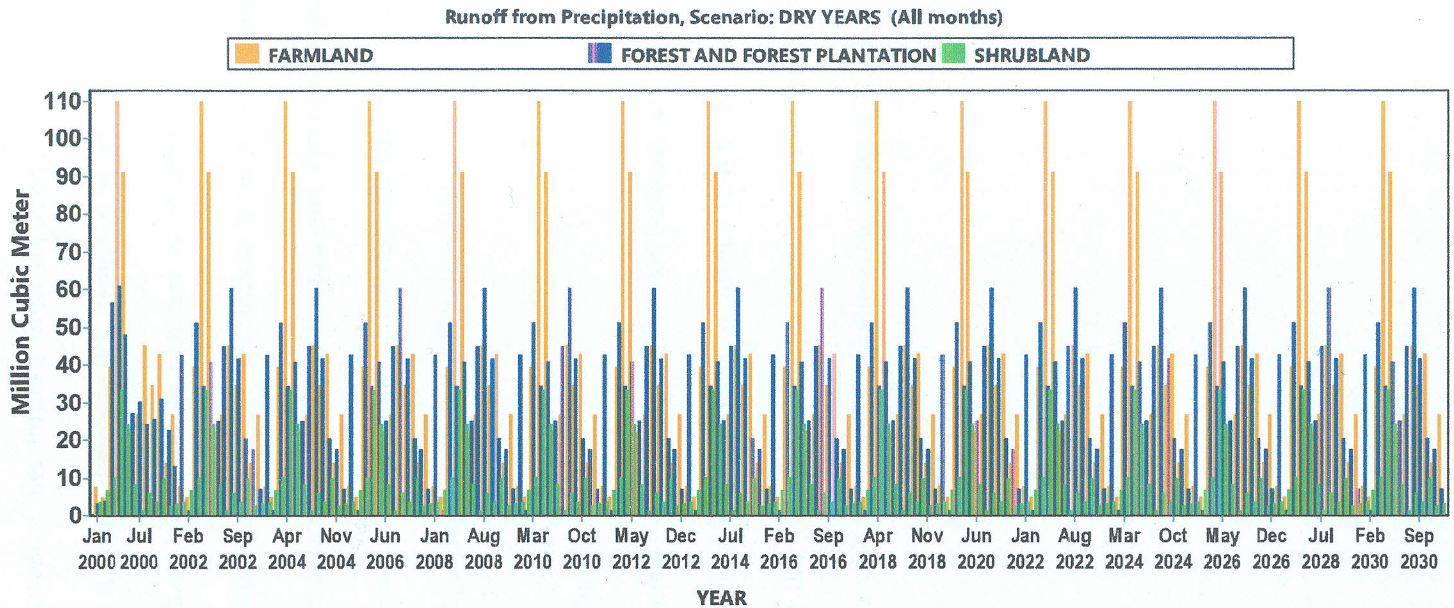

Figure 4.23: Run-off from Precipitation, Scenario: DRY YEARS (All Months)

4.6.8: Demand Site Inflows and Outflows

Demand site inflows and outflows show the amount of water abstracted to meet the requirement of specific demand sites. Outflows depict consumption values and return flows to the source if any. Currently, the inflows from the river, 38.3mM^3, and the consumption, -33.9 mM^3, are at a near balance, which means most of the inflows is for consumption and very insignificant amounts are returned as return-flows back to the source. The difference in consumption Outflow and Inflow from River Nyangores is catered for by underground water sources such as springs and Boreholes and other surface water sources such as water pans. This means the demand site outflows are not returned to the system but is lost to evaporation and infiltration (Figure 4.24).

4.6.9 Land Class Inflows and Outflows

Monthly average Land class inflows and outflows, for the business as usual account shows a marked precipitation inflow in the months of April - 236.8 and May - 208.4 which are long rain periods in the year in the sub-catchment. They also register the highest surface run-off periods as well as evapotranspiration rates (Figure 4.25).

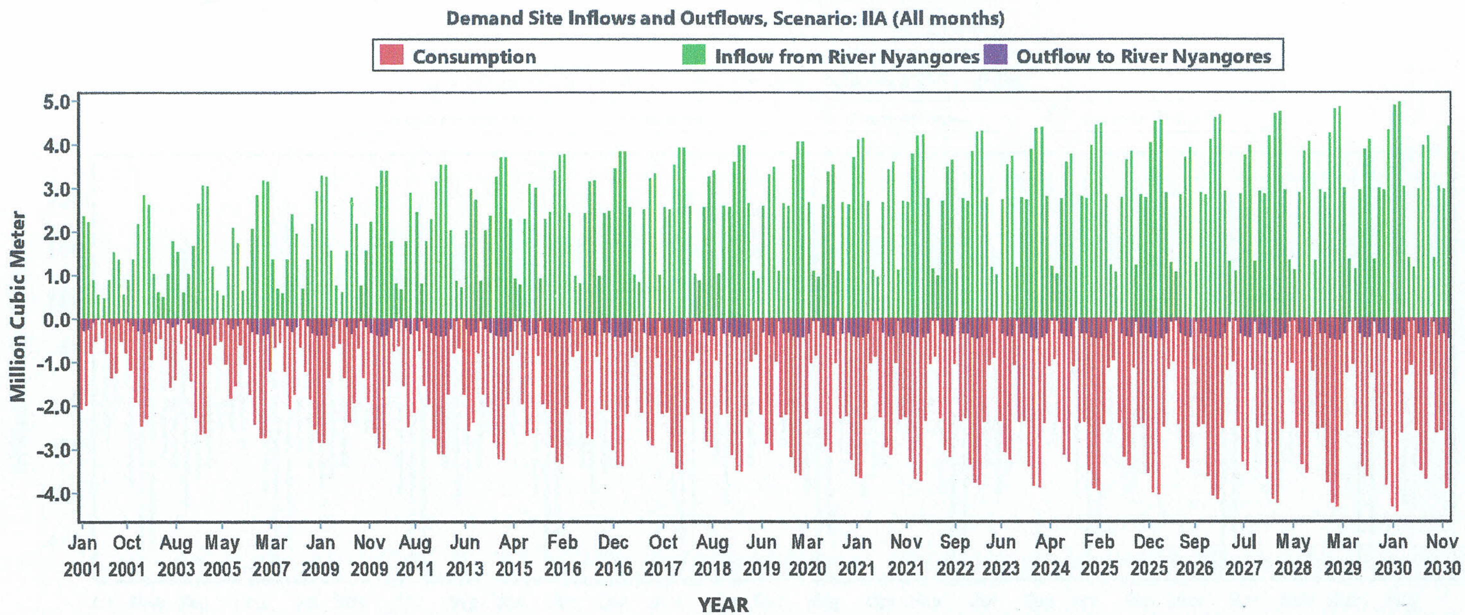

Figure 4.24: Demand Site inflows and outflows

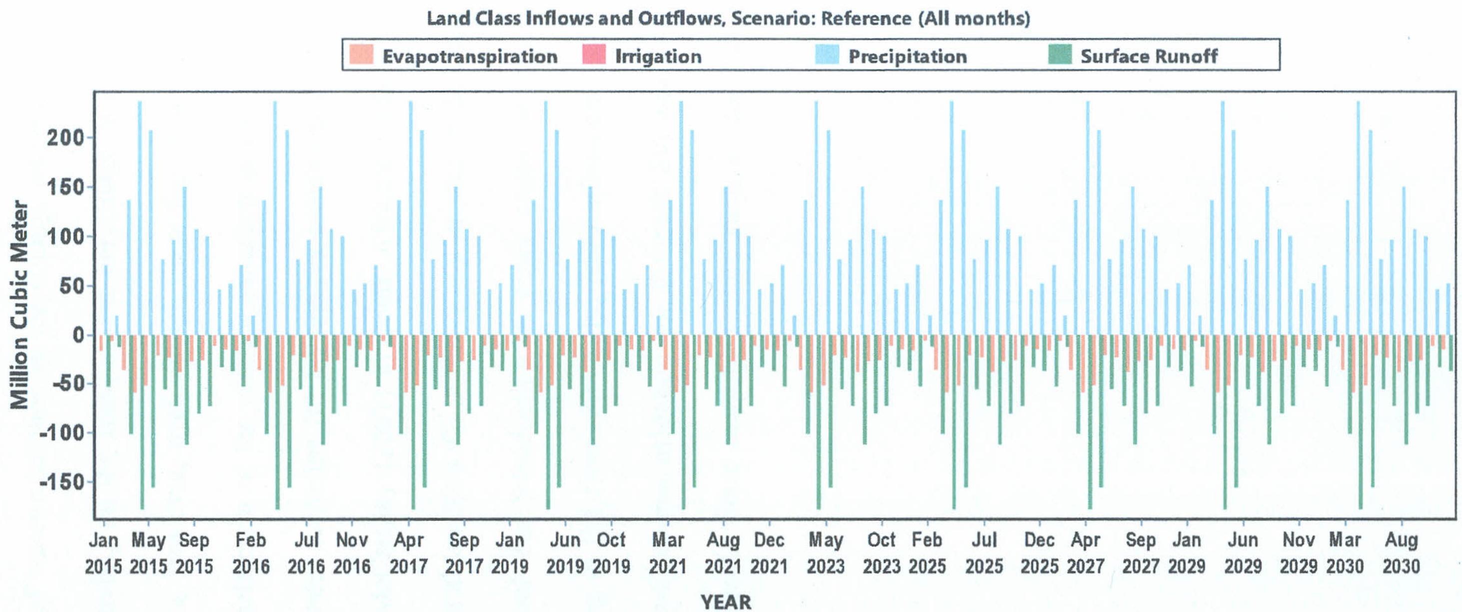

Figure 4.25: Land Class Inflows and Outflows, Scenario: Reference (All Months)

4.7 Comparisons of Results with Other Studies

The results from the water use situation are very similar to those achieved by NEMA (2009) in the Bomet District Environment Action Plan 2009-2013 which found out that springs account for 25% of water allocation in the county, while the river accounts for between 45% - 56% depending on the season. This percentage is similar to that of the study which obtained 52%. However, even though these figures account for the entire county of Bomet, it is a reflection of the realistic situation in the sub-catchment. The result from the WEAP model scenarios for Nyangores catchment compares with those obtained by Arranz and McCartney (2007) in South Africa's Olifants catchment who found out that groundwater abstraction did not have any impact on the naturalized stream flows. They also found out that introduction of water conservation measures would ensure more water flowing in the river. Similarly, full implementation of the planned expansion of the Kaboson-Chebaraa irrigation for the next five years would result in shortages in the near future in other demand sectors such as domestic consumption upstream.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

The aim of the study was to simulate water resource allocation and use for purposes of better planning and sustainable management of water resources of the Nyangores catchment. To achieve this overall aim, the study focused on three distinct objectives such as, identifying the major water resources of the Nyangores sub-catchment, determine the supply, demand and quality of the water resources and finally, simulate the impact of planning and management options on the future of water resources in the Nyangores sub-catchment using scenario development of the Weap Model. This chapter therefore draws conclusions and makes recommendations on areas that require further research focus.

5.2 Conclusion

In objective number one, the results indicate that the major water sources and supplies in the sub-catchment include the River Nyangores, springs, wells and boreholes. The Nyangores River was noted to be the most important water source serving 52% of the catchment population with that figure going down only during the rainy seasons. The boreholes serve only 4% of the catchment population. The upstream and downstream areas have 75% of the springs, wells and water pans. All the major water intake points along the river Nyangores are also found downstream, with only the Tenwek Mission Hospital intake and the Bomet Water Supply and Treatment company located midstream. This is because of two reasons, one, there is a high population density, 478 persons/Km^2, in the middle and lower reaches of the sub-catchment compared to the upper reaches.

The major water demand sites identified were; Irrigation at 15Mm^3 per year, Rural and Urban Domestic consumption at 6 Mm^3 and 3.8Mm^3, Livestock consumption at 2.7Mm^3 and the industrial water consumption at 0.2Mm^3 in that order.

Results for objective number two indicate that there are 30 springs discharging a total of 4752 m^3/day, 9 Boreholes and wells providing 108 m^3/day, 3 water pans servicing a capacity of 7,500 m3/day, 1 river and 2 streams with an a capacity of 950,400 m^3/ day. Total available water supply was 1,000,260 m3/ day, a value that is currently not sufficiently exploited due to a lack of proper water storage and distribution infrastructure. However, this supply also diminishes in the dry season and in the seasons with less rainfall.

Water quality parameters measured were pH and TDS as it was meant to be a rapid test to roughly determine the suitability of identified water sources for human consumption. The pH values derived were between 6.0 and 8.9 with several of the sources falling between the recommended values of between pH 6.5 and ph 8.5 for most drinking water sources. The low pH 6.0 value was obtained at Olbutyo which is a water intake point in the downstream area of the catchment. Along the river banks, leading to the Olbutyo site, there are several laundry points, animal drinking points as well as an accumulation of pesticides, herbicides and fertilizers from the farms. The waste from the urban centers that is washed into the river during rainy seasons also contributes to these erratic values downstream. TDS values ranging between 40 to 1050 mg/l were obtained within the sub-catchment. The values were also noted to be closer to the World Health Organization recommended TDS values of below 1000 mg/l (WHO, 2003).

The last Objectives' results sought to respond to the simulation of the impact of water use and allocation on the future of water resource use and management options using the WEAP scenario analysis. The results found that under the current water use situation, total annual demand is expected to rise from the current total of 27.2 Mm^3 per year to 44.3Mm^3 per year. A 61% increase. However, under a 40% improvement in the water conservation strategy (IWC Scenario), the annual water demand shall increase to only 33.5Mm^3, a 23% increase. In the scenario, Higher Population Growth rate (HPG) the human population growth is expected to drive demand from the current 27.2Mm3 to 86.5Mm^3 which can be reduced to 65.2Mm^3 per annum using IWC strategies. More specifically, the current annual irrigation water needs is at 9.6Mm^3 because the entire irrigation scheme is not fully exploited to its potential, and that value, under current circumstances will rise to 15.3Mm^3 per year by the year 2030. Under an Increased irrigation Area, IIA demand shall be 90.3Mm^3, and the land use and land cover change shall register a demand of 44.4 Mm^3 by the year 2030. Unmet demand was noted to increase in the drier months as we approach the year 2030. The unmet demand in the year 2030, under the current circumstance shall be 5.4Mm^3 while with IWC strategies that figure would reduce to 3.7Mm^3 in the same period. Unmet demand for the different scenarios shall register mostly under irrigation and livestock water needs because of the priority allocation which gives domestic water consumption priority number 1. Meaning, during the drier months, the available water will first satisfy the needs of domestic consumers before being allocated for livestock, irrigation and industrial purposes.

5.3 Recommendations

The following recommendations, based on the outcomes of the study are therefore proposed for the sustainable allocation and management of water resources in the sub-catchment. These recommendations target policy makers/ the county government, Water Resources Management Authority, the Tea Industry, the Water Resource Users Association and development partners working in the Nyangores sub-catchment of the upper Mara River basin.

i. The Mapped water resources indicate that the downstream area of the catchment requires the establishment of more community water supply centers. This is because the only major reliable water source as seen on the map is the Nyangores River yet growing urban centers like Sigor are within 30 Kilometres of the river. Proper protection of the major water sources in the mid and upper catchment is important to ensure sustainability.

ii. The current water supply, demand and quality situation has shown that most of the available water resources are not being exploited due to poor planning and infrastructural deficiencies. The manner in which some of the springs and wells were protected has led to the drying up of 25% of the protected water sources. Protection would reduce contamination as well as reduce the TDS values in downstream sources. It would also allow for treatment of the water so as to regulate the pH levels.

iii. The increase in population of Bomet town and its environs and that of upstream towns such as Keringet and Kiptagich was shown to increase the unmet demand in downstream areas of Chepalungu as we approach the year 2030. Therefore, a water allocation plan and a controlled urban growth is hereby recommended to ensure avoidance of conflicts with downstream users especially in the lean months of December through March.

5.4 Further Research

The study focused more on how water is allocated in the sub-catchment based on major supply sources, demand sites and scenarios based on the same. However, for future studies, focus could be targeted on some of the following suggested areas of study;-

i. The water quality study undertaken was a rapid one meant to roughly gauge the suitability of the water sources for human and animal consumption. The results are therefore not conclusive enough to warrant a public health directive but are enough to indicate a trend that might be useful for future researchers to focus on. Future studies on water quality should therefore be accompanied by comprehensive laboratory tests.

ii. The WEAP modeling employed a relatively lumped approach to calculate run-off as well as to delineate the disaggregated and splintered demand sites. A study with a more elaborate approach where run-off from each land class is calculated independently and each demand site is considered as a stand-alone site would provide an in-depth analysis of the water allocation complexity in the sub-catchment. The Impact of climate change on simulated scenarios of future water resources can be explored.

iii. Underground water supply was not comprehensively captured in this study beyond the wells, springs and boreholes. A study targeting underground water reserves in the sub-catchment would provide a more complete picture of the hydrological cycle and its potential in the allocation of water in the sub-catchment.

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APPENDICES:

APPENDIX 1: QUESTIONNAIRE

KENYATTA UNIVERSITY

Questionnaire To Select Senior Individuals At Government Agencies And Non-Governmental Organizations Within Bomet County For The Purposes Of Carrying Out An Msc. Environmental Science Research Project On Simulation Of Water Resource Use And Allocation In Nyangores Sub-Catchment. Respondents Have Been Purposely Selected To Participate In This Survey And Their Voluntary Participation Is Highly Appreciated. Respondent Opinions Will Be Strictly Confidential.

Date... Time..........................

Enumerator....................................

Respondent name.............................

Position in organization......................

Objective I: Water Supply/ Sources

A. Water Resource Management Authority (WARMA) and Water Resource Users Association (Nyangores WRUA).

1. How many water sources exist in the SUBCATCHMENT area?
    a. Springs
    b. Wells
    c. Rivers/streams
    d. Water pans
    e. Reservoirs
2. How many active (renewed) abstraction permits have been issued in the catchment area (both for groundwater and surface water)?
3. What is the estimated rise in annual water demand in the area?
4. What is the capacity of the Reservoirs in the area if any ?
    i. Reservoir A
    ii. Reservoir B
    iii. Reservoir C
5. Do you have estimated figures on the amount of groundwater reserves in the area?
6. Are there any Rain-water harvesting initiatives and programs in the catchment?
7. What is the percentage of households that have adopted roof-water harvesting technologies?
8. What is the annual precipitation of the area?
9. What is the average discharge rate (dry season and wet season) of ;
    a. Ainopng'etunyek stream? (Cubic meters per day).
    b. Chepkositonik stream? (Cubic meters per day).
    c. Nyangores River? (Cubic meters per day).

Objective II: Water Demand/Sinks and Status

B. Bomet Water And Sewerage Company

1. What are the Major water demand sites in the area?
2. How many clients (household, municipal, industrial, school etc) are served by your water company on a daily basis?
3. What is the Percentage of your customers who are metered? – This would apply separately to all customer categories (residential, institutional, commercial, industrial and municipal).
4. What is the estimated daily water demands for Bomet, Silibwet and Tenwek urban centers (in Cubic meters per day)?
5. Is there a wastewater treatment plant in the catchment?
   a. What is the operational capacity? (cubic meters per day).

C. County Government of Bomet / Ministry Of Agriculture, Livestock and Fisheries.

1. What are the day time urban populations of Bomet, Silibwet and Tenwek centers?
2. Are there any major water projects existing in the area?
3. How many livestock units are within the catchment?
   a. Cattle
   b. Sheep
   c. Goats
   d. Donkeys
   e. Others
4. What is the rural population of people living within the catchment?
5. What is the estimated rural water demand/ consumption per household?
6. What is the average household distance to the major water sources in the catchment? (Springs, wells, river or streams).

<u>Objective III: Planned Water Projects</u>

1. Are there any planned Irrigation schemes within the county?
   Yes ( )   No ( )
2. If Yes, What is the estimated water capacity of each?
3. What is the land size set aside for the scheme? (Ha)
4. What would be the main source of water for this irrigation scheme (s)? (River/stream water, Borehole, springs, Well, Other).
5. Are there any major Water projects currently under construction or planned for the near future by the county government? (Dams, Waterworks, Hydro-power, Waste Water Treatment plant, other).
   a. Do you have an idea of the average water demands for these planned projects?
   b. Where do you plan to source water for these projects? (River, dam, spring, rainfall, other).
6. Are there any planned water conservation projects or policy for the area? (Reuse plans, forest demarcations, artificial wetlands, other).
   a) What is their estimated capacity in Ha and/ Cubic Meters?

APPENDIX 2: TIRGAGA FACTORY DAILY WATER USE (Nov and Dec, 2014)

Tirgaga Tea Factory Daily Water Consumption (M^3)		
Day	Nov-14	Dec-14
1	95	84
2	94	89
3	92	92
4	95	98
5	105	94
6	89	87
7	90	91
8	93	82
9	89	96
10	103	91
11	99	93
12	97	94
13	102	95
14	96	97
15	102	88
16	94	91
17	99	99
18	98	90
19	96	91
20	100	94
21	99	89
22	107	83
23	97	87
24	105	84
25	110	89
26	95	93
27	97	96
28	99	94
29	94	90
30	104	95
31	-	98

APPENDIX 3: ATTRIBUTES OF WATER RESOURCES SAMPLED FOR QUALITY.

Abstraction & Demand Point	Coordinates	Elevation (m)	pH	EC (µ/cm)	TDS (mg/L)	Remarks
Kapcheluch Community water Project	S 00°41.183, E 035°22.994	2142	7.0	40	50	Supplies 23 connected H/Holds and has a water kiosk together consuming 2000l per day. Sourced from river
Bomet Water Supply	S 00°47.198, E 035°20.653	1836	6.5	50	60	Treatment facility for Bomet town.
Kenon Spring	S 00°42.299, E 035°25.066	2056	7.0	130	100	Forest Edge and tea zone area.
Kenon Spring 2	S 00°42.314, E 035°139	2039	7.2	180	130	Clear patch, approximately 100sqm sprayed by chemical to clear vegetation and grass. Chemical type 'Glycel'
Kapkurukerwet Spring	S 00°41.941, E 035°24.724	2118	6.9	180	90	Spring surrounded by broadleaved plant 'Sabetet', 'lugumeito', 'serweriet' and 'Aunet'.
Soti Village Spring	S 00°42.030, E 035°24.517	2118	6.7	180	90	Discharge very clean but slow at 0.16 L/s
Kibochet Spring	S 00°42.047, E 035°23.925	2051	7.0	210	100	Surrounded by Tea Farms, very fast Discharge at 0.4 L/s
Ainapsabet Spring	S 00°40.838, E 035°23.698	2114	6.5	200	80	Private pump installed by Mr. Kemei a dairy farmer. N-WRUA planted trees here three years ago. Discharge, very slow, almost quiet flow. Croton all round, spring area encroached by Tea Plantations Upto edge of water.

Ngomwet Community Spring	S 00°42.911, E 035°20.972	2034	7.5	280	140	Protected spring Fairly fast Discharge 0.3 L/s
Wamkong water point-Ainopngetunyek	S 00°34.826, E 035°38.018	2424	7.4	100	40	Under olenguruoni road, very clear water, Bamboo plants, eucalyptus vs cypress woodlot surround the water point right next to the river. Mixed indigenous and commercial woodlots rise uphill in the background.
Enoosini Stream	S 00°33.121, E 035°37.310	2454	7.3	130	60	At Kapkoros Factory bridge, animal drinking point, domestic water source, stone quarrying for road construction.
Kimororoch Spring	S 00°31.268, E 035°36.624	2475	6.5	80	40	Unprotected, very clear waters, bamboo woodlot, water discharging at 25s/10L (quite fast), serves about 50 H/Holds. Discharge 0.4 L/s
Kimororoch Spring 2	S 00°31.093, E 035°36.300	2455	6.4	100	40	Unprotected, covered in bamboo woodlot, presence of livestock tracks, steep slope, very wet. Discharge; 0.4 L/s
Sisimto Stream/ water Point	S 00°31.114, E 035°35.139	2409	7.0	120	50	Leads to a waterfall, cattle drinking point, very cool and cold waters.
Kibwaot Spring Source	S 00°28.640, E 035°39.271	2565	7.0	100	50	Wetland, swamp with reeds at extreme end, 50% lilies, open source serving both animals and people. Very clear water, mix of indigenous and exotic woodlot on the sides, few dead trees in middle of swamp. Discharge: 6 s/L

Chebaraa Spring and Dam	S 00°27.922, E 035°39.811	2579	7.8	110	50	Size; approximately 150m x 100m, numerous springlets join from the highest end. 3 Private eucalyptus woodlot pan out very close to the edge. White faced whistling ducks plenty on the dam. Dam occasionally dredged using the Constituency development Funds (CDF). Dug by white settlers in the 40's. Discharge: 0.5 s/L
Kapkores Dam	S 00°27.065, E 035°39.502	2582	7.5	120	50	Deeper than Chebaraa Dam, surrounded by gently sloping land, also by reeds. A variety of water birds.
Bararget Forest Spring	S 00°24.408, E 035°44.415	2831	7.5	200	100	At the highest point of Nyangores Catchment, Mostly indigenous trees, Cedar, springlets sprout from all round including from the roadside, very clear, cool and cold waters. Heavy clearing going on in the forest. Discharge: 0.39 s/L
Sororik Water Pan	S 00°27.678, E 035°41.810	2651	7.5	170	100	Desilted by *Kazikwavijana*initiative in 2010, lots of waterbirds, sandpipers, 1/4 of surface covered by lilies. Surrounded by Maize Plantations and homesteads. Near Kiptagich-Keringet Road.
Lower Catchment						
Olbutyo water Point (Nyangores)	S 00°51.311, E 035°16.708	1858	6.2	140	60	Quarrying on the sides of the river.
Kamaech Open Well	S 00°54.705, E 035°17.426	1891	7.6	580	290	Shallow well, cattle watering well. Also place for washing clothes, showers etc. Dug out and filled with rain water, protected well.
Nusut Seasonal Stream	S 00°52.070, E 035°16.940	1858	6.9	190	90	The stream used to flow throughout but now just seasonal, and the water is brown in color.

Kaboson water point (Nyangores)	S 00°59.356, E 035°15.583	1731	7.5	140	70	Ballast and stone quarrying going on at the site. Washing of clothes and animal watering.
Kabuson Mission Hospital Intake	S 01°00.056, E 035°15.042	1705	7.5	160	80	Intake for Kaboson Mission Hospital and Kaboson Girls Boarding school.
Nogirwet+Chebaraa Irrigation Intake	S 00°58.801, E 035°15.274	1739	7	150	70	Funded by EU and the former county council of Bomet.
Kibangas Spring	S 00°53.198, E 035°17.646	1872	6.8	300	150	Water levels down compared to June 2014, flowing only through one pipe as opposed to two. Huge *Saunet* Tree standing next to spring.
Itembe Borehole	S 00°47.012, E 035°18.134	1957	8.9	2310	1150	Salty water, Depth 130m, production capacity =1.5m3/hr, Tank 300000. Pumped after every 1 and 1/2 days, runs for 8 hrs each time. Been operating for 3 years. Used residentially by people around Itembe.
Chemaiywa Spring	S 00°47.246, E 035°24.211	2136	6.8	260	170	Merige Ward. Protected spring, water flowing into a 'bowl'. Surrounded by indigenous trees, cedar. Also a cattle drinking place. Steep slope, almost 300m from road at Merige Hospital.
Stegro Tea Factory Water Supply	S 00°46.021, E 035°25.334	2052	6.5	370	180	Eucalyptus woodlots on one side, supplies Merigicentre, to supply factory too, currently supplying 100000 pumped for 8 hours and used for 13 hours only then pumped again.

(Source; Author, Field Measurements and observation)

APPENDIX 4: PERMITTED WATER ABSTRACTION AND PERMIT AMOUNTS

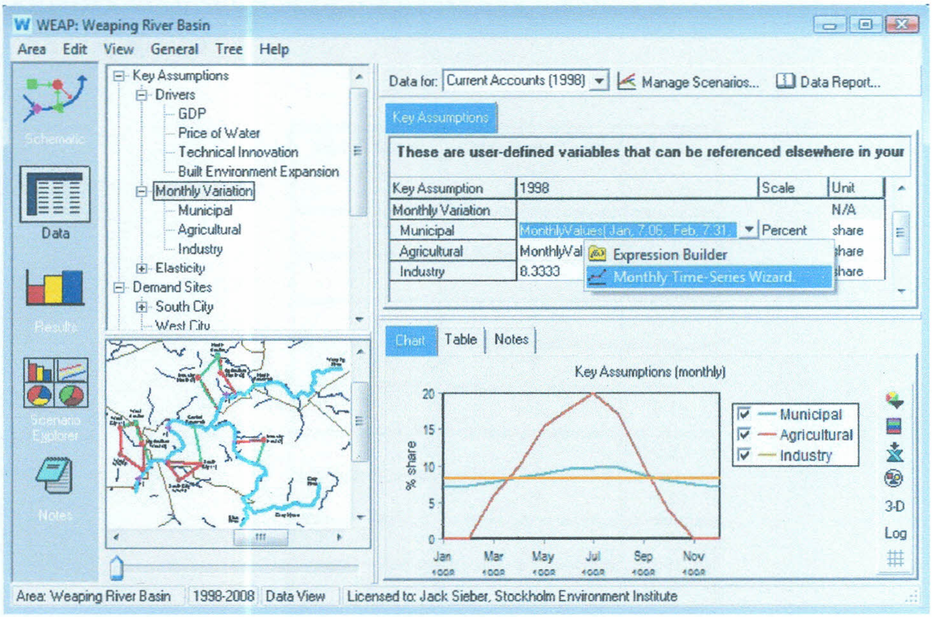
Station	Latitude	Longitude	Amount (M^{3}/day)	Use
BOMET WS	-0.78988	35.34664	360	Public
CHEPALUNGU WS	-0.98635	35.27785	981	Public
KABOSON GOSPEL MISSION	1.01556	35.26167	445.5	Domestic
KABOSON IRRIGATION SCHEME	1.18917	35.32611	3300	Irrigation
KAPCHELUCH COMMUNITY WS	-0.70176	35.38726	70.5	Domestic
KIPTAGICH TEA FACTORY	-0.60661	35.58722	200	Industrial/Domestic
MOGOMBET COMMUNITY WS	-0.73299	35.3602	1300	Public
SIGOR SEC. SCHOOL	-0.91333	35.26865	45.91	Domestic
TENWEK HOSP. WS	-0.74445	35.3637	118.18	Domestic
TIRGAGA TEA FACTORY	-0.71477	35.36632	88	Industrial
TUMOI COMMUNITY WS	-0.89265	35.2698	2228	Domestic
NYAGORES FOREST STATION			40.09	Domestic/Irrigation
NDARAWETA SEC. SCHOOL			23.04	Domestic
JOSEPH NGETICH			45	Domestic
STANLEY SANG			6.8	Domestic
KABOSON SEC. SCHOOL			19.35	Domestic
SIONGIROI WATER PROJECT			76.5	Domestic
AOONET COMMUNITY SHG			283.5	Domestic
LEONARD KEMEI			2.7	Domestic

Source, WRMA Kericho, 2014

APPENDIX 5: WATER SOURCE QUANTITY AND STATUS

Water Source	Altitude	Amount l/s	Location	Status
Bararget	2831	0.29	upstream	Unprotected
Chebaraa	2579	0.13	upstream	Unprotected
Kibwaot	2565	0.166	upstream	Unprotected
Kimororoch	2475	0.28	Upstream	Unprotected
Chemaiywa	2136	0.3	Midstream	Protected
Kapkurkerwet	2118	0.45	Midstream	Unprotected
Soti	2118	0.17	Midstream	Unprotected
Ainapsebet	2114	0.13	Midstream	Protected
Kenon	2056	0.27	Midstream	Unprotected
Stegro springs	2052	0.16	Midstream	protected
Kibochet	2051	0.25	Midstream	Protected
Ngomwet	2032	0.3	Midstream	Protected
Itembe BH	1957	0.017	Midstream	Protected
Kamaech well	1891	0.16	Downstream	Protected
Kibangas	1872	0.12	Downstream	protected
Kapkesiego spring	2039	0.14	Midstream	unprotected
Bukacha	2058	0.16	Midstream	Unprotected
Kapsimet	2153	0.12	Midstream	Protected
Kiromwok	2193	0.14	Midstream	Protected
Chemeres	2237	0.18	upstream	Protected
Njerian	1952	0.14	Downstream	protected
Kapsebet	1933	0.15	Downstream	Unprotected
chepchirik	1945	0.17	Downstream	Protected
Birirbei	1952	0.09	Downstream	Protected
Kipsegon	1906	0.11	Downstream	Unprotected
Ngererit	1904	0.15	Downstream	Unprotected
Kinyogi	1849	0.15	downstream	Protected
Chepkitach	2021	0.13	midstream	Protected
Tegat BH	2174	0.017	midstream	unprotected
Lelechonik	1899	0.16	downstream	Protected
Sororik pan	2651	0.4	upstream	Unprotected
Kapkores	2582	0.38	Upstream	Unprotected
Enoosini	2454	stream	upstream	NA
Wamkong	2424	Ainopngetunyek stream	midstream	NA
Sisimto	2409	waterfall	midstream	NA

APPENDIX 6: WEAP SCHEMATIC AND SYSTEM MODEL



Source: Weap-User Guide, SieberJ. &Purkey D., (2005)

APPENDIX 7(a): WEIGHTED ESTIMATES FOR CALCULATING TROPICAL LIVESTOCK UNITS

Body Weight (kg)	Metabolic Body Weight (kg $^{0.75}$)	T L U
5	3	0.05
10	6	0.09
15	8	0.12
20	9	0.15
25	11	0.18
30	13	0.20
35	14	0.23
40	16	0.25
45	17	0.28
50	19	0.30
60	22	0.34
75	25	0.41
100	32	0.50
125	37	0.59
150	43	0.68
200	53	0.85
250	63	1.00
300	72	1.15
350	81	1.29
400	89	1.42
450	98	1.55
500	106	1.68
600	121	1.93
700	136	2.16

(Source; Heady H.F, 1975)

APPENDIX 7(b): CALCULATION OF DAILY WATER REQUIREMENT FOR THE TROPICA LIVESTOCK UNIT;

Animal water requirement is given by;

$W_{TLU} = N_{TLU} \times L_d$

Where;

W_{TLU} = TLU daily water requirement

N_{TLU} = Tropical livestock Units value.

L_d = Amount of water consumed by 1TLU per day (often given as 30 liters per day)

Therefore;

256, 320 * 30L / day = 7689600L /day

= 7689.6 m^3 / day

APPENDIX 7 (c): CALCULATION OF CROP WATER REQUIREMENT

Plant and Irrigation Crop Coefficient Values (Kc) for Common Crops at Chebaraa and Kaboson Irrigation Scheme. (Source: FAO, 1998)

Crop Family	Crop type	Kc initial	Kc mid	Kc end	Max. Crop height (m)
Vegetables (Solanacea)	Eggplant	0.6	1.15	0.8	0
	Sweet potatoes	0.6	1.05	0.9	0.8
	Tomatoes	0.6	1.152	0.7-0.9	0.6
Legumes	Bean/chickpea/groundnuts	0.4	1.15	0.55	0
Cereals	Maize/sorghum/rice/millet	0.3	1.15	0.4	1
Tropical fruits and Trees	Tea (Non-shade)	0.95	1	1	1.5
	Citrus with groundcover/weeds (70% canopy)	0.75	0.7	0.75	4
	Tropical trees	1	1	1	10
Forages	Grazing pastures/extensive green	0.3	0.75	0.75	0.1

Given by the formula as presented by Zotarelli *et al*, (2009); Such that

$$ET_c = K_c ET_o$$ Where;

ET_c=Crop evapotranspiration in mm/day, K_c = Crop factor (unit less) taken as 1.15for K_{mid} of solonacea vegetables to be commonly grown. ET_o = Reference crop evapo-transpiration in mm/day. ET_o for Chepalungu is estimated as 5.0 mm/day (FAO, 1998). ET_c = 1.15*5.0 = 5.75 mm/day. Taking overall efficiency (conveyance, distribution, and application as (0.95*0.95*0.85/100%)) as 76.4%

The Unit Gross water demand (UGWD) which is total amount needed including losses is obtained by;

$$UGWD = \frac{ETc}{Efficiency}$$

$$UGWD = \frac{5.75}{0.764}$$

= 7.5 mm/day, Since 1 mm/day =0.116 l/s/ha

Therefore; UGWD = 0.116 * 7.5 = 0.87 l/s/ha

Scheme water requirement (SWR) is water needed to irrigate the whole farm i.e. 600 ha (150ha + 450 Ha) which is obtained by equation;

$$SWR = \frac{UGWD*24*7*A}{h*d}$$

Where *h* is no. of irrigation hours per day, *d* no. of irrigation days per week; A is area to be irrigated in ha. Farmers at Kaboson and Chebaraa scheme will irrigate for 24 hours since there is no insecurity problems and 7 days in a week. Therefore;

$$SWR = \frac{0.87 * 24 * 7 * 600}{24 * 7}$$

= 522 l/s. Therefore, daily irrigation scheme water requirement is; 522 *60*60*24 = 45100800 L = 45100.8 M^3/day

APPENDIX 8: ANNUAL WATER DEMAND AND MONTHLY SUPPLY REQUIREMENT CALCULATIONS

A demand site's (DS) demand for water is calculated as the sum of the demands for all the demand site's bottom-level branches (Br). A bottom-level branch is one that has no branches below it (SEI, 2005). For example, in the demand site such as a family house unit; Showers, Toilets and washing are the bottom-level branches for a family house under Bomet town– family house demand.

Annual demand $_{DS} = \sum_{Br}$ (Total Activity level$_{Br}$X Water Use Rate$_{Br}$)

Monthly Demand: The demand for a month (m) equals that month's fraction of the adjusted annual demand.

Monthly Demand $_{DS,m}$=MonthlyVariationFraction$_{DS,m}$ X AdjustedAnnualDemand$_{DS}$

Monthly supply requirement:The monthly demand represents the amount of water needed each month by the demand site for its use, while the supply requirement is the actual amount needed from the supply sources. The supply requirement takes the demand

and adjusts it to account for internal reuse, demand side management strategies for reducing demand, and internal losses.

$MonthlySupplyRequirement_{DS,m}$ = ($MonthlyDemand_{DS,m}$ X (1-$ReuseRate_{DS}$) X (1-$DSMSavings_{DS}$)) / (1-$LossRate_{DS}$)

APPENDIX 9: CHI SQUARE TEST FOR DISCHARGE

Discharge (L/s)

	Observed N	Expected N	Residual
0.017	2	1.7	.3
0.09	1	1.7	-.7
0.11	1	1.7	-.7
0.12	2	1.7	.3
0.13	3	1.7	1.3
0.14	3	1.7	1.3
0.15	3	1.7	1.3
0.16	4	1.7	2.3
0.166	1	1.7	-.7
0.17	2	1.7	.3
0.18	1	1.7	-.7
0.25	1	1.7	-.7
0.27	1	1.7	-.7
0.28	1	1.7	-.7
0.29	1	1.7	-.7
0.3	2	1.7	.3
0.38	1	1.7	-.7
0.4	1	1.7	-.7
0.45	1	1.7	-.7
Total	32		

Test Statistics

	Discharge
Chi-Square	9.562[a]
Df	18
Asymp. Sig.	.945

a. 19 cells (100.0%) have expected frequencies less than 5. The minimum expected cell frequency is 1.7.

Correlations

		l/s	m.a.s.l
l/s	Pearson Correlation	1	.468**
	Sig. (2-tailed)		.007
	N	32	32
m.a.s.l	Pearson Correlation	.468**	1
	Sig. (2-tailed)	.007	
	N	32	32

**. Correlation is significant at the 0.01 level (2-tailed).

APPENDIX 10: WEAP OUTPUTS

Table; Land class Inflows and Outflows, Scenario: LULCC

mM3	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Evapotranspiration	-16	-6.5	-36.6	-62	-54.7	-21.3	-23.8	-39	-28	-28	-12	-15
Precipitation	67.7	18.7	137	244	214	76.6	96.3	151	108	102	45.9	54.3
Surface Runoff	-52	-12.2	-100	-182	-159	-55.3	-72.5	-112	-80	-74	-34	-38.4