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ASSESSMENT OF WATER DEMAND PRESSURE ON SURFACE WATER RESOURCES IN BURGURET RIVER SUB-CATCHMENT USING GIS SWAT

By

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A thesis submitted to the Department of Environmental and Biosystems Engineering, University of Nairobi, in partial fulfilment of the requirements for the Degree in Masters of Science in Environmental and Biosystems Engineering

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DECLARATION

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

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DEDICATION

To my daughters Iona and Kelly.

ACKNOWLEDGEMENT

I wish to express my deepest indebtedness to Dr. Christian Omuto for his treasured guidance, direction, and constructive discussion, which profoundly mattered in the completion of my project work. His invaluable support shaped the outcome of this work.

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Finally, I thank God for being with me throughout the entire time of studying and who has made it possible for this project work to come to conclusion.

ABSTRACT

Assessment water availability and use in any catchment is a preliminary key requirement for policy administrators and leaders to make an appropriate decision on water allocation. This ensures utilisation of water resources in a sustainable way thus understanding the quantity of water resources available over time. The study aimed at establishing water resources demand and availability at different seasons.

In order to determine water available at different seasons in the Burguret Sub-catchment as well as filling the missing data for river flow data, SWAT model was applied. Three-year period was applied to calibrate SWAT. Validation was done in a two-year period pegged on daily flow data. Calibration outcomes showed that, an acceptable degree among simulated and observed daily flows with NSE value of 0.63 while RSR was 0.63. The Performance Efficiency (R^2) value for observed vs simulated daily flow data for the basin was 0.74 and 0.7 for the validation and calibration period respectively.

Assessment of abstractions along Burguret River and analysis of the same was carried out to determine the water demand. To determine total water demand for irrigation every user/abstractor, a Demand-Based Estimate Method was used.

The research showed that most of the water abstracted from Burguret sub-catchment was mainly used for irrigation. There has been a huge increase in

water demand over time. Out of 113 abstractions surveyed along Burguret River, only eight known abstractors have clear permit records. This indicated the little level of water utilization legality. It was also observed that 88% of water abstractors in the sub-catchment were small-scale farmers where most of them used portable pumps.

The abstraction survey conducted during the dry season (normal flow period), the total abstracted quantity was found to be 20685 m^3 per day. The authorized abstraction during normal flow is 149 m^3 per day. This means water utilization is approximately 15 times the authorized quantities.

With water demand for irrigation water being the highest and is increasing with time in the catchment, the situation was found to be worsened by inadequate water resources management as well as rainfall variability. Unwarranted abstractions of the river especially `during dry seasons have often resulted in reduced stream flow and highly affect the downstream users.

The research study found that viable use of available surface water resources combined with better natural flow management is crucial. This can only be realised with the serious collaboration of farmers in the catchment for both communities and individual farmers.

The study recommended that a comprehensive water allocation assessment in the catchment for all users should be carried out. This will manage demand that will improve water use thus improving returns from it whilst deterring crisis and conflicts caused by unmet demand. Further, proper irrigation methods or water saving techniques should be promoted to reduce water wastage and harness floodwater for use during dry seasons. To reduce non-compliance, it was recommended all users should be educated on the governing policies and legislation for water resources. This can be achieved through strengthening WRUAs by empowering the local water users to manage them thus implementing their mandate of regulating water rights in the catchment.

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LIST OF ABBREVIATIONS

ASTER: Advance Space Borne Thermal Emission and Reflection Radiometer

BD: Bulk Density (BD)

CEC: Cation Exchange Capacity

CETRAD: Centre for Training and integrated Research in Asal Development

DEM: Digital Elevation Model

ELCO: Electrical Conductivity

GIS: Geographical Information System

HRUs: Hydrologic Response Units

ILRI: International Livestock Research Institute

NF: Normal Flow

NSE: Nash-Sutcliffe Efficiency

NWMP: National Water Master Plan

NRM^3: Natural Resources Monitoring, Modelling and Management

RSR: Root Mean Square Error

SWAT: Soil and Water Assessment Tool

TOTC: Total Carbon

USGS: United State Geological Survey

WRA: Water Resources Authority

WRUA: Water Resource User Associations

1 INTRODUCTION

1.1 Background Information

The significance of freshwater to human life cannot be overstressed. It affects all part of human existence on the earth's surface. This is due to its use from consumption, farming, cleaning, industrial use, power generation, transport and sustaining the ecosystem. According to Thornton (2002), the man's body amounts to 50-65% of water thus making water a vital necessity of life next to air.

Water covers about 70% of the earth's surface. However, it's inadequate for human beings as freshwater (Peter, 2003). Freshwater comprises of about 3% of whole water available on earth's surface yet it is less than 1% that is readily available to be utilized by human beings (Hu, 2006). Notwithstanding the significance of freshwater and its availability, fresh water is swiftly diminishing throughout the world. Several reasons depict the rapid exhaustion of fresh water resource. These reasons comprise of but not limited to; increased irrigation, rapid population growth, pollution, industrialization, urbanization, and destruction of water catchment areas (Butler and Memon, 2006).

The use of fresh water rises as population increases. The water usage globally rose from about 1000 km^3 annually in the year 1940 to about 4130 cubic kilometers annually in the year 1990 and was anticipated to go up to 5000 cubic kilometers annually by the year 2000 (Aswathanarayana, 2001).

In Kenya, population growth, increased economic activities and enhanced living standards have resulted in high demand for freshwater especially in arid areas. As a result, water scarcity is mainly experienced during dry periods which are provoked by low rainfall hence low river flows. It is noted that during dry seasons there is also a rise in demand especially for water to irrigate farms. Pollution of water and inadequate water storage has contributed to water scarcity. Competition and conflicts over freshwater use are inevitable due to increased freshwater demand.

This paper will focus on Burguret Sub-catchment in assessing water demand and availability over space and time. The Burguret Sub-catchment is facing surface water demand pressure mainly due to increased irrigation water requirement.

The SWAT incorporates interactions among all the processes and segments that balance systems of water and influence water in a given region. It is a model intended or designed to forecast impacts land use activities on sediments, water, and agricultural chemical pollution at the catchment scale. The data required by SWAT include soil properties, topography, weather variables, and vegetation and land management practices. SWAT can also be used to model ungauged basins and predict comparative impacts of scenarios for instance changes in climate, management practices, water quality, and quantity or any other variable.

1.2 Problem Statement and Justification

The water availability in the Burguret River Sub-catchment is mainly influenced by natural and human-influenced factors. The Burguret River Sub-catchment lies largely in Semi-Arid Lands. The main water source for the flow of the river is rainfall hence with seasonal rainfall pattern and drought cycles, declining river flows have resulted. This is the major natural factor leading to the diminishing river flow.

Land management practice factors in the sub-catchment highly affect the spatiotemporal availability of river water and groundwater. These factors influence the dividing of rainfall into runoff and infiltration. The major changes in land use in the sub catchment include change of existing forests to farming land, bushland to land for grazing to farming land, and wetland to farming land. These land use and management uses have resulted in high runoff with low river flow during dry seasons. From available data, the water discharges at Burguret River sub-catchment shows a considerable change in overall average annual flow rate. This necessitates a study to carry out spatiotemporal analysis of water requirements in the area.

There is also increased water demand for human, livestock, and wildlife in the sub-catchment. With increased human population, there has been a rise in irrigation potential in the sub-catchment, especially around riparian areas. This has resulted in increased pressure on the river water. With farming as a source of livelihood, the users practise small-scale irrigation along the rivers hence, resulting into over-abstraction of river water. According to Schuler (2004), commercial horticulture rose at a rate of 9% between the years 1991 to 2002. In addition, during prolonged dry periods, this rigorous farming worsens the scenario (Liniger et al., 1998b).

The basin has also experienced insufficient management of water needs and availability and there has been high reliance river water in the basin. The fast growing population mainly small-scale settlement has resulted to increased demand for river water for irrigation consequently uncontrolled abstraction of irrigation water. There has been over-abstraction of water in the upstream part since the introduction of irrigated agriculture. The abstractions of water have been accused of decreased water resources in the downstream thus resulting to conflict.

The government of Kenya is considering in investing in irrigation infrastructure in the area, Kieni Irrigation Development project, where a dam is proposed. This project will depend on water from this basin thus increased water needs.

Despite the fact that there are many studies on water scarcity, changes and disparities in the sub-catchment, water resource availability have not been considered. There is an evident research gap referenced to the interdependence between water needs and availability in Burguret sub-catchment on different seasons.

Precise information on the situation and trend of sub-catchment's water resources is of great significance to support sustainable social and economic development. This research will aim at informing government and stakeholders on water resources in the study area. It also aims at initiating and promoting new approaches in research and education to the assessment of social and economic benefits of climatological. The research work will seek to generate a guide to the priorities of Meteorological and hydrological departments for infrastructure asset, and service delivery. Therefore, this study seeks to carry out an assessment of water demand pressure of surface water resources under different temporal and spatial scales using SWAT and GIS.

1.3 Study Objectives

1.3.1 Overall Objective

The general objective was to assess water demand pressure on surface water resources in Burguret River Sub-catchment.

1.3.2 Specific Objectives

The specific objectives were:

1) To assess surface water demand dynamics in the study area;
2) To assess available surface water in the study area;
3) To establish a relationship between surface water demand and water availability in the study area.

1.4 Hypothesis

If there is increased human population within a catchment, there is increased water demand as well as change of land use and this will lead to alterations in the water yields in the catchment due to abstractions.

1.5 Research Questions

To guide this study, the following research questions were considered:-

1) What is the relationship between water use and water availability in a semi-arid river?
2) What is the relationship between water abstraction and water demand?
3) What are the factors that influence the rate of water demand in the sub-catchment?

1.6 Study Report Organization

This study is organized into 5 chapters. Chapter 1 is the introduction and covers a brief overview of the proposed area of study. In addition, the problem statement and justification, objective of the study, hypothesis, research questions, and study limitations of the study is also presented. Chapter 2 covers concepts from the literature on water availability and demand. Chapter 3 is the methodology. This chapter covers the methods and the data that were used in the analysis to get results and in attaining the goals of the study. Section 4 covers result and discussion. This chapter presents the results and discussion from the various methods that helped in the achievement of the objectives in the study. Section 5 presents the conclusion and recommendation of the study.

1.7 Scope of the Study

The research targets to contribute to the studies on sub-catchment management in relation to water allocation in semi-arid sub-catchments. The Burguret Sub-catchment was used. The model was applied to determine the water availability at the sub-catchment.

2 LITERATURE REVIEW

2.1 Introduction

This section offers an outline of surface water demand dynamics and availability, at different seasons. It critically addresses the issue of water allocation and planning mainly covering the water allocation methods in Kenya. It also presents water resources management in ASAL catchments with inclination to surface water. A brief assessment on the use of model in the determination of water availability and allocation is also covered in this section. Also among the reviewed sections are the previous case studies of scholars who tried to contribute solutions associated to the problem of the research work.

2.2 The Water Resources in Kenya

In Kenya, water resources are unevenly distributed over space and time, a condition worsened by the inconsistency of climate. As a result, there have been flood and drought cycles. According to UN (2005), about 80% of the country is ASAL and nonetheless, it hosts 50% of livestock and about 34% of the human population.

In Kenya, there are five major catchment basins, which have an average total of $19{,}691 \times 10^6 m^3/yr$ surface water and $618 \times 10^6 m^3/yr$.

The Table 2-1 shows water resources available by catchment.

Table 2-1 Water Resources Availability in Kenya per Catchment

Basin	Area (Km²)	Rain (mm/yr)	Runoff (mm/yr)	Surface water (10^6 m^3/yr)	Ground water (10^6 m^3/yr)
Victoria	46,229	1,245	149	11,672	116
Rift Valley	130,452	535	6	2,784	126
Athi	66,837	585	19	1,152	87
Tana	126,026	535	36	3,744	147
Ewaso Ngiro	210,226	255	4	339	142
Total				**19,691**	**618**

Source: MoWI, 2009c

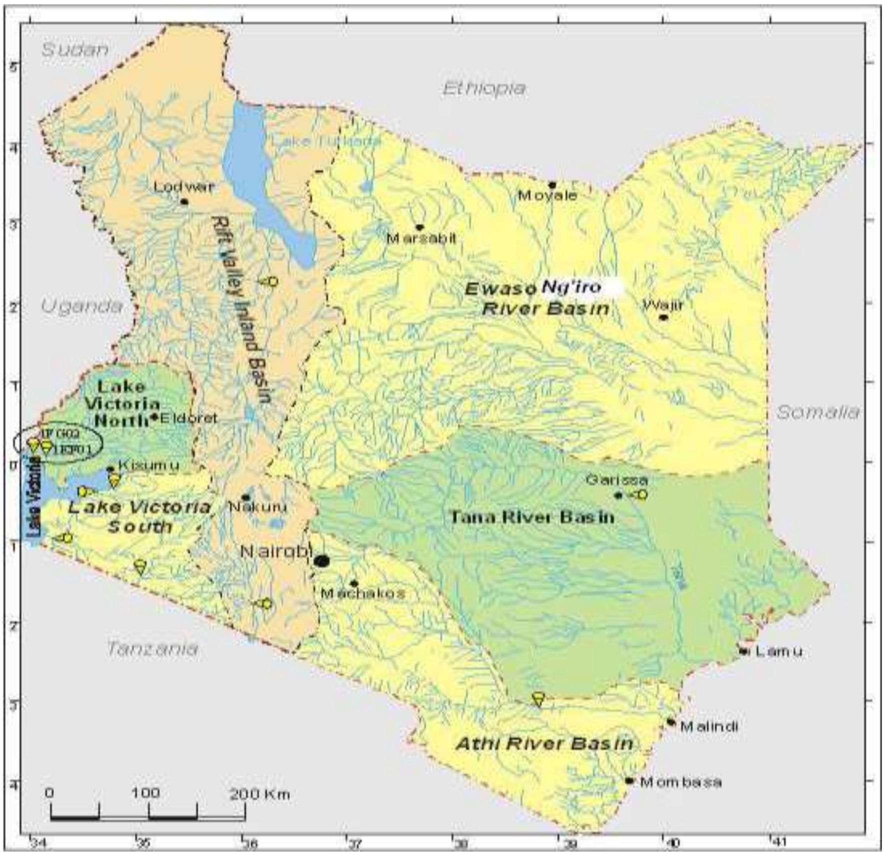


Figure 2-1 **Map Showing Catchments in Kenya (Source: MoWI, 2009c)**

2.2.1 Temporal Variations in the Availability of Water

In Kenya, rainfall across the country is remarkably irregular and erratic with exceptionally low runoff in northeastern and high runoff in western Kenya. As a result, there is a big variance in the amount of water availability even at district levels. There has been high variability between different seasons and within the same seasons due to soaring disparities in av5erage precipitation and evapotranspiration (UN, 2005).

2.3 Changes in the Kenya Water Sector

In Kenya, changes in the water sector started in the 1980s. In 1980/90s several studies amongst them, National Water Master plan of 1992 appreciated that there exist major challenge in the growth of the water sector in the country (NWMP, 1992). These challenges were due to the institutional and legal framework, lack of comprehensive policy, and inadequate financing. These challenges were found to be connected to Water Act cap372 (1972) in force then and this lead to the development of water policy to address the gaps and challenges highlighted and this gave birth Water Act (2002). The Water Act of 2002 was passed and came into force in the year 2003 to 2016. The Constitution of Kenya was promulgated in the year 2010 and ushered in a devolved system of governance in the country. Counties, therefore, got a significant say in many issues, including water. The 2002 Act, therefore, became inadequate, and the need to enact a new law arose. The law that was enacted in the Water Act of 2016.

2.3.1 Water Resources Authority

The body tasked with the running of water resources in the 2016 Act is the Water Resources Authority (WRA), which replaced WARMA under the 2002 Act. The functions of WRA are to amongst others articulate and implement principles and rules for the administration and use of water resources.

2.3.2 National Water Harvesting & Storage Authority

The Act establishes a National Water Harvesting and Storage Authority whose function is to:

- Improve national waterworks for storing and flood control of water resources;
- Sustain water works infrastructure;
- Provide records for the preparation of the water resources control policies;
- Develop and implement water harvesting strategies; and
- Carry out strategic water emergency interventions during drought;

2.3.3 Water Service Providers

The 2016 Act requires the County Governments to establish Water Service Providers. Water Service Providers are tasked with the providing of water amenities within certain areas.

A County-owned service provider is expected to hold the County or the National public water facilities on behalf of the citizens.

2.3.4 The Water Services Regulatory Board

The Act institutes the Water Services Regulatory Board whose purpose is to defend the welfare of consumers.. The functions of the Board are to (amongst many others):

- Define standards for the providing of water amenities;
- Assess and endorse tariffs to the water services providers;
- Establish permit requirements.

2.3.5 Water Tribunal

The Water Tribunal is the dispute resolution organ of the sector. It replaces the Water Appeal Board established under the 2002 Act. Appeals from the Water Tribunal lie in the Environment and Land Court.

2.3.6 Water Sector Trust Fund

The 2016 Act establishes a Fund whose purpose is to offer provisional grants to counties. This is additionally to the equalisation monies and to help in funding the growth and managing of water amenities in arid zones.

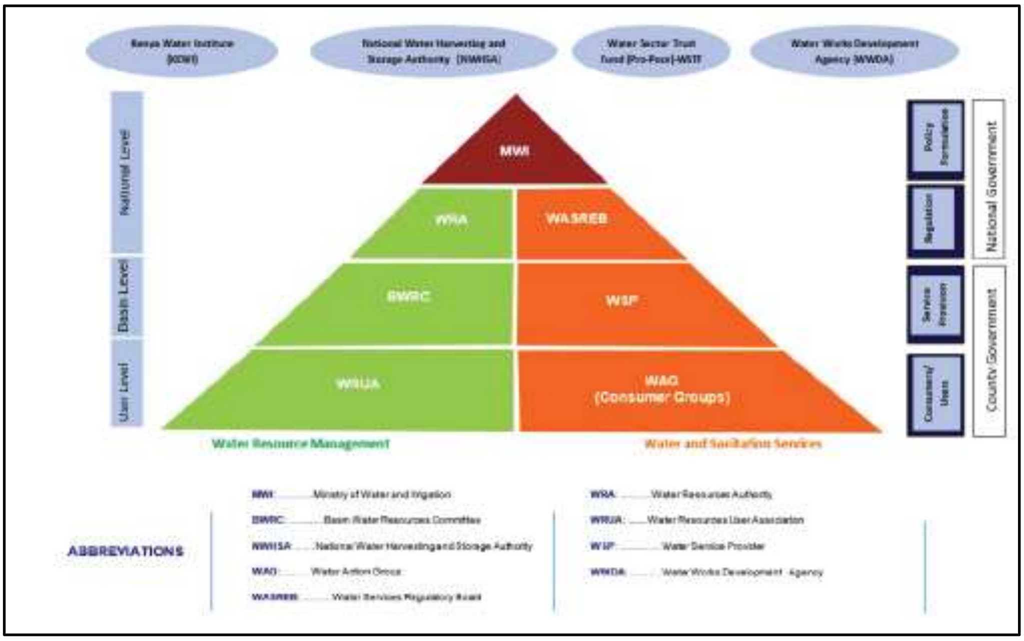


Figure 2-2 Kenya Institutional Structure in the Water Sector (Source: Water Act, 2016)

2.4 Water Resource Management in Asal Catchment- Upper Ewaso Ng'iro North River Basin

2.4.1 Land Cover

The Upper Ewaso Ng'iro North river catchment has an incredibly wide-ranging land cover. The land cover includes savannah, scrubland, grassland, forest, woodland rain fed crops, irrigated crops, and wetlands. Figure 2-3 and Table 2-2 show the land cover in the catchment.

Table 2-2 Land Cover in the Agro Climatic Zones in the Upper Ewaso Ng'iro North River Basin

	Total		**Zone A**		**Zone B**		**Zone C**	
Land Cover	Area (km2)	Area (%)	Area (km2)	Area (%)	Area (km2)	Area (%)	Area (km2)	Area (%)
Forest	1907.2	2.28	970.8	30.76	785.2	5.45	151.2	0.23
Woodland	1663.5	1.99	56.5	1.79	692.1	4.8	914.9	1.38
Bushlands	6075.5	7.26	310.7	9.85	1237.3	8.59	4527.5	6.85
Shrublands	19666.6	23.5	100.7	3.19	2335	16.21	17230.8	26.06
Shrub savannah	34099.9	40.74	162.4	5.15	4209.1	29.21	29728.4	44.95
Grassland	8605.4	10.28	79.2	2.51	756.4	5.25	7769.8	11.75
Rainfed crop	2422.8	2.89	885.4	28.06	1517.2	10.53	20.3	0.03
Irrigated crop	51.5	0.06	8.6	0.27	42.9	0.3	0	0
Scattered rainfed crops	4434.4	5.3	563.2	17.85	2719.7	18.88	1151.5	1.74
Bare areas	269.6	0.32	13.9	0.44	10.2	0.07	245.5	0.37
Wetlands	4458.9	5.33	3.8	0.12	90.5	0.63	4364.6	6.6
Urban and Settlement	40.1	0.05	0.4	0.02	12.6	0.09	27	0.04

Source: ILRI (2011)

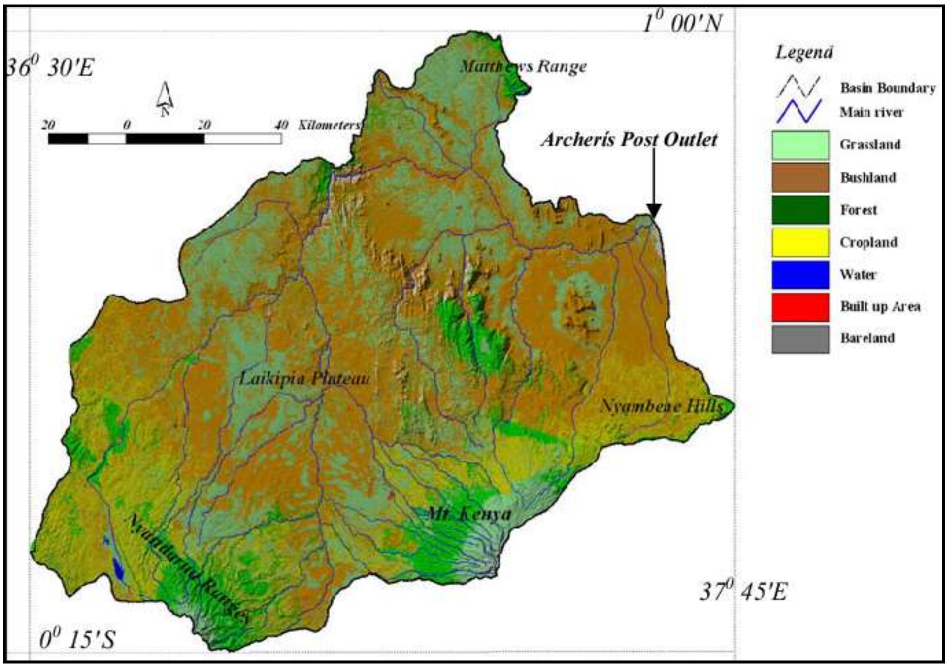
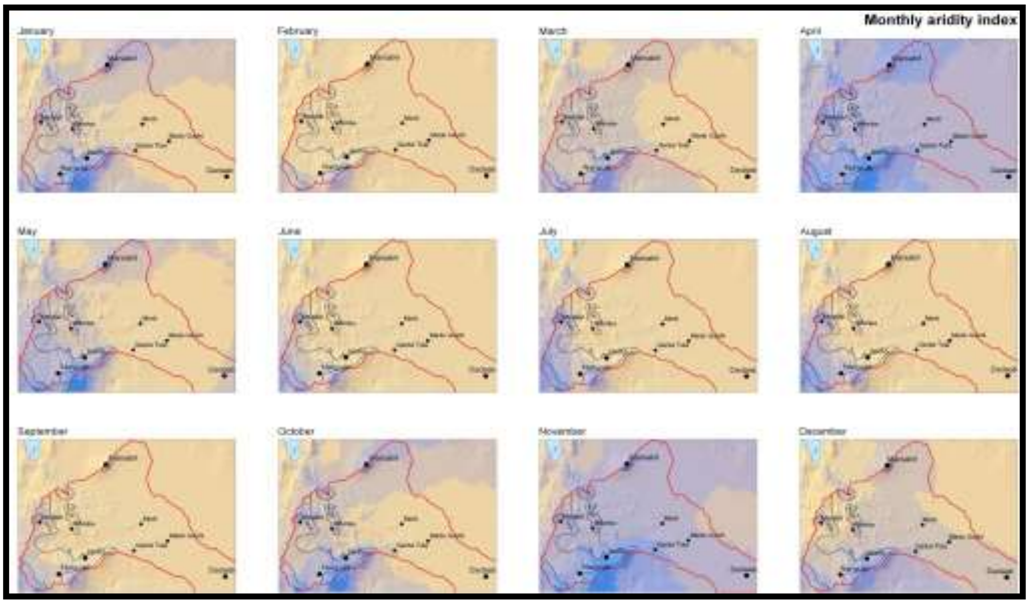


Figure 2-3 Land Cover in the Upper Ewaso Ng'iro North River Basin (Source: ILRI, 2011)

2.4.2 Climate vs Agro-Climatic Areas

According to Sombroek et al (1982),' Kenya has seven agro-climate zones founded on aridity index. The areas with index more than fifty percent have great cropping prospective. According to ILRI (2011), the areas marked for high agricultural potential are agro-climatic zones 1, 2, and 3. Zones 4, 5, 6 and 7 have index less than fifty percent with annual of rainfall below 110mm. These zones are normally denoted to as ASALs. Figure **2-4** shows agro climatological zones of the basin.



Key

Figure 2-4 **Aridity Index (Source: ILRI, 2011)**

Table 2-3 Agro Climatic Zones of the Upper Ewaso Ng'iro North River Basin

Agroclimatic Zones	ACZ	Zones	Area (km2)	Area (%)
Humid	I	a	386	0.5
Sub-humid	II	a	815	1
Semi-humid	III	a	2011	2.4
Semi-humid to semi-arid	IV	b	3568	4.3
Semi-arid to arid	V	b	10855	12.9
Arid to very arid	VI	c	14124	16.8
Very Arid	VII	c	52088	62.1

Source: Gichuki, et. al (1998).

2.4.3 Land Use

The Upper Ewaso Ng'iro North river basin has mainly seven land-use types. Livestock production is dominant in land use with about 91 % of the catchment area. The Table 2-4 summarizes the land-use in the Upper Ewaso Ng'iro North river basin.

Table 2-4 Catchment under Seven Land Use Classes

	Zone A		Zone B		Zone C		Total	
Land use	**Area (km2)**	**Area (%)**	**Area (km2)**	**Area (%)**	**Area (km2)**	**Area (%)**	**Area (km2)**	**Area %**
Wildlife Conservation	25	0.8	137	0.9	2708	4.1	2869	3.4
Conservation forestry	394	12.3	1924	13.3	330	0.5	2648	3.2
Livestock production	1368	42.6	7296	50.6	60299	91.1	68963	82.2
Production forestry	157	4.9	370	2.6	0	0	526	0.6
Mixed crop-livestock production	1265	39.4	3893	27	0	0	5158	6.2
Irrigated crop production	2	0.1	43	0.3	0	0	45	0.1
Livestock production and wildlife conservation	0	0	761	5.3	2875	4.3	3637	4.3

Source: Gichuki, et. al (1998).

2.5 Water Resources Status in Upper Ewaso Ng'iro North River Basin

2.5.1 Rainfall

The basin receives mean annual rainfall ranging from 350 mm to 1500mm. the rainfall distribution is influenced by elevation and direction of key features. These features include Mt. Kenya, Hills Nyambene and Nyandarua, and Ridges Mathews Lariak, Marmanet and Ndundori. There are four seasons in the basin. These include long rain, continental rain short rains and dry seasons. 29-40% of annual rainfall in the basin is derived from the long rains between mid-March and Mid-June. Figure **2-5** shows the annual rainfall dispersal in the basin (Gichuki et al, 1998).

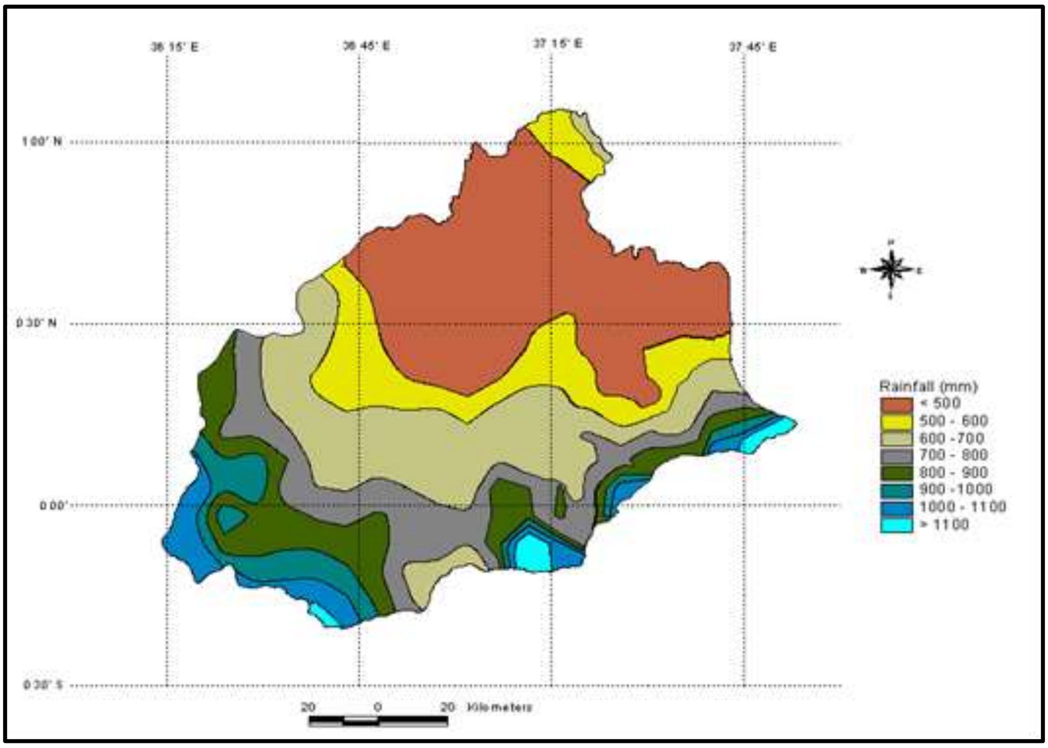


Figure 2-5 **Rainfall Distribution (Annual Mean) of Upper Ewaso Ng'iro North river basin (Source: Mati, 1998)**

2.5.2 Surface Water

The Upper Ewaso Ng'iro North river basin can be described into 3 sub-basins. They include Mt.Kenya, Narok and Lowland sub-basins. The three basins have a common point referred to as Junction. This junction is the confluence of Ewaso Ng’iro Rivers and Ewaso Narok. The comparative contribution of these basins to the flow of the river at Archers Post differs with precipitations system (Gichuki et al., 1998b).

According to Gichuki (1998), analysis of comparative contribution shows that Mt.Kenya and Narok sub-basins vehave high precipitation and enhanced ground cover thus supplies the majority of water in the dry periods. Mt.Kenya subsystem contributes most during normal precipitation and dry seasons and as well as for dry and wet periods. The Narok sub-basin maintains discharges moderate at Archer's Post around June to September (Continental Rainfall). Ewaso Ng'iro Lowland sub-basins supply most of the flow of water in the periods with high rainfall. This is characterized by high runoff due to nearly bare catchment area at the start of the rains a shown Table 2-5.

Table 2-5 Sources of Flows at Archer's Post.

Period	Ewaso Narok	Ewaso Ng'iro-Mt.	Ewaso Ng'iro-Lowland
	Sub-basin	Kenya Sub-basin	Catchment
	(5AC8) (3,380 km2)	(5D5) (4,640 km2)	Sub-basin* (7,180 km2)
1951 (wet year)	22	22	56
1952 (dry year)	18	75	7
1960 (average rainfall year)	11	67	22
April (wet month)	11	40	49
September (dry month)	59	41	0
November (wet month)	23	36	42
February (dry month)	28	69	3
Annual mean	30	46	24

Sources: NRM[3], 2000.

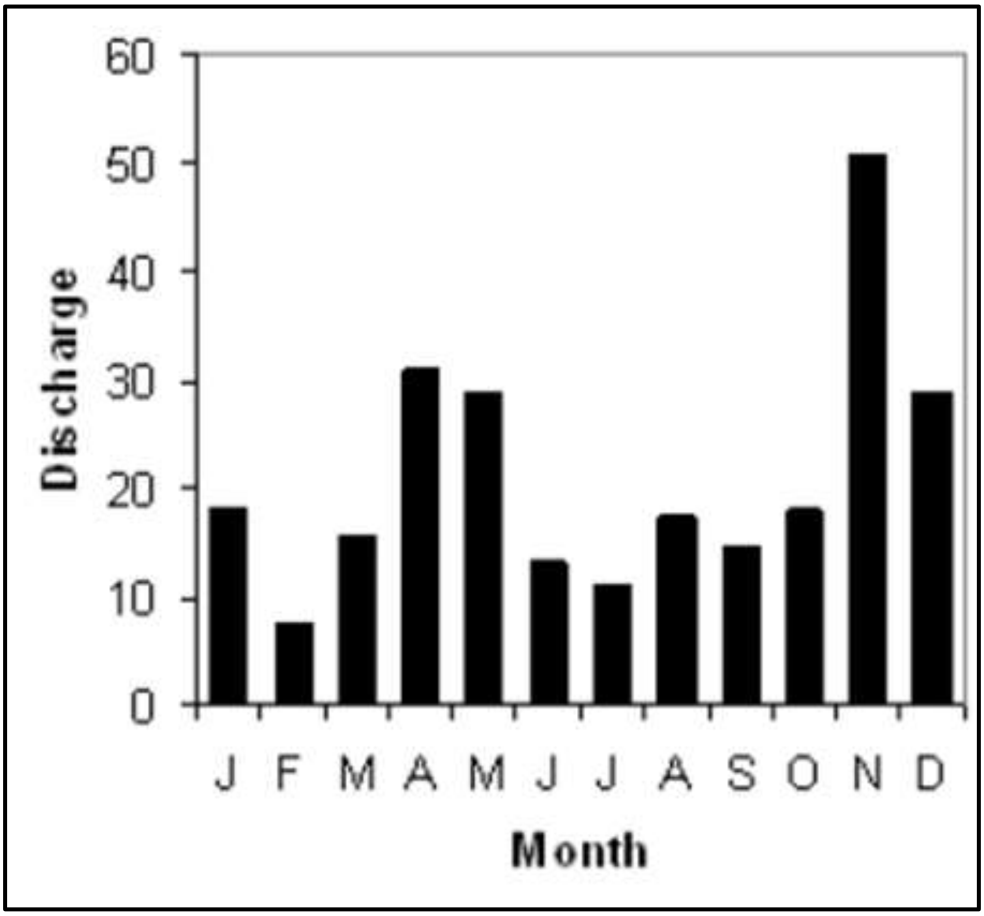


Figure 2-6 **Average discharge in cubic meters per second based between 1960-2010 at Archer's Post (Source: ILRI, 2011)**

The flow analysis at Archers post from 1960 displays an obvious tendency of declining dry flow. Gichuki et al (1999) observed that since 1970 the flow has been decreasing. A period between 1960 and 2000 the minimum annual flow recorded was 6.8m^3/s in 1980 and a maximum of 82.36 m^3/s in 1961. The mean flow recorded was 20.8 m^3/s. The flow increased between the year 1998 and the year 2000 with a mean flow of about 350 m^3/s in May 1998 with flow dropping to nil in the month of February year 1999.

According to Liniger (1995), February has the lowest river flow recorded at Archers Posts gauging station. The mean for the months of February fell from about 10m^3/s in1960s to about 1 m^3/s in the 1990s. In 1984, 1986, 1991, 1994, 1997, and 2000 the river dried up to a 60km upstream stretch of Buffalo springs (Gichuki et al. 1995). The decreased discharges are largely associated with a rising abstraction of water upstream and the cycles of drought.

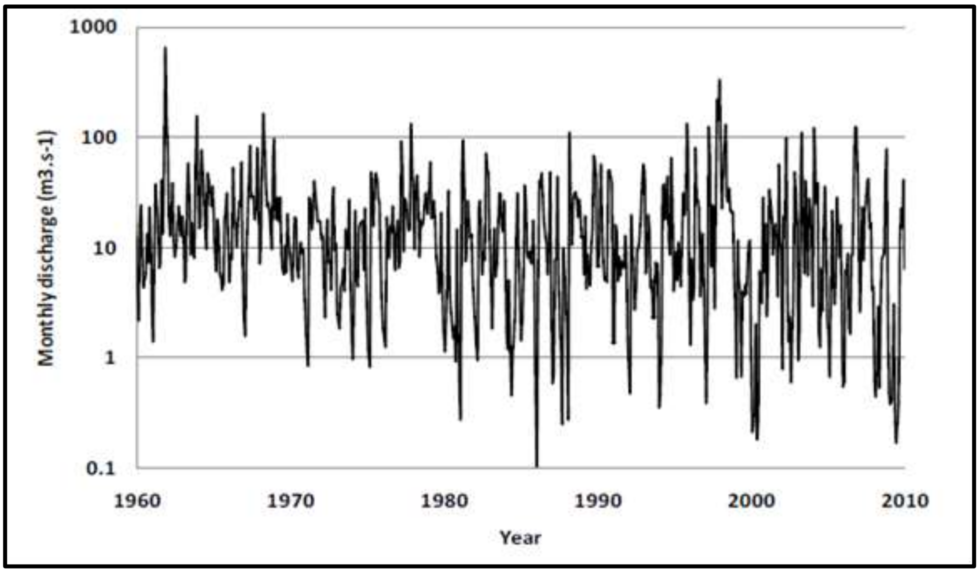


Figure 2-7 Monthly Discharges vs Time in Years at Archer's Post (Source: ILRI, 2011)

2.5.3 Ground Water

Ewaso Ng'iro Catchment has a total of groundwater replenished ranging between 120 to 220 million cubic meters annually (MOWD, 1987). During the dry seasons, the springs discharge to the Ewaso Ng'iro River. This is of great significance to wildlife and pastoralists downstream. Hydrogeological properties of a certain area influences groundwater yields. The discharge in the catchment of static water ranges from 0.3 cubic meters per hour to 13.7cubic meter per hour and a depth of 5.3 to 96 meters.

Several of factors influence the number of boreholes in the catchment. They include groundwater potential, alternative water source available, economic activities in a given area, and borehole ownership. The government owns most of the boreholes in communal owned lands and pastoral areas. Boreholes are distributed in Ewaso Ng'iro catchment as shown in Figure 2-8.

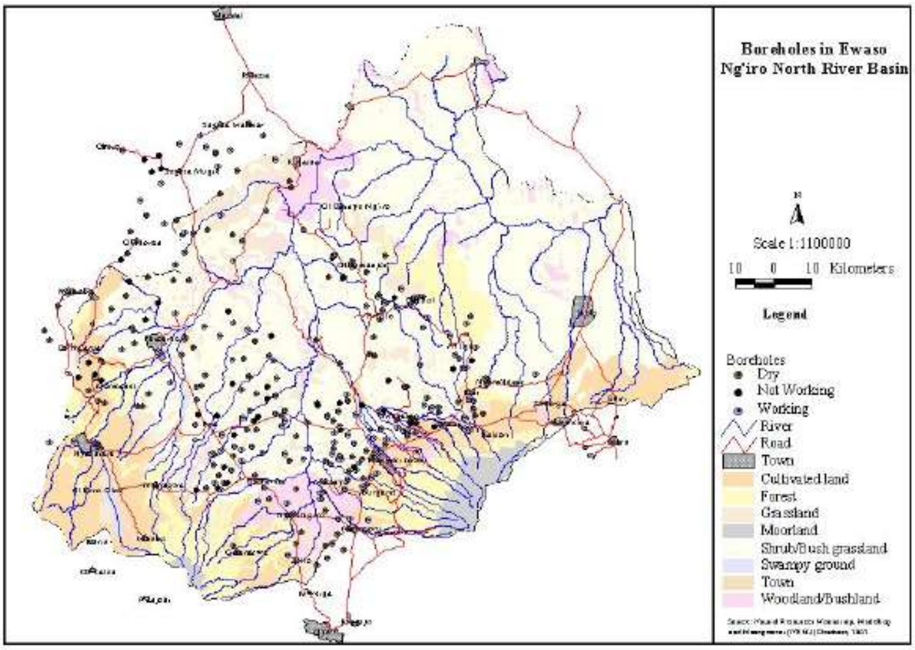


Figure 2-8 Wells Distribution in the Basin (Source: ILRI, 2011)

2.6 Water Demand

2.6.1 Water Demand Pressure in Kenya

According to the National Water Master Plan (NWMP) of 1992, water demand in key groups will increase considerably from 2000Mm^3/year in 1990 to about 6000 Mm^3/year in 2010. These categories are domestic, industrial, agriculture including, wildlife, livestock irrigation, and hydropower. Kenya has been classified as a country under water scarcity with its large area being arid and semi-arid. The developments both social and economic projected by vision 2030, will require more fresh water than present-day (Kenya, 2008). Irrigated agriculture is the leading sector in water usage.

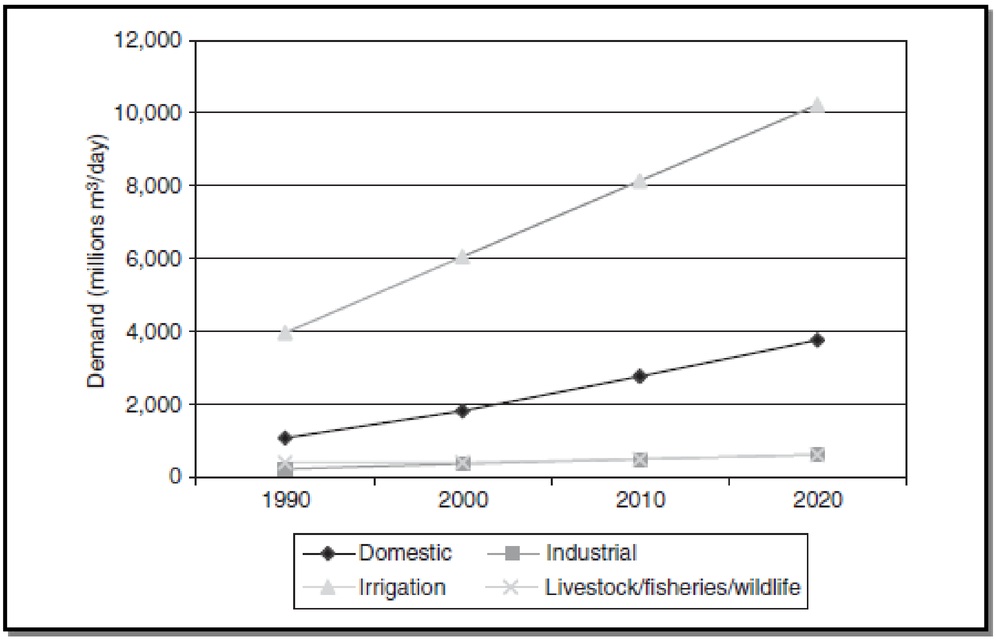


Figure 2-9 **Estimated Water Demand (Source: MoWD, 1992)**

2.6.2 Growing pressure on Water Resources at Upper Ewaso Ng'iro North River Basin

The key source of water in the basin is river discharges, which is habitually in excess during the wet season and becomes scarce during the dry season. Water demand is highest during the dry season up 80% of available river water and the scenarios are worsened by large scale, capital intensive farming where flowers and vegetables for the overseas market are grown (Linger et al., 1998).

A river abstraction survey carried by Rural Focus presented a comprehension of the key consumers of water in the catchment. The survey centred on the water users and the volume of water diverted. The survey was carried during the dry season on six rivers namely Burguret, Likii, Nguisishi, Sirimon, Naro Moru, and Nanyuki. Based on a group of users, it consist of generally by the small-scale water users was at about 85%, followed by Community Water Projects (CWPs) at 10% and commercial farms at 6%. Nevertheless, based on the amount of water abstracted, a different scenario was derived. Community water projects abstracted most of the water at 67% of the total amount abstracted. Large commercial farms at 14%, followed by small-scale abstractors at 11% while the municipals system at 8%. This is represented in the Figure 2-10 and the Figure 2-11.

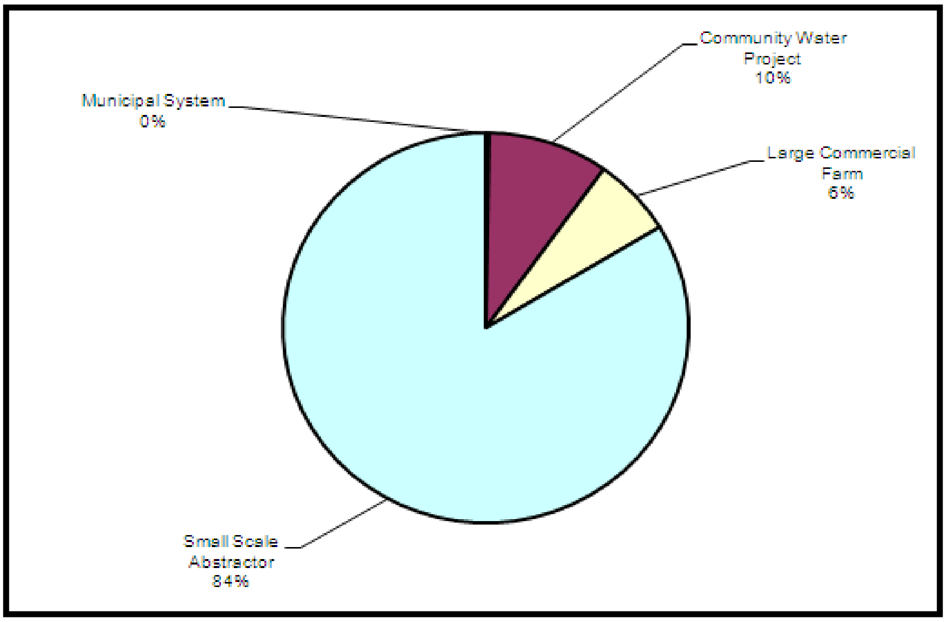


Figure 2-10 **The Percentage of Number of Water Users in the Upper Ewaso Ng'iro North River Basin (Source: Rural Focus, 2006)**

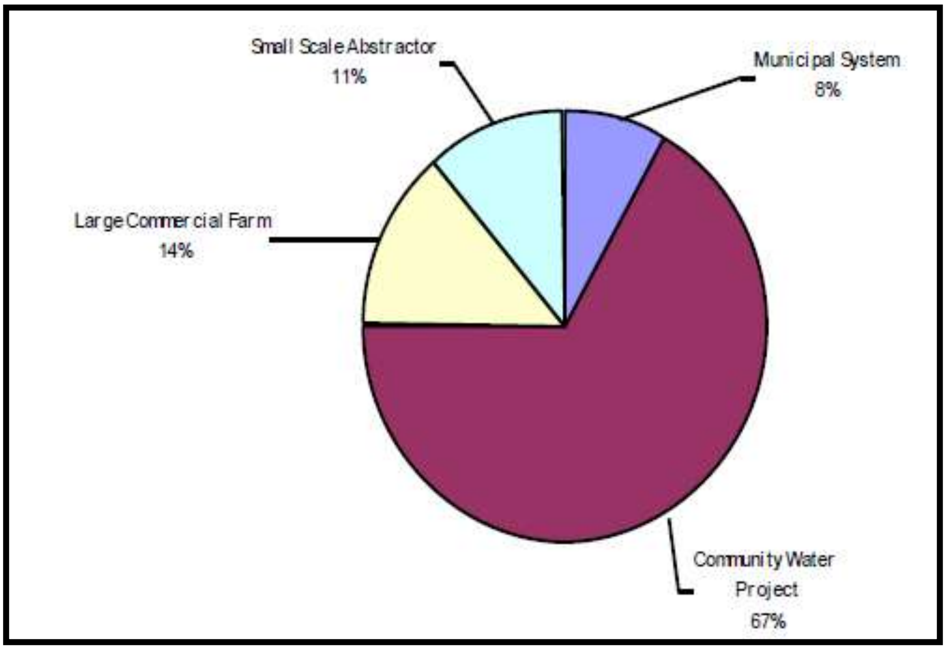


Figure 2-11 **Type of the Water Users and Percentage of Volume Water Used in the Basin (Source: Rural Focus, 2006)**

2.7 Water Allocation and Planning

Water scarcity has continued to grow globally thus calling for water allocation plans and policies to combat conflicts associated to access to water at international, regional and local levels. Water resources allocation has remained ultimate in the course of determining amount of water is available for usage among consumers. There is a number of challenges that have led to development over time in water allocation planning and they include but not limited to; economic growth, increased water abstraction, a decline of freshwater ecosystem, and climate change (Speed *et. al.*2013).

2.7.1 Water Allocation Methods

Methods of water allocation are in most cases established on composite guidelines for dealing with inconsistency in balancing the political, environmental, social and economic implications of diverse allocation of water scenarios. In today's world, the allocation of water is basically based on ever-changing economies, water rating motivations, and the response of water usage to climate change.

The method for water allocation involves distributing water at different levels, which comprise of geographical and administrative levels. Total water accessible within the basin is prime in a developing water allocation plan. Water allocation method involves assessment of water available in a basin, water use and predicted water demand in the future, and environmental flows. Water allocation method is designed to achieve equitable distribution of the limited resource. They include environment; development; harmonising supply and demand and upholding the proficient water use. Figure 2-12 show a water allocation method where environmental flows have been used as the desired indicator for the base of valuation allocation (Speed *et. al.*, 2013).

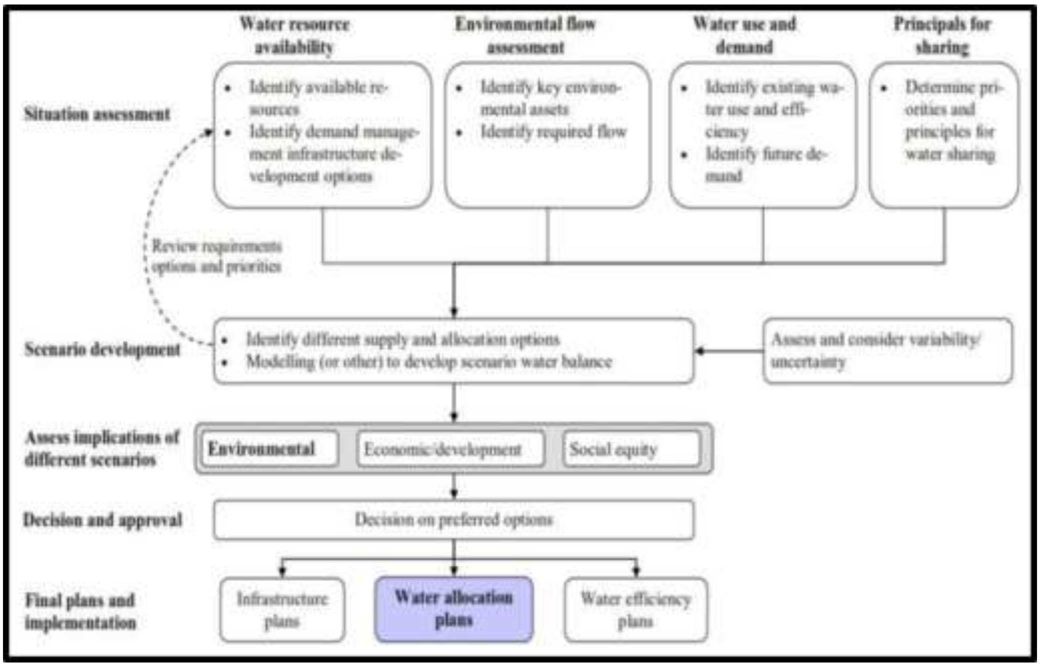


Figure 2-12: Water Allocation and Planning Process (Source: Speed et. al., 2013)

2.7.2 Water Allocation Methods in Kenya

Insufficient managing of water resources and the general decline of rainfall in Kenya have heightened problems associated with water scarcity. In recent decades, water use conflicts have increased owing to the increased demand for accessible water resources. Governmental Management and River Water Users Association undertake the water management activities.

2.7.2.1 Governmental Management

In Kenya conflicts surrounding water resources has never been made easier by the existing legislation of the water resources. According to Gichuki and Ngigi (2001), there are a number of reasons why existing administration and legislation has never eased water-related conflicts. Complicated and unclear legislation is one of the reasons. Water is declared as a common resource owned by the government according to the Water Act and main priority is granted to domestic use. Different administrative levels such as boards, ministries and authorities have a say in the water distribution. Over time, this has caused insecurity about administrative and legislation and so most people do not take it seriously. Lack of enforcement is another reason. Penalties for over abstracting are very low and do not prevent the users from drawing more water than they are permitted. Others include administrative boundaries and random allocation.

2.7.2.2 River Water Users Associations

The River Water Users Associations (RWUAs) a self-help group movement, has been taking the place in facing water shortage in some catchment in Kenya especially Upper Ewaso Ng'iro North river basin sub-catchments. This has increased community involvement and participation in various forums addressing water scarcity. The RWUAs have a number of objectives:

- They promote the legal activity of water use that upholds the essentials of all users depending on river water;
- They monitor and observe water resources in the catchment;
- They safeguard an impartial distribution of water among users;
- They act as a bridge between water users and government agencies.

2.8 Hydrological Modelling

Hydrologic models are the mathematical functions, which articulates the different components of a hydrological cycle (Beven et al., 1979).

According to Schultz, (1993), the key components of a hydrology in any area of study include surface water and groundwater. The relationship of these sub-systems depends on features such as geological features, geographic features and ecological features.

2.8.1 Various Hydrological Models Used

The ANSWERS-2000 model for pollution controlling was established by Bouraoui for modelling an average annual sediment yield and surface runoff Bouraoui et al.,1986).

Yuan et al. (2001), executed the AnnAGNPS Model . The purpose of this model was to gather all requisite data from the Mississippi Delta Management System Evaluation Area (MDMSEA) so that AnnAGNPS can be authenticated. .

The Stockholm Environment Institute's Boston Centre at the Tellus Institute developed WEAP21. WEAP21 was intended to support rather than to substitute the experienced developer. The model deals with demand and supply inclinations, to resolve the water distribution issues (Yates, 2005).

The Danish Hydraulic Institute (DHI) developed MIKE BASIN for hydrological modelling. MIKE BASIN forms a system in which different stream units. (Christensen, 2006).

2.8.2 Application of SWAT in Water Allocation

SWAT is a model for the river basin, which is one of the prominent spatially distributed hydrological models. SWAT runs on an everyday period. SWAT encompasses a GIS interface and computes every day balances from climatological, land use and soil files. SWAT has the ability to envisage the impacts of management river basins. The model has been extended in water resources application as well as in agriculture. With the ability of SWAT to convert raster and vector data into model outputs, the result is a comprehensive hydrologic model that could be used to the river basin users. SWAT will provide estimates of peak and low flows that can be used to enlighten the water users potential of flooding hazard as well as seasons of water scarcity thus informing management of managing water allocation during low flows.

2.8.3 Why was SWAT Chosen

SWAT was chosen because of the extensive successful use in modeling various catchments in the world. The model is in public domain for use on the SWAT website (www.swat.tamu.edu) with enormous user support. This includes user forums, user manuals and training videos (Loi, 2010).

2.8.4 Limitations of SWAT

According to White (2009), some of the limitations associated with SWAT indicated that HRU’s do not represent local features adequately in terms of pervious and impervious layers. This is for both surface and groundwater and SWAT do not account for these differences in flow from one to another. He also pointed out that calibration is challenging due to uncertainties in the form of process simplification. The biggest uncertainty is in rainfall and temperature data further compounded by regionalization in SWAT at sub-basin level. Another limitation is that the model requires large volume sets of data to run. Other limitations include that the model is not applicable for 2D or 3D hydraulics applications.

2.9 Previous Studies Using SWAT

Opere and Okello (2011) medelled Nyando River. Flow data was accessible for two river gauging stations. The flow data was starting from 1950 to 1997, although there were missing gaps. From simulation, the NSE was found to be 0.46 while the R^2 was 0.24.

Setegn et al. (2008) established a hydrologic model for Lake Tana basin. The SWAT2005 was applied. The SCS curve number II was found to be the most profound factor for the catchment. Calibration resulted with coefficient of determination 0.71 and Nash Sutcliff Efficiency 0.61 for Gumara catchment..

Chebud et al. (2009) carried out water balance of Lake Tana. The research aimed at reviewing water balance components and undertake modelling over the Lake. The major constituent of water balance were projected independently using diverse methods of evapotranspiration approximation. Average monthly and yearly discharges of over 40 years (1960 to 2003) were used to evaluate the discharge. The study showed there has been high-suspended inflow from the basin (BCEOM 1999). The research established that the theory of surface runoff from the un-gauged catchment would not cause substantial uncertainty.

2.10 Conclusions of the Literature Review

Water scarcity in many catchments in Kenya continues to be experienced despite government agencies effort to ease it. Although in most of the catchment especially in Upper Ewaso Ng'iro North river basin where WUAs are actively involved, little has been realised in obtaining users commitment to the effective management of water resource. Because of this water scarcity, conflicts arise with consequences. This is as a result of a limited access to water of quality and in terms of quantity mainly caused by upstream users. Therefore studying the relationship between water availability and use is significant in addressing and managing these conflicts.

3 MATERIALS AND METHODS

3.1 Study Area

This study was carried out in Burguret River Sub-catchment which is sub-basin of Ewaso Ng'iro River basin and traverses Laikipia as well as Nyeri Counties. It covers an area of 210 km^2 which is approximately 1.5% of the upper Ewaso Ng'iro Catchment. Burguret River is one of the important rivers in the catchment and originates in Mt. Kenya and drains to Ewaso Ng'iro River. The altitude ranges from 4200 to 1800 masl. On the upstream, the sub-catchment consists of natural forest and plantation forest. The lower part is mainly populated by small scale farmers and ranchers. Both small scale and commercial irrigation are practiced in the catchment.

Due to elevation gradient, soils and climate difference in the catchment, ecological zones have resulted from humid to semi-arid. The basin is situated in a leeward part of the mountain thus contributing to low rainfall compared to the windward side. The annual rainfall ranges from 2000 mm in highland to 600 mm in lowlands. There are two rainy seasons annually, long and short rain, however, rainfall varies considerably from year to year as well as to seasons. The catchment traverses five ecological zones. It starts from Mt. Kenya to plains of Laikipia plateau. The ecological zones include the afro-alpine zone, the moorland zone, the forest zone, the foot zone, and the savannah zone. The Location of the study area is shown in Figure 3-1.

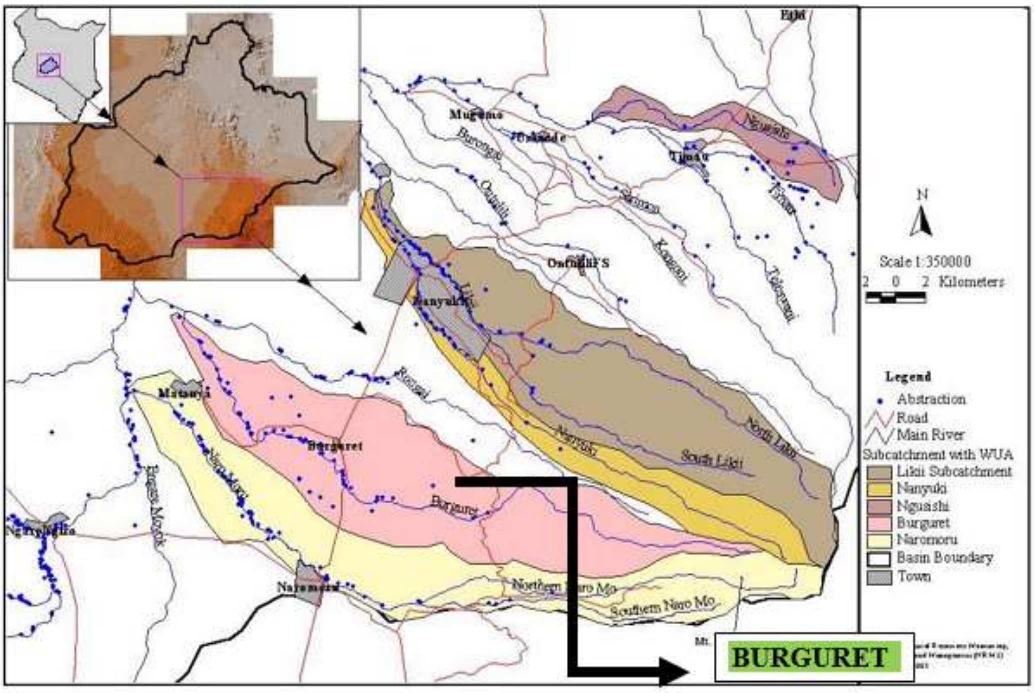


Figure 3-1 Location of the Study Area.

3.2 DATA TYPES AND DATA COLLECTION

Social and natural processes and interactions of both brings about the dynamics in a water catchment. This research encompasses of studying dynamics of water resource in the catchment comprising the link between water demand and water availability. Analysis of the Burguret Sub-catchment was analysed largely during the dry spells when water demand is high. A comprehensive description of the datasets and their sources are articulated in this section.

3.2.1 Data Types

To determine the water demand in the basin, the following data sets were used;

- Population data ;
- Irrigation water requirement data;
- Abstraction data.

To determine the water availability in the basin, the following data sets were used;

- Land use data;
- Soil data;
- Meteorological (Rainfall, radiation, temperature, humidity, etc);
- River flow data;
- Digital Elevation Model (DEM);

3.2.2 Data Collection

To determine the demand and availability of water in the basin, the data was collected from both local and global sources. The existing literature and previous research work on different water sources in the basin was also reviewed. The meteorological datasets, hydrological data such as river flow and abstraction data, were collected from Water Resources Authority (WRA), Centre for Training and Integrated Research in Asal Development (CETRAD), International Livestock Research Institute (ILRI), and Rural Focus. The spatial datasets such as land use and soil data were compiled to shape from Kenya Soil

Survey. Digital Elevation Model was collected from Advance Space-Borne Thermal Emission and Reflection Radiometer (ASTER).

3.3 Data Quality

Most climatological records are usually characterized by inconsistencies, which could be as a result of instrument changes, changes in gauge location or surrounding conditions or changes in observation procedures (Sahin & Cigizoglu, 2010). Methods used in data collection, estimation of missing records, transmission and processing are in most cases with associated errors and this may cause the heterogeneity of the records (González-Rouco et al., 2001). In this study, the climatological data collected was pre-processed by CETRAD to check for the quality of those climatological records.

3.4 Data Analysis

3.4.1 Assessment Surface Water Demand Dynamics in the Study Area

To assess surface water demand dynamics in the study area, the Burguret river sub-catchment was studied. In the Burguret basin, the largest water user is irrigation. About 46% of the basin is under irrigation both large scale and small-scale schemes (NRM3 Database, 2002). The crops are mainly irrigated during dry seasons, which occurs from February to March and July to September. To determine total water demand for irrigation every user/abstractor, a Demand-Based Estimate Method was used. The worst-case demand scenario was considered where there is no rainfall to supplement for irrigation. The only demand components considered were; Irrigation, Domestic and livestock water demand. The water demand in m^3/day was given by the following equations.

People: Dw = No of People * 40 Liters per Day * 10^{-3}

Livestock: Dw = No of Livestock *60 Liters per Day *10^{-3}

Where Dw is water demand m^3

MoWI (2015)

Irrigation: The following parameters were assumed in calculating irrigation demand.

Reference Potential Evapotranspiration ETo = 5mm

Crop Factor Kc = 0.8

Irrigation Efficiency η = 70%

Dw = ETo * A * 4047 * 10^{-3} X 0.8 *(100/70)

Where

A = Area in Acres

(Adapted from FAO, 1977)

ArcMap was used to map points of water demand (Abstraction Points) for irrigation in relation to the amount of water abstracted and the data was then presented in the form of a map showing the locations of the abstractors.

3.4.2 Determination of Surface Water Availability

To determine the surface water availability in Burguret, SWAT was applied to model surface runoff flows thus generating available surface water as well as the comparing to observed discharges. The Model-based on curve number method and was built using ArcGIS interface known as ArcSWAT. The hydrologic cycle simulated by the model was established on the equation of balance:

$$SW_t = SW_0 + \sum_{i=1}^{n}\left(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}\right) \tag{3.1}$$

where, SW_t and SW_0 are the final and initial soil water content on day i (mm H2O), t the time steps on day i, R_{day} the rainfall that reaches the soil surface on day i (mm), Q_{surf} the surface runoff on day i (mm), E_a the evapotranspiration on day i (mm), w_{seep} the interflow on day i (mm), and Q_{gw} is the baseflow on day i (mm) (Neitsch et al. 2005).

The steps that were followed in SWAT are shown the .

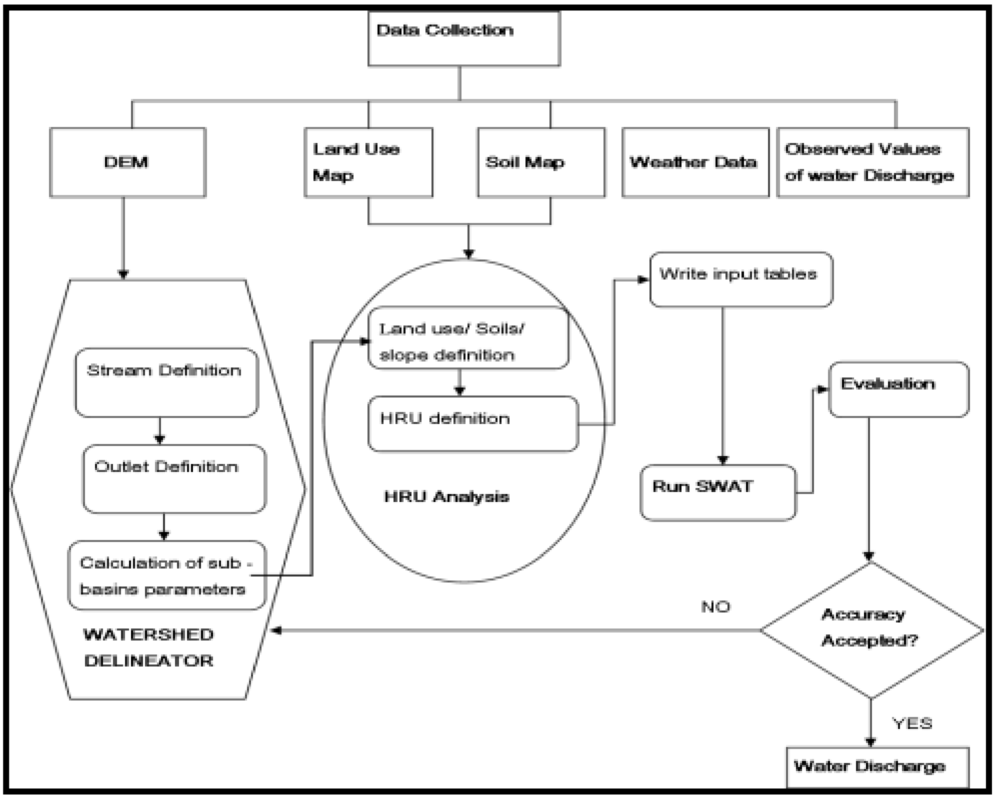


Figure 3-2 Flow Chart Showing Procedure in SWAT Application

Source (Lam et al., 2010).

The numerical techniques were applied for assessing model presentation. In this study, NSE was used for the assessment of model for testing.

3.4.3 Limitations of SWAT

The following are the limitations of using SWAT:

- Spatial representation of HRUs disregards pollutant routing in a basin;
- SWAT procedures are empirical;
- Not appropriate for 2D or 3D hydraulics uses.

3.4.4 SWAT Modelling

The SWAT was used in this study as the integrated modelling tool for hydrological modelling since it has a definite approach of water balance in the soil. SWAT permits a number of procedures to be modelled in the basin. Usually, delineation takes place and results to units of watersheds which are treated as separate units. The watersheds are further divided into small units referred to as HRUs which are composed of similar characteristics (soil and land use). The model mostly uses the SCS Curve Number for surface runoff estimation. This study was based on the SCS Curve Number for surface runoff estimation.

3.4.5 Model Input Data

The data used in this study was gathered from both local and global sources and included DEM, land use map, soil map, and meteorological data.

3.4.5.1 River Flow Data

The river flow records used were acquired from WRA. The Burguret River gauging station (5BC06) data was studied. The observed streamflow data obtained were daily discharges from February 1948 to December 2010. However, only data for 14 years (1997-2010) was used for the purpose of this study because it had limited missing gaps. This data was used for calibration and validation purposes.

3.4.5.2 Digital Elevation Model

The digital elevation model of Burguret sub-catchment was collected from global digital elevation data ASTER with 30 meters resolution. Figure 3-3 shows DEM collected from ASTER. The DEM was used to delineate basin and formed the foundation of all spatial data and SWAT model set-up.

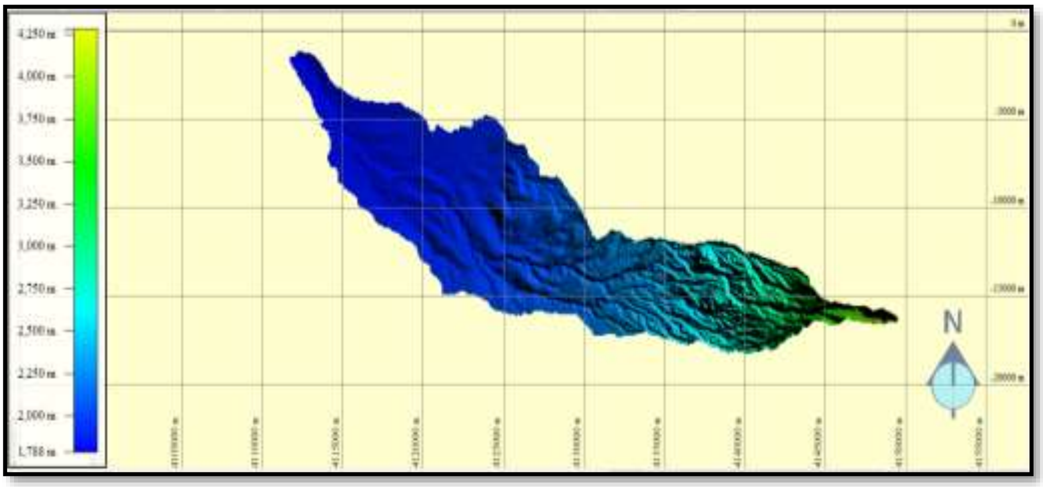


Figure 3-3 Digital Elevation Model from ASTER

3.4.5.3 Soil Data

Soil data with different properties were obtained from the Kenya Soil Survey inform of shapefile. KENSOTER table was used to determine different features for the soil units in the area of study. Some of the properties of soil determined are shown the Table 3-1. Figure 3-4 shows different types of soil in the sub-catchment.

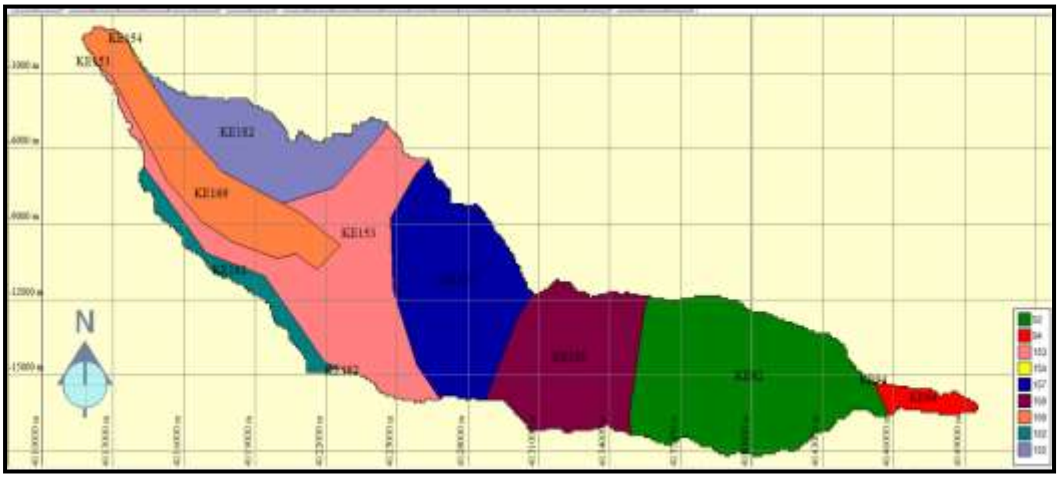


Figure 3-4 Soils in the Basin

Table 3-1 Some of the Properties for Soils in the Basin

SOIL UNITS ID	BD	% CLAY	% SILT	%SAND	EC
KE92	0.89	44	26	30	0
KE94	1.14	27	35	38	0
KE153	1.16	46	28.5	25.5	0
KE154	1.05	53	32	15	0
KE157	1.09	19.5	38.5	42	0
KE158	0.82	40	30	30	0
KE169	1.44	16	26	58	0
KE182	1.255	22	47	31	0

3.4.5.4 Land Use

Land-use is a significant aspect that influences runoff in a watershed. It also influences erosion and evapotranspiration. The land-use data were acquired from the United State Geological Survey (USGS). The land use types were regrouped based on the topographical map (1:50,000) available, and images.

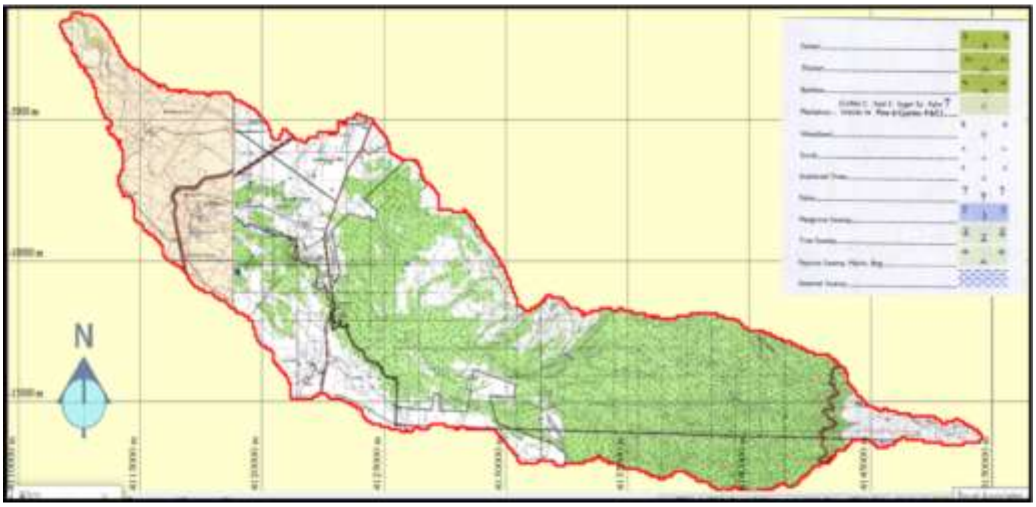


Figure 3-5 Major Land Use on Topographical Map (1:50,000)

The reclassification of the land was carried out to characterize definite land cover such as Cropland, forests and barren. The land abbreviations are shown in Table 3-2.

Table 3-2 Reclassification Observed Burguret land Use to SWAT Land Use Types

Kenya Land Use	SWAT Land Use	SWAT Land Use Code	Total Catchment
Agriculture Sparse	Cropland and Pasture	AGRL	45.73%
Plantation	Mixed Forest Land	FRST	22.79%
Woodland	Deciduous Forest land	FRSD	6.23%
Forest	Evergreen Forest Land	FRSE	2.03%
Grassland	Savannah	RNGE	1.51%
Shrub Land	Shrub Cover	RNGB	21.34%
Bare Land	Barren	BARR	0.39%

Figure 3-6 Satellite Imagery for Burguret Sub-catchment

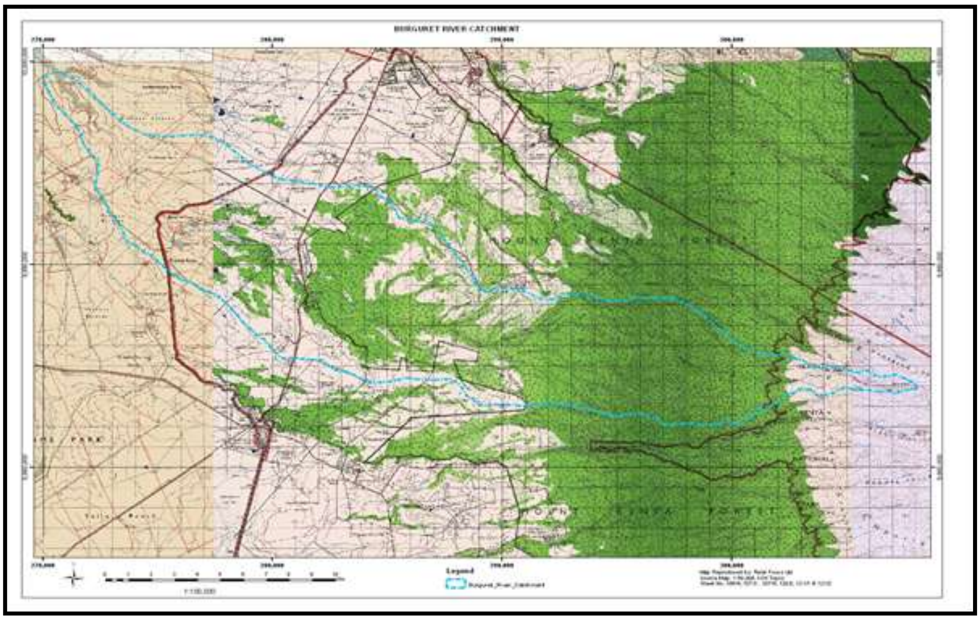


Figure 3-7 Topographical Map of Burguret Sub-catchment

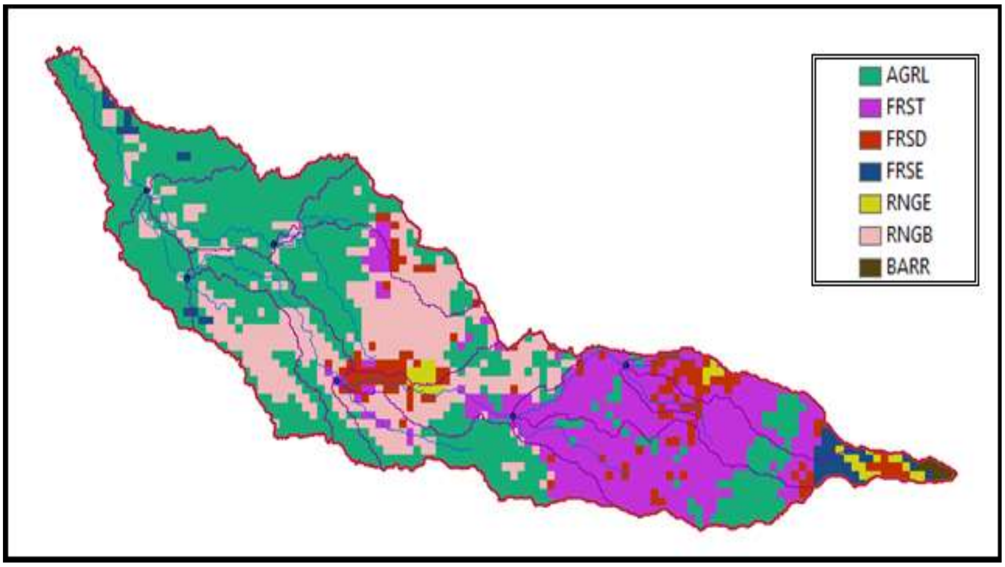


Figure 3-8 Re-classed Land Use data for SWAT Simulations

3.4.5.5 <u>Weather Data</u>

Daily meteorological data is required by the model. The weather Generator was used to input data to SWAT and was derived from 14 years of daily meteorological data. The datasets generated included Rainfall, temperatures (both maximum and minimum), solar, humidity and wind. The output for the data encompassed: Standard deviation for rainfall, Average monthly precipitation, and mean a number of times (days) of rainfall in a given month.

3.4.6 Establishing Relationship between Water Demand and Water Availability

To establish a relationship between water demand pressure and water availability at different seasons of the year, CropWat model based on the

Penman-Monteith equation was applied. The model was used to determine the quantity of water applied in irrigation at various times of the year. Vegetables, Tomatoes and Green Beans were assumed to be the most applicable and most-consuming irrigated crops in the area. No other crop was considered and the irrigation water requirements were assumed as estimations for actual water demand. The mean monthly and annual rainfall was analysed with hotspots (abstraction points) where water scarcity was instituted. GIS was used to map points of water demand for irrigation in relation to the amount of water abstracted and water available generated from the SWAT model. The scenarios were done based on dry season, length of the Burguret River. The data was then presented in the form of graphs showing different scenarios of cumulative abstraction.

4 RESULTS AND DISCUSSION

4.1 Introduction

This section presents data analysis obtained from the field and discussions of results of the SWAT application to Burguret Sub-catchment. The main aim of the study was to assess the demand pressure on surface water in the Burguret sub-catchment area.

4.2 Water Availability Analysis

Water availability was generated from the SWAT Model and use of the streamflow data that was obtained from WARMA.

4.2.1 Catchment Hydrology

This study focused on a semi-arid watershed where surface water is heavily abstracted for irrigated agriculture. To simulate the aspects of catchment hydrology, hydrological process and events were defined as the model uses hydrologic response units (HRUs). In this study, only quantity of surface runoff was considered for determining demand pressure on it. SWAT was used for simulating runoff from the catchment. SWAT Analysis

The Curve Number Method was used to simulate surface runoff and hence model infiltration process indirectly. The difference between the rainfall and surface runoff was the water available for percolation and subsequent percolation. A total of 15 subbasins were generated by SWAT as shown in Figure 4-1.

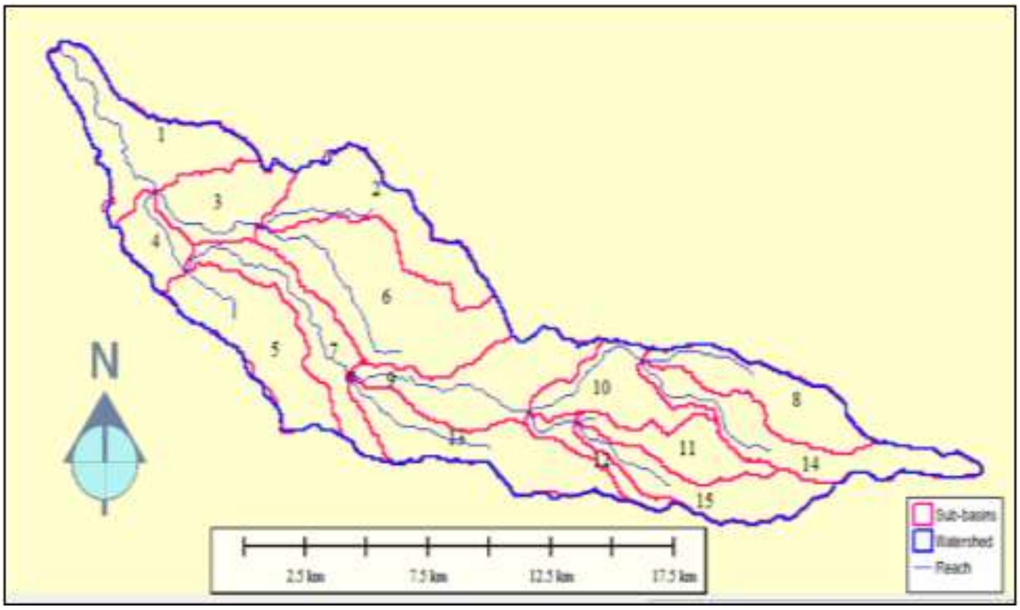


Figure 4-1 A map Showing SWAT Sub-basins within the Study Area

4.2.1.1 <u>SWAT Results</u>

A final and successful simulation was carried out and agreeable runoff results were achieved with Nash-Sutcliffe Efficiency value of 0.63. Burguret river simulation from 1997 to 2010 showed a reasonable alignment amongst monthly measured and simulated discharges. The model over predicted flow during certain periods and under predicted in others while in some periods, the observed and simulated flows agreed. In general, the model underpredicted high flows while simulating low flows fairly. The simulated curves fairy followed the observed flow at 5BCO6 gauging station located at E 2814777 N9987966, Datum Arc 1960.

Discharges results for 15 sub-basins were extracted from the output .rch files which contained the simulated flow for each reach as total discharge at the outlet of every reach.

4.2.1.2 Flow Results

The streamflow results are shown in Figure 4-2. The simulated data was based on the average monthly values at the end of subbasin 15. The measured daily flow was converted to monthly average flow data ranges from 1997 to 2010.

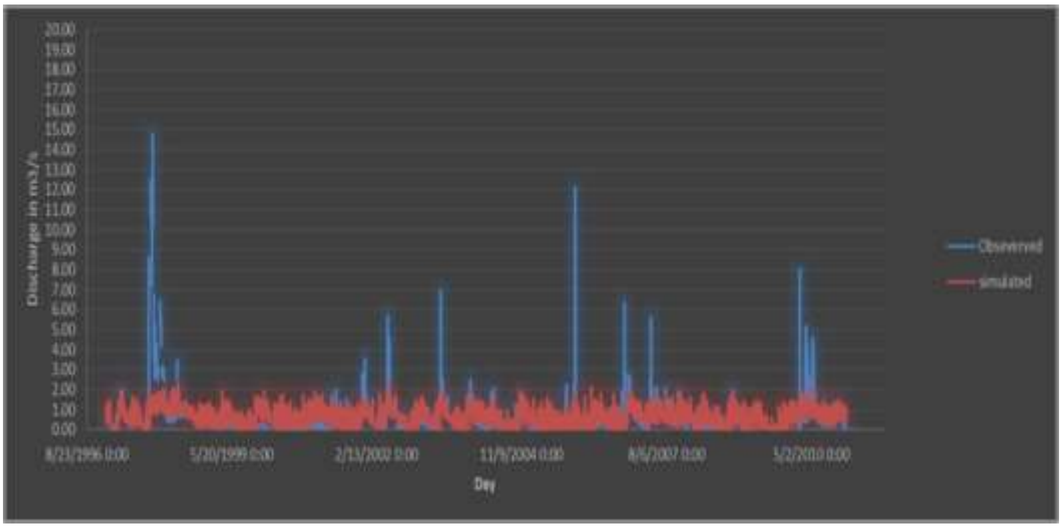


Figure 4-2 Hydrographs of Observed and Simulated Daily Discharges between 1/1/2001 and 31/12/2003

This was an indication that the model worked okay and therefore can be used to fill missing data as well as for forecasting of discharges. It was observed that for certain periods the model overpredicted while others time it underpredicted. This was attributed to the fact that the observed flows we based prompt readings. For the data collected, all the observed readings were done at 9.am while simulated discharges are based on daily averages.

The mean monthly observed discharges and mean monthly simulated discharges revealed that they tallied well unlike daily discharges as shown in Figure 4-3.

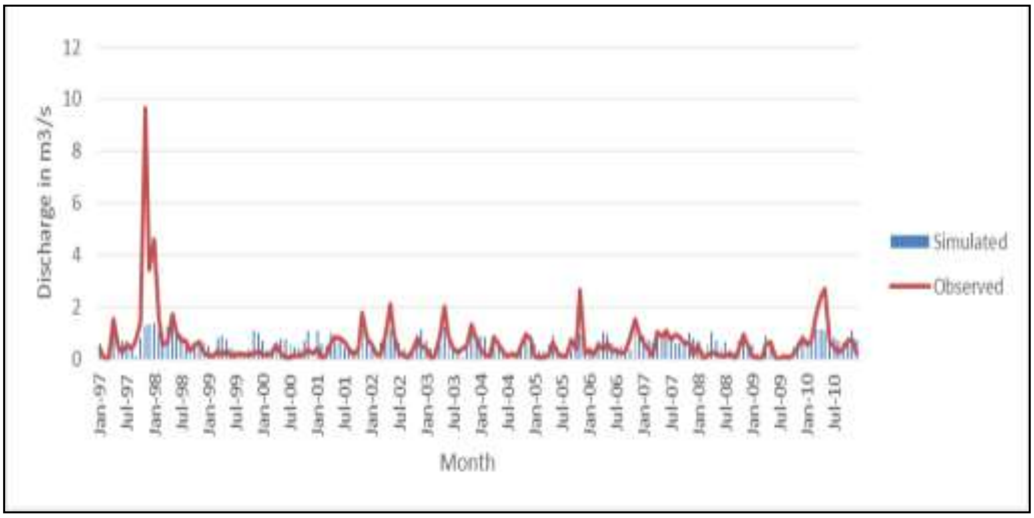


Figure 4-3 Hydrographs of Mean Monthly Observed and Simulated between 1/1/1997 and 31/12/2010

4.2.2 SWAT Model Calibration and Validation

The results presented an acceptable relationship between simulated and observed flows. The calculated NSE value was 0.63 RSR was 0.63. This indicated that the Model performed well and could, therefore, be applied for flow prediction. Generally, the Model performance efficiency defines how well the probability distributions of simulated and observed data fits each other Moriasi *et. al.* (2007).

The Performance Efficiency (R^2) value for observed vs simulated daily streamflow for the basin was 0.74 and 0.70 for the calibration and validation respectively as shown in Figure 4-2 and Figure 4-3.

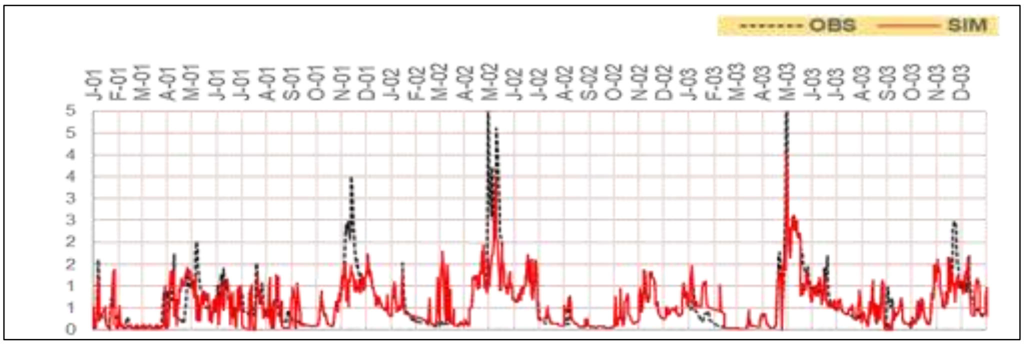


Figure 4-4 Hydrographs of Simulated and Observed Mean Daily Flows in Month for the Calibration Period 1/1/2001to 31/12/2003.

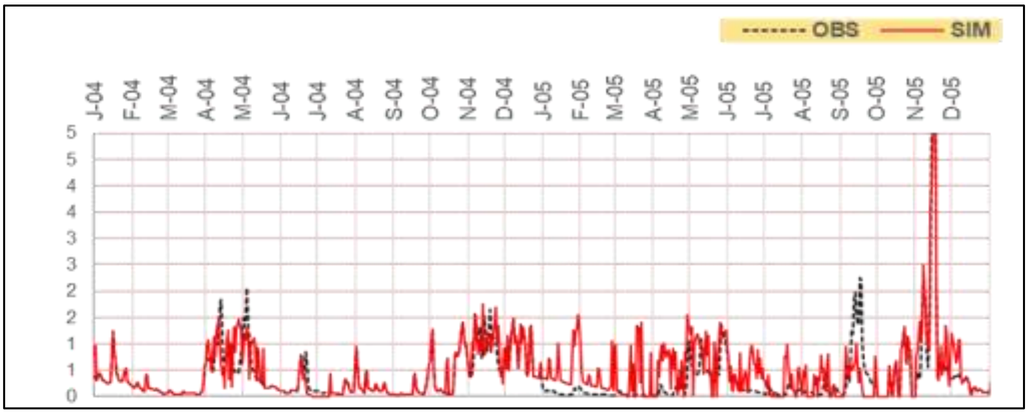


Figure 4-5 Hydrographs of Simulated and Observed Mean Daily Flows in Month for the Validation Period 1/1/2004 to 31/12/2005.

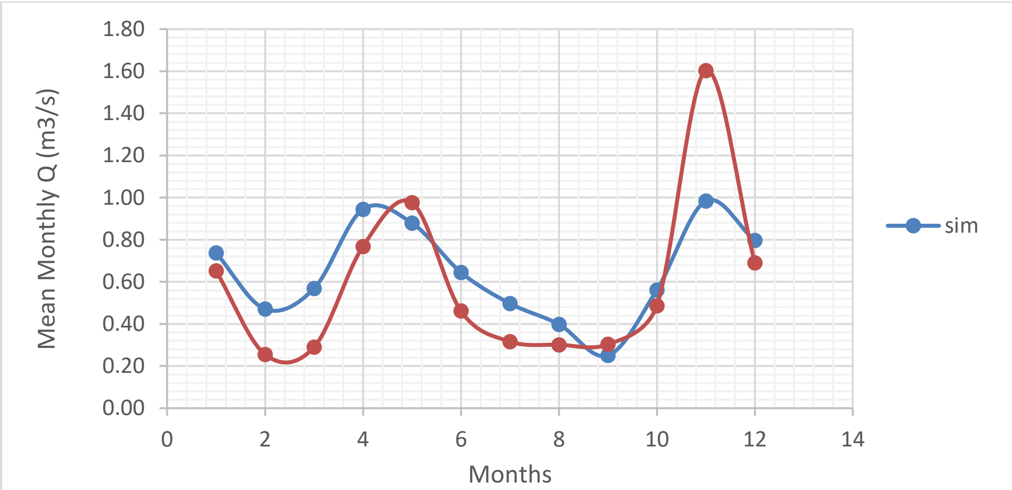


Figure 4-6 Mean Monthly SWAT Simulated and Observed Stream Flow

4.3 Water Demand Dynamics

The secondary data on water demand was obtained from WRA and Centre for Training and Integrated Research in Asal Development (CETRAD). To understand the water demand phenomenon of Burguret River Sub-catchment, the water demand was studied for three Water Users Groups:-

a) Communal Water Projects Users;
b) Domestic Water Users;
c) Large Scale Water Users.

4.3.1 Communal Water Project Users

There are five community water projects in the sub-catchment at both middle zone and upper zone and they include-

i. NGK Water Project – upper zone;
ii. Mureru Water Project – upper zone;
iii. Gatune Water Project – upper zone;
iv. Burguret Water Project – middle zone;
v. Kamangura Water Project – middle zone.

These community water projects serve both individual and institutions within the communities. The institutions are mainly the schools and health centres in addition to commercial irrigation farm, Turi Farm of 17 ha and Mount Rock Hotel. The water is abstracted through gravity intakes. The community projects are yet to obtain abstraction permits. Their legal support document for water abstraction is the form of authorisation. The Table below shows the extent of irrigation by community water project users

Table 4-1 Extent of Irrigation by Community Water Project users

The extent of land under irrigation	*Middle Belt*	*Upper Belt*
None	26.1	3.4
Up to 1 acre	39.1	51.7
Up to 2 acres	21.7	31.0
Over 2 acres	13.0	13.8
	100	100

4.3.2 Small Scale/Domestic Water Users

For the domestic water users, the water is drawn by jerry cans for domestic use and the livestock get water from the river. This group of users is located around the river. Pump users also referred to as riparian owners, also follow under this category. They are mainly located at the downstream of the sub-catchment. The land directly borders the Burguret River or some distance away but convenient to abstract water directly. In most cases, they use a pump and furrows.

4.3.3 Large Scale Water Users

In Burguret Sub-catchment, there are two large-scale farmers that is, Tambuzi and Turi Farms. They practise extensive cultivation thus high usage of water as well as fertilizers and chemicals. They have large water reservoirs for harnessing the flood flow.

Table 4-2 Prominent Water Commercial Users

Farm	Area under Irrigation (acres)	Abstraction Method	Storage (m3)
Turi	17.5	Tee from Kamangura W.P. and borehole	68,000
Tambuzi	35	Fixed pump on river	70,000

The Commercial Non-Farming User also fall under this category in the Sub catchment and are shown the Table 4-3 giving the method of supply.

Table 4-3 Method of Water Supply for Commercial Non-farming

Abstractor	Method of Water Supply	Volume ($m^{3/}$day
Mountain Rock Hotel	Burguret W.P. Unlined Forrow	209.95
Tam Trout Restaurant and Fish Farm	Furrow Pump	270
Ol Pejeta Ranching (Sweetwater's Game Sanctuary)	Furrow	6480

4.4 Abstraction Survey Results

According to data collected, a total of 113 no of abstractions were observed and analysed. The Demand Estimate Method was applied as one of the major method to the quantities of river abstraction. The considered water use cells considered were; irrigation water, domestic use, and cattle water demand. Pumping capacity, double gauging, and channel current meter gauging were also applied to access quantities s of river abstraction.

Table 4-4 presents the data for abstraction with calculated abstraction data in Appendix 1.

Table 4-4 Total Livestock Owned by Households in the Study Area

Watershed Belts	*Average HH L/stock No.*				*Total HHs No.*	*Livestock Total Estimate*			
	Cattle.	*Goats*	*Sheep*	*Chicken*		*Cattle.*	*Goats*	*Sheep*	*Chicken*
Upper	3	6	9	10	1,873	5619	11238	16857	18730
Middle	4	7	11	18	2110	8440	14770	23210	37980
Lower	3	7	6	14	906.5	2719.5	6345.5	5439	12691
	4	7	9	14	4,890	16,779	32,354	45,506	69,401

Figure 4-7 shows the abstraction points on the Burguret River with some names of the major abstractors.

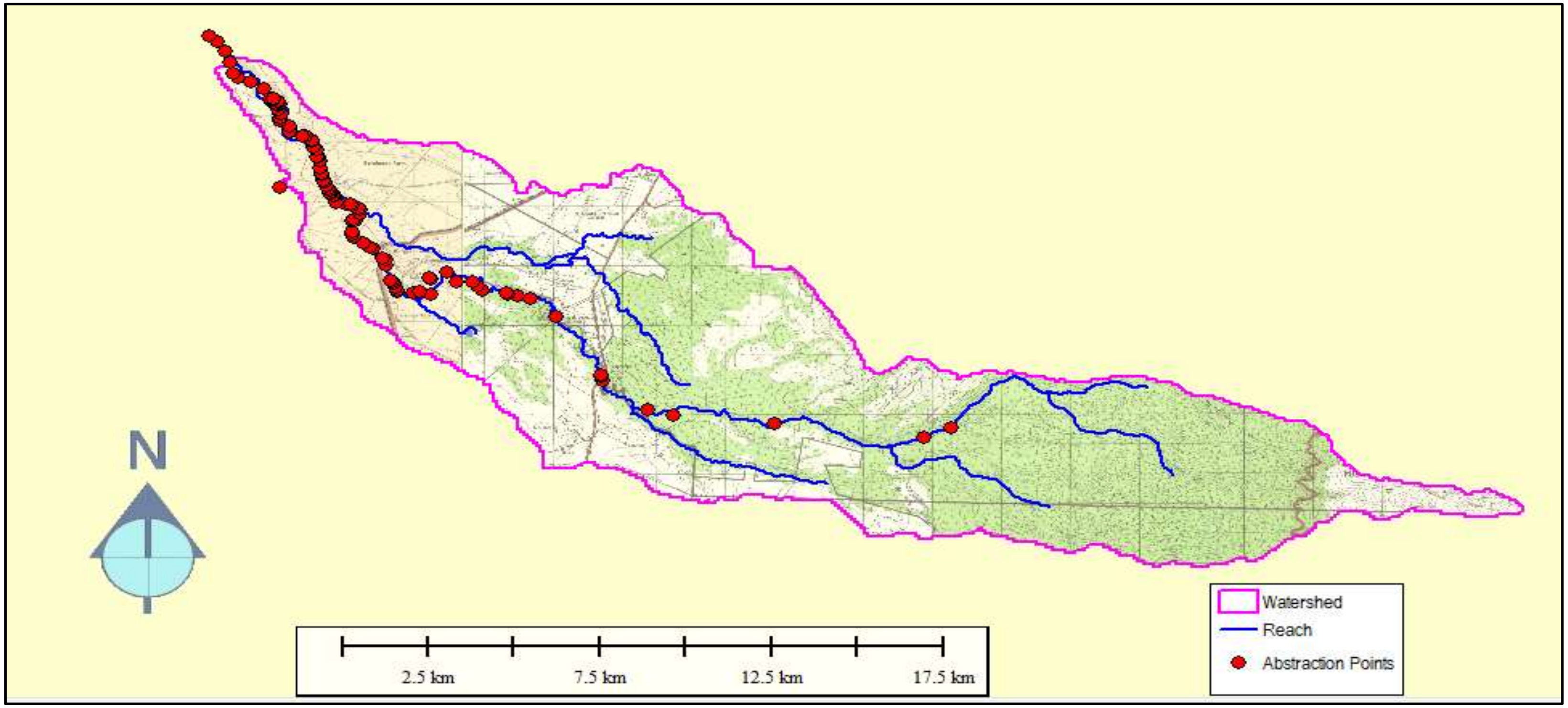


Figure 4-7 Spatial Distribution of Abstraction Points along River Burguret

From Figure 4-7 there has been a massive increase in water abstraction thus increased water demand over time. In 1997, there were only 43 known abstraction points compared to today, which has over 100 abstraction points. Further observations showed that the extent of water abstraction is growing downstream in the catchment. This is qualified by the fact that the upper part is largely forested with lower parts under subsistence farming as shown in Figure 3-7.

4.4.1 Authorised Abstraction

According to data collected from WRA, out of 113 abstractions only eight known abstractors have clear permit records. Another 21 permits record exist but have unclear records. This is where the permit does not tally the name of the abstractor. This indicated that the level of utilizing water legally is very low, as each abstraction, the point should have a valid permit as presented in Appendix 2.

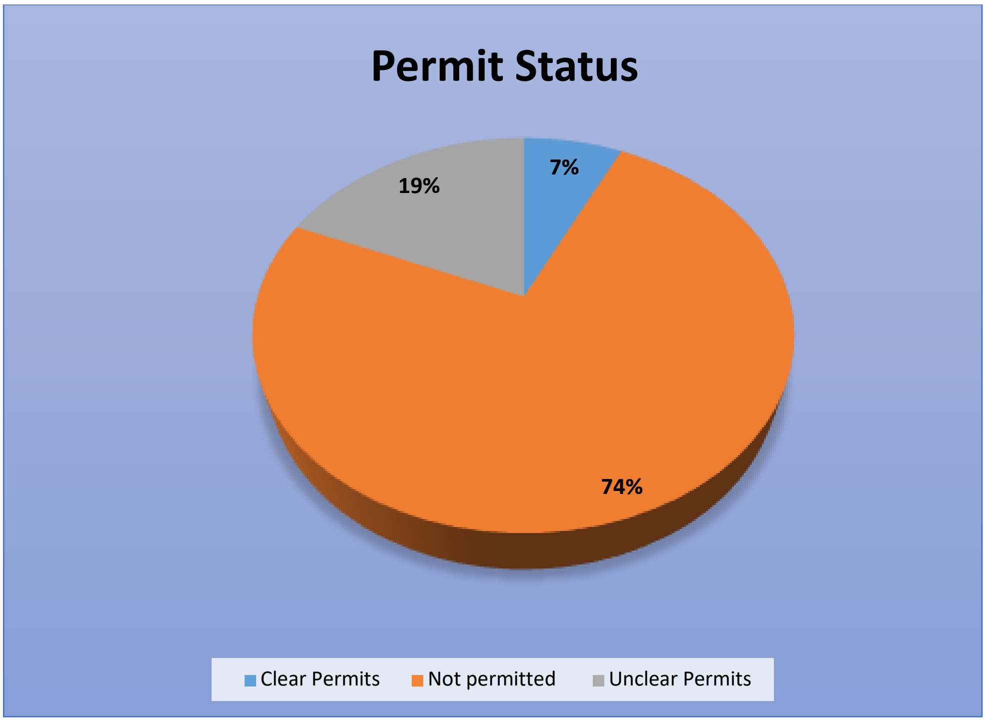


Figure 4-8 Permit Status at Burguret River

4.4.2 Types of Abstraction

To understand the types of abstraction, the abstractors were largely categorized as Community Projects, Small Scale and Large Scale. According to the data collected, 88% were small-scale abstractors and 8% were large-scale abstractors. In addition, only 4% were community projects.

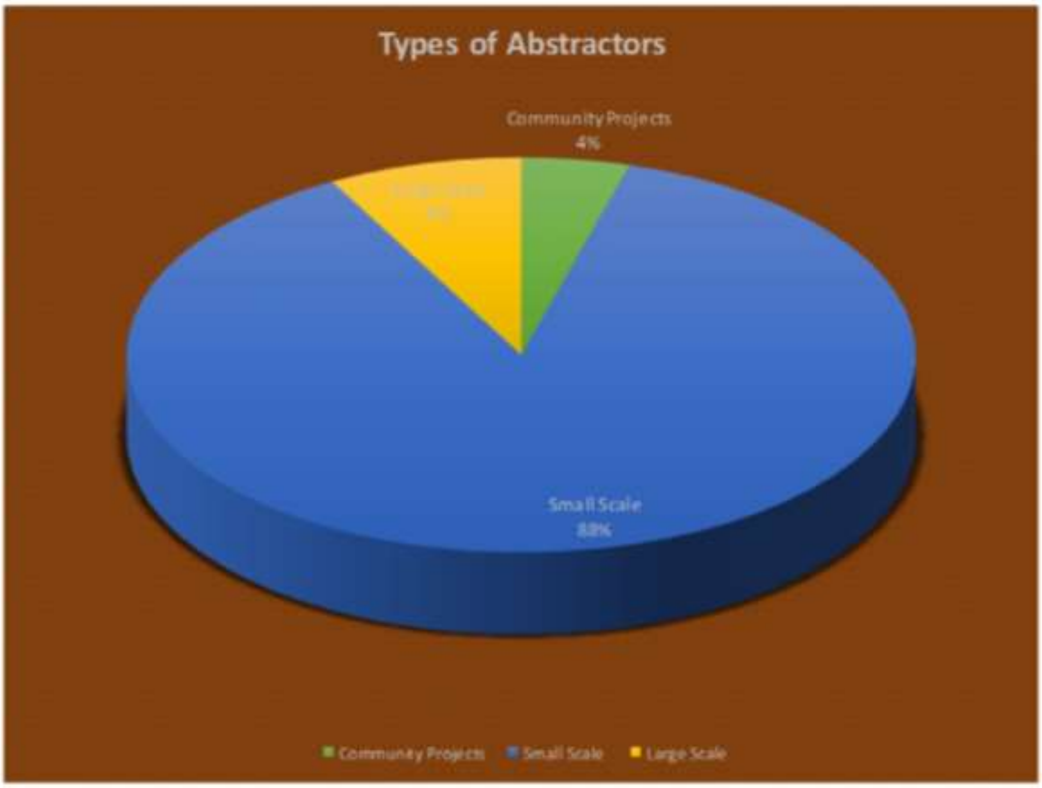


Figure 4-9 Permit Status at Burguret River

4.4.3 Methods of Abstraction

The main methods of abstraction were classified as Portable Pumps, Fixed pumps, Furrow, Gravity Pipes and Hydram Pumps. The figure below show the method used for abstraction with portable pumps at 88%

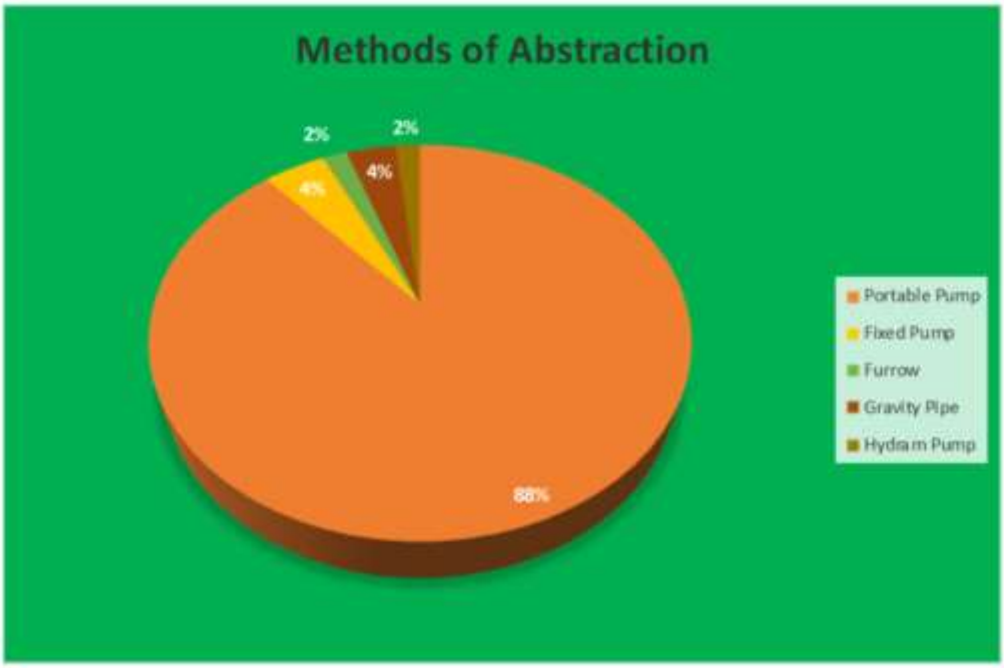


Figure 4-10 Methods of Abstraction at Burguret River

4.4.4 Authorised Water Amounts versus Abstracted Amounts

An abstraction survey data obtained from CETRAD on legally permitted abstractions against the total abstracted quantity indicated that 20685m^3 per day were abstracted during normal flow periods.The legally permitted abstraction during normal flow is 149 m^3 per day. This means the water utilization is approximately 15 times the authorized quantities as shown in Table 4-5.

Table 4-5: Water Allocation against Water Abstracted

Description	Mean Daily Abstraction (m3/day)
Total Normal Flow Allocation	149.00
Total Flow Flood Allocation	2,224.00
Total dry Season Abstraction	20,685.00
Dry season abstractions in excess of NF	20,536.00

From the Table above it can be deduced that the amount of water drawn is often in excess of the permitted water allocation.

4.5 Establishing Relationship between Water Demand and Water Availability

4.5.1 Relationship between Rainfall and Irrigation Water Requirements

To determine irrigation water demand by different times, CROPWATt model based on the Penman-Monteith equation was used. The output of the model includes irrigation water requirement for each crop and was taken as estimations for water abstraction at different seasons. Vegetables, Tomatoes and Green Beans are most applicable and most-consuming irrigated crops in the area. No other crop was considered. The evapotranspiration and rainfall data was generated from CLIMWAT for use and analyses. Nanyuki meteorological station was used for the purpose of the study and found sufficient. Figure 4-11 and Table 4-6 shows the mean monthly rainfall and rainfall results from CROPWAT model respectively.

The mean monthly and annual rainfall for this rainfall station was analysed. The results indicated that the area receives an average of 651mm per year of effective rainfall. Figure 4-11 shows mean monthly rainfall.

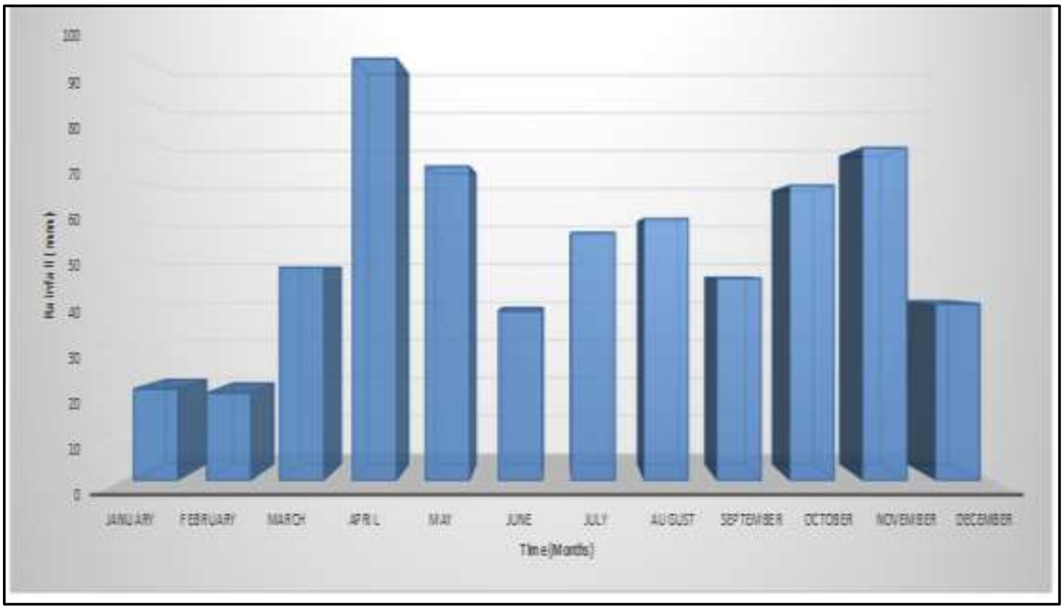


Figure 4-11   Mean Monthly Rainfall of the Study Area

Table 4-6 Water Requirement for the Study Area

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Small Vegetables	113.40	63.30	-	-	-	-	-	-	-	-	1.10	51.20
2. Tomato	-	-	-	-	-	4.50	4.90	25.50	81.40	51.60	2.70	-
3. Green beans	-	15.20	35.40	12.50	7.80	-	-	-	-	-	-	-
Net scheme irr.req. in mm/day	3.70	2.80	1.10	0.40	0.30	0.10	0.20	0.80	2.70	1.70	0.10	1.70
Net scheme irr.req.in mm/month	113.40	78.50	35.40	12.50	7.80	4.50	4.90	25.50	81.40	51.60	3.80	51.20
Net scheme irr.req.in l/s/h	0.42	0.32	0.13	0.05	0.03	0.02	0.02	0.10	0.31	0.19	0.01	0.19
Overall Scheme efficiency	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
Gross scheme irr.req. in mm/day	5.29	4.00	1.57	0.57	0.43	0.14	0.29	1.14	3.86	2.43	0.14	2.43
Gross scheme irr.req.in mm/month	162.00	112.14	50.57	17.86	11.14	6.43	7.00	36.43	116.29	73.71	5.43	73.14
Gross scheme irr.req.in l/s/h	0.60	0.46	0.19	0.07	0.04	0.03	0.03	0.14	0.44	0.27	0.01	0.27
Irr.req. for actual area (l/s/h)	0.60	0.46	0.19	0.07	0.04	0.03	0.03	0.14	0.44	0.27	0.01	0.27

The investigation of the occurrence of rainfall and dry seasons was based on mean monthly precipitation and evaporation data. The dry period was defined by overlaying the crop water requirement in the table above. The sufficiency of precipitation to meet water requirement during the full period of growth was established based on soil moisture and water requirements. It was observed that during the dry months, the water requirement exceeded the rainfall thus warranting more river abstractions during the dry season especially the critical growth period where shortage in water would severely affect the produce.

Figure 4-12 Crop Water Requirement v/s Rainfall in mm

4.5.2 Relationship between Observed Rainfall and Discharges

The investigation for the mean monthly rainfall and river discharges are represented here in this section. The mean monthly rainfall and mean monthly discharge were analysed to illustrate how they relate. The bars in the figure below characterizes the discharge while the line series represent rainfall.

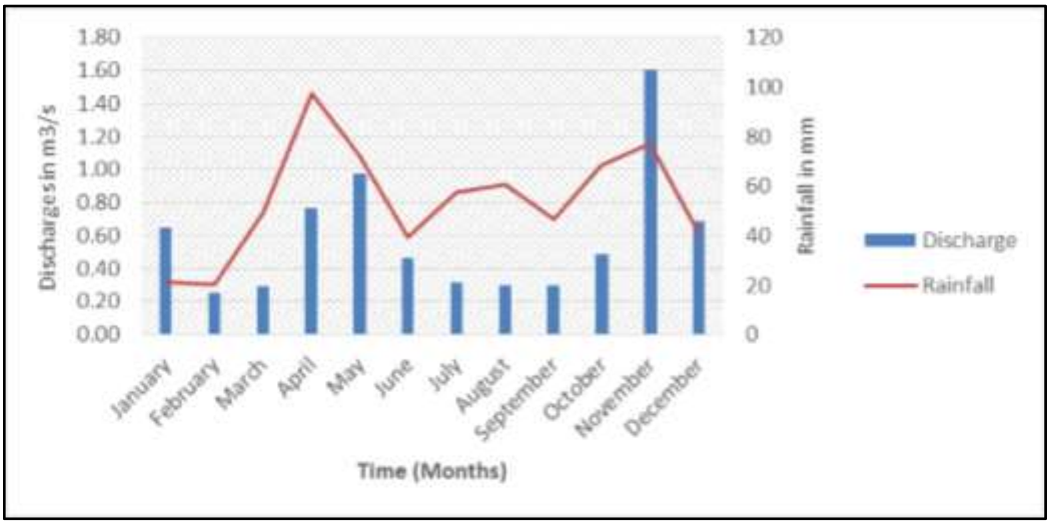


Figure 4-13 Relationship between Mean Monthly Rainfall and Mean Monthly Observed River Discharge for the Period

It was depicted that the study area has two rainfall seasons with the highest rainfall in March, April, and May with highest received in April. The other rainy season is on October, November, and December with November receiving the highest rainfall. The rainfall and discharges also show the same regimes, however, there exists a difference in the peaks of the rainfall regimes and the discharge

4.5.3 Observed and Simulated Discharges over Time

Burguret River discharges being the primary source of water for irrigation becomes limited during the dry seasons when the demand is highest. Although Burguret River originates from upstream dense forested areas and provides the flow continuously throughout the year, analysis from the long term both observed and simulated data shows a major change in the flow rates, overall, over the recent past years. This was represented in Figure 4-14 and Figure 4-15.

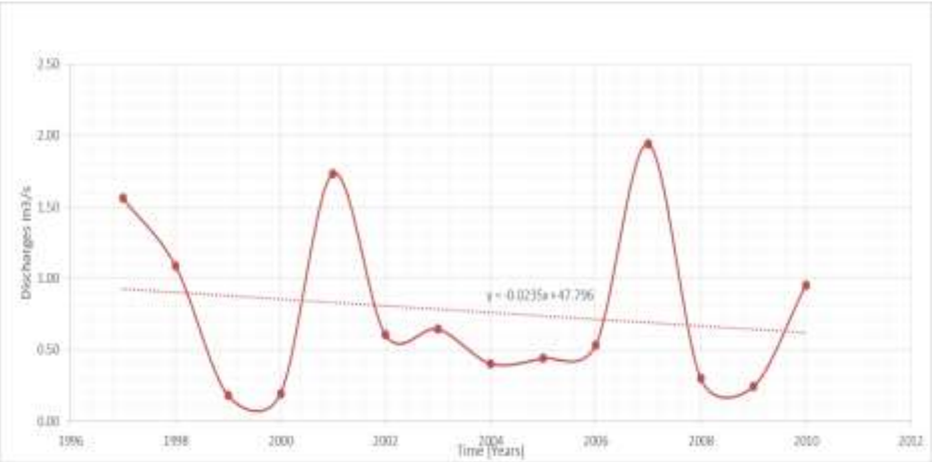


Figure 4-14 Observed Mean Annual Flow for Burguret Flow

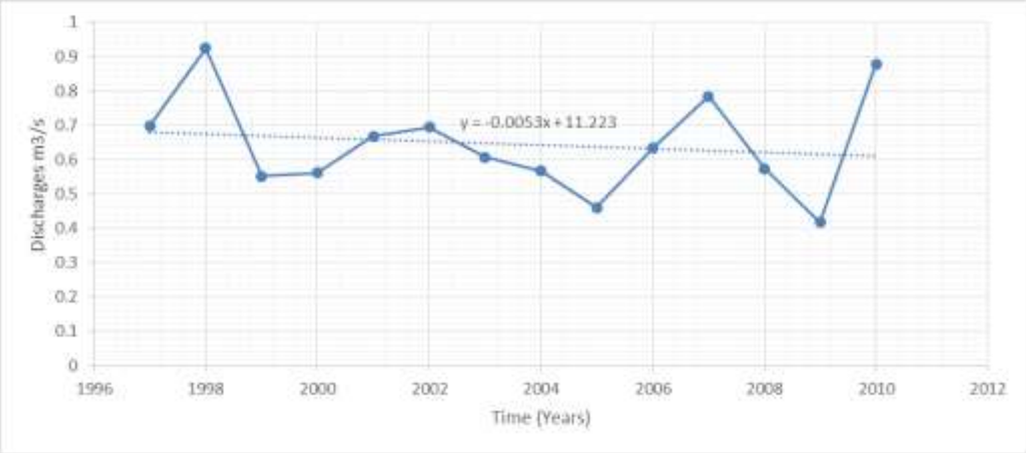


Figure 4-15 Simulated Mean Annual Flow for Burguret Flow

A decline in flow regime was observed both dry seasons and wet season. This was mainly attributed human-induced factors with the main factor being the increased demand for irrigation water with riparian areas over the time with a degree of water abstraction increasing downstream in the catchment as shown the Figure 4-16. The other factors attributed to the decline in flow is natural factors. The key natural factors resulting to the decreasing of river flows are periodic rainfall pattern and drought series.

4.5.4 Analysis of Distribution of River Abstraction Points

From cumulative river water abstraction analysis it was observed that the water abstractions among the existing abstractions depended on the intended use as well as the type of abstraction works. It was observed that there was no uniformity in distribution means as showed in Figure 4-16.

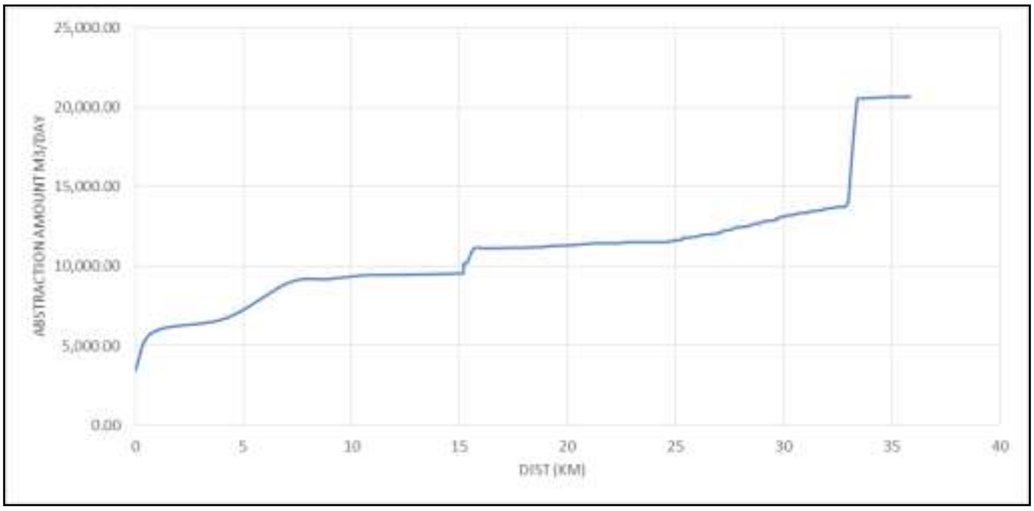


Figure 4-16 Cumulative Water Abstractions along Burguret River

There are 113 known abstraction points along the Burguret River in comparable to 43 in 1997. From Figure 4-16, it was observed that the extent of water abstraction is growing downstream in the catchment where the irrigable area is expansive thus warranting more abstractions.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Surface Water Demand

From this study, the sub-catchment had a total of 113 abstractors. The concentration of major piped water under gravity was observed at upper parts of the river. There was also the existence of open canals abstraction in some sections and only a few fixed pumped system were observed. Portable pumps system dominated water abstraction scenario where smallholder farmers used it. The observed streamflow data reveals progressive diminishing river flows as a result of excessive water abstractions and hence increase water-related conflicts. The decline of the flow was also associated with seasonal rainfall pattern, low rainfall/high evaporation and drought cycles. The excessive abstraction was heavily linked with the high financial returns from irrigated agriculture as well as low efficiency of water use, especially for smallholder farmers. The water demand is expected to continue increasing due growth of population and irrigation development.

5.1.2 Availability of Surface Water

Using SWAT model on the Burguret sub-catchment, the water yields in the sub-catchment were assessed. The period 2001-2003 of the observed flow was used for the calibration process of the model and 2004-2005 was used for the validation process. The SWAT model was found to capture well hydrological processes in the Catchment. The major source of water in the research area is discharged from the river, which is depended on climatic conditions. The river discharges are usually high during rainy seasons and become inadequate during dry periods when water demand is high. The flow regime was observed to be on the decline for both dry and wet seasons over time. While the water is limited in the sub-catchment, it is not utilized effectively as it is lost on conveyance to the users. Improving water supply in dry seasons is crucial in the catchment such rainwater harvesting.

5.1.3 Water Demand versus Water Availability

From this study, water management issues in the Burguret river catchments is presented. The study showed that the surface water in the study area could only meet water demand pressure only during rainy seasons and that the surface water resource is diminishing over time. There are critical shortages during dry seasons due to high demand for irrigation water. Though water is scarce in the catchment, it is not utilised in an effective way as required as too much of it is lost on its way to the water user and inefficient methods of water application to crops. Therefore, a viable use of available surface water resources combined with better natural flow management is crucial. This can only be realised with serious collaboration of farmers in the catchment both communities and individual farmers. The unmet demand pressure for surface water was seen causing conflict in the catchment. This was mainly caused by the alleged unequal allocation of water resources where downstream users blame upstream users for over obstructing leaving almost nothing to flow downstream.

5.2 Recommendations

The study of surface water demand pressure in Burguret catchment has led to a number of conclusions. Focussing on these inferences, the resulting recommendations were made based on water demand and its availability.

The results of this study formed the basis for an informed decision in the sub-catchment in terms of short and long-term implementation of development projects and strategic planning policies.

Due to observed increased water demand over time, there is a need to carry out a comprehensive water allocation assessment in the catchment for all users. The stakeholder and all beneficiaries should be fully involved allocation of water resources as well as sharing assessment. To reduce non-compliance and water conflicts in the catchment, all users should be educated on the governing policies and legislation for water resources.

With the observed decline of the river flow over time, proper irrigation methods or water saving techniques should be promoted to reduce water wastage. From the simulated and observed discharges, the catchment has a high potential for flood water harvesting potential thus the use of storage to harness floodwater should be promoted for use during dry seasons.

REFERENCES

Abraham, T. and Roddick, F. (1999). "Survey of Spatio-Temporal Databases", GeoInformatica. Vol. 3 (1): 61-99.

Arnold, J. G., & Fohrer, N. (2005). SWAT2000: current capabilities and research opportunities in applied watershed modelling. *Hydrological processes*, *19*(3), 563-572.

Aswathanarayana, U. (2001). Water Resources Management and the Environment. A.A Balkema, Abingdon, Oxfordshire, UK.

Bardhan, P. And Dayton, J. (2002). Unequal irrigators: heterogeneity and commons management in large-scale multivariate research. In: E. Ostrom, T. Dietz, N. Dolšak, P.C. Stern, S. Stonich and E.U. Weber (Editors), The drama of the commons. National Academy Press, Washington, DC.

BCEOM, (1999). Abay River Basin integrated master plan, main report, MoWR, Addis Ababa, Ethiopia.

Berger, P. (1989). Rainfall and agroclimatology of the Laikipia plateau, Kenya. Geographica Bernensia, African Studies Series Vol. A7 Berne.

Bouraoui ,F., Dillaha, T.A., (1996). ANSWERS-2000:Runoff and sediment transport model, Journal of Environmental Engineering 1996.122:493-502

Butler, D. and Memon, F. (2006). Water Demand Management IWA: London, UK.

Caroline, B. (2014). The Drivers of Non-Revenue Water How Effective Are Non-Revenue Water Reduction Programs? Policy Research Working Paper.

Chebud, A and Melesse, M. (2009). Modelling lake stage and water balance of Lake Tana, Ethiopia

Christensen, F. (2006). Coupling between the River Basin Management Model (MIKE BASIN) and the 3D Hydrological Model (Mike SHE) with use of the OPENMI System, Geological survey of Denmark and DHI Water and Environment, Copenhagen, Denmark.

De Villiers, M. (2000). Water the fate of our most precious resource.Boston: Houghton Mifflin Company.

FAO, (1977) Crop water requirements. Irrigation and Drainage Paper No. 24, FAO, Rome.

Gichuki, F. N., Liniger H. P., and Schwilch G. (1998A). Knowledge about highland-lowland interactions: The role of a natural resource information system. In Resources, actors and policies-towards sustainable regional development in the highland-lowland system of Mt. Kenya. Eastern and Southern Africa Journal 8 (15). Special Issue. Nairobi.

Gichuki, F. N., Liniger H. P., Macmillan G., and G. Gikonyo. (1998B). Scarce water: Exploring resource availability, use and improved management. In Resources, actors and policies-towards sustainable regional development in the highland- lowland system of Mount Kenya. Eastern and Southern Africa Journal 8 (15-28). Special Issue, Nairobi.

Gichuki, F., Liniger,H., Macmillan L.C., Schwilch. G., And Gikonyo, J.K. (1998). Scarce water: exploring resource availability, use and improved management. Eastern and Southern Africa Geographical Journal 8: 15-27.

Gichuki, F. N., Ngigi, S. (2001): Community Management of Matanya Irrigation Project. Water Users Associations Support Initiative Report No. 5. NRM3, Nanyuki, Kenya

Gichuki, F. N. (2001): Water Scarcity and Associated Conflicts – Experiences from the Upper Ewaso Ng'iro North Basin. Water Users Associations Support Initiative Report No. 8. NRM3, Nanyuki, Kenya.

Government of Kenya (2016): The Water Act 2016, Government printer, Nairobi, Kenya.

González-Rouco, J. F., Jiménez, J. L., Quesada, V., & Valero, F. (2001). Quality control and homogeneity of precipitation data in the southwest of Europe. Journal of Climate, 14(5), 964-978.

http://www.tandfonline.com/doi/abs/10.1080/19475705.2010.533703?journalCode=tgnh20

HU, D. (2006). Water Rights. An International and Comparative study.131IWA London, UK.

ILRI (International Livestock Research Institute) (2011). http//www.ilri.org4

Kenya, Republic of (2008). Kenya Vision 2030. A Globally Competitive and Prosperous Kenya. Government Printers.

Kihara, F. (1997). An investigation into the soil loss problem in the upper Ewaso Ng'iro North Basin. MSC Thesis presented to the Department of Agricultural Engineering, University of Nairobi.

Kiteme,B.P. (2005). Understanding Development Priorities of Local Actors in the Upper Ewaso Ngiro Catchment.

Liniger, H. P. (1995). Endangered water-A global overview of degradation, conflicts and strategies for improvement. Development and Environment Report No. 12. Lang Drucl AG. Bern, Switzerland: Centre for Development and Environment.

Loi, N.K., (2010). Assessing the impacts of land use/ land cover changes and practices on water discharge and sedimentation using SWAT:Case study in

Dong Nai watershed – Vietnam, International Symposium on Geoinformatics for Spatial Infrastructure Development in Earth and Allied Sciences 2010.

LRP, (1996) Information and Data Exchange, Report of Group 1 for the Water Awareness Campaign.

Lam, Q. D., Schmalz, B., & Fohrer, N. (2010). Modelling point and diffuse source pollution of nitrate in a rural lowland catchment using the SWAT model. Agricultural Water Management, 97(2), 317-325.

Mati, B. M.; Muchiri, J. M., Njenga, K., Penning de Vries, F., Merrey, D. J. (2005). Assessing water availability under pastoral livestock systems in drought-prone Isiolo District, Kenya. Working Paper 106. Colombo, Sri Lanka: International Water Management Institute (IWMI).

Mati, B.M. ; Gichuki, F.N. ; Morgan, R.P.C. ; Quinton, J.N. ; Brewer, T. ; and Liniger, H.P. (1998). GIS data for erosion assessment in the upper Ewaso ngiro north basin, Kenya. Proceedings of the 1998 ESRI International User Conference, San Diego, http:/www/esri.com/library/userconf/proc98/PROCEDD.HTM

Mati, B.M. ; Muchiri, J.M. ; Njenga, K. Penning de Vries, F. ; and Merry, D.J. (2006). Assessing water availability under pastoral livestock systems in drought-prone Isiolo District, Kenya. International Water Management Institute, Working Paper 106.

Ministry of Water and Irrigation (MoWI), (2009c). Integrated Water Resources Management Strategy and Water Efficiency Plan for Kenya. Nairobi: Ministry of Water and Irrigation, Nairobi.

Ministry of Water Development (2015) Practise Manual for Small dams, pans and other water Conservation Structures in Kenya, 2nd Edition. Republic of Kenya, Nairobi.

Ming-Shu, T., Xiao-Yong, ZHAN., (2004). Estimation of runoff and sediment yield in the Redrock Creek watershed using AnnAGNPS and GIS, Journal of Environmental Sciences, Vol.16, No.5, pp. 865-867,2004.

Moriasi, N. D., Arnold, G. J., Van Liew, W. M., Bingner, L. R., Harmel, D. R., & Veith, L. T. (2007). Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. American Society of Agricultural and Biological Engineers, 50 (3), 885 - 900.

MoWD (1987). Water Resources Assessment Study in Laikipia District. Nairobi, Kenya: Government of Kenya.

MoWD. (Ministry of Water Development). (1992). Water resources development and use plan towards 2010. Vol.1 of National Water Master Plan. Nairobi, Kenya.

NRM3 Database, (2002). Natural Resources Monitoring Modelling and Management Project GIS and Digital Data Database.

Ojwang', G. O., and Wargute, P.W. (2009). The population trends and distribution of large herbivores in Laikipia district. Department of Resource Surveys and Remote Sensing, Nairobi, Kenya.

Opere, O., and Okello B. N., (2011). Hydrologic analysis for River Nyando using SWAT. University of Nairobi, Department of Civil Engineering, Nairobi, Kenya.

Ostrom, E., Dietz, T., Dolsak, N., Stern, P.C. and Stovich, S. (2002). The drama of the commons. National Academy Press, Washington D.C., USA.

R. Speed, Li Y., T. Le Quesne, G. Pegram and Z. Zhiwei (2013). Basin Water Allocation Planning. Principles, procedures and approaches for basin allocation planning, UNESCO, Paris.

Rural Focus (2006). Where is the water going to. Abstraction Surveys carried out in 2002 and 2004.

Sahin, S., & Cigizoglu, H. K. (2010). Homogeneity analysis of Turkish meteorological data set. Hydrological Processes, 24(8), 981-992.

Setegn, S.G., Srinivasan, R., Dargahi, B. (2008). Hydrological Modelling in the Lake Tana Basin, Ethiopia using SWAT model. The Open Hydrology Journal Vol 2, 49-62.

Schuler, R. (2004). Commercial Horticulture North-West of Mt. Kenya: A Sector Analysis with Emphasis on Implications on River Water Resources of the Upper Ewaso Ng'iro Basin. Master Thesis, University of Bern, Bern, Switzerland.

Schultz, G.A. (1993). Hydrological modelling based remote sensing information. Adv. Space Res., Vol. 13, No. 5.

Seethapathi, P.V., Tyagi, J.V., Saheb, S.M (1997). Daily rainfall runoff modelling of Brahmani river at rengali reservoir, CS (AR) 3/(96-97), National Institute of Hydrology, Kakinada.

Sombroek W C, Braun H M H and van der Pouw B J A. (1982). Explanatory soil map and agro-climatic zone map of Kenya. Report E1. National Agricultural Laboratories, Soil Survey Unit, Nairobi, Kenya. 56 pp.

Speed R., Li Y., T. Le Quesne, G. Pegram and Z. Zhiwei (2013) Basin Water Allocation Planning. Principles, procedures and approaches for basin allocation planning, UNESCO, Paris. Rural Focus Ltd, 2012 (Unpublished report), Abstraction and Pollution Loading Survey Protocols.

Thornton, J. (2002). Water Loss control Manual. McGraw-Hill Companies: New York, USA.

UN, (2003). Water for People. Water for life. UNESCO and Bergham Books

UN-Water / WWAP,(2005). Kenya National Water Development Report. Prepared for the 2nd UN WorldWater Development Report, Water: A shared responsibility. Prepared by the Ministry of Water andIrrigation, Nairobi, June 2005.

UN-Water, (2012). Managing Water Under Uncertainty and Risk: World Water Development Report 4 at http://www.unwater.org/publications/publications-detail/en/c/202715/

Water Resources Management Authority (2008), Rift Valley Catchment Area, CMS-RVCA,Catchment Management Strategy: Draft. WRMA, Nairobi, Kenya.

Wiesmann, U. (1998). Sustainable regional development in rural Africa: Conceptual framework and case studies from Kenya. African Studies Series A14. Berne, Switzerland: Geographica Bernensia.

White, E.R., (2009). Development and Application of a Physically Based Landscape Water Balance in the Swat Model.

WRI (World Resoures Institute) (1998). Freshwater resources and withdrawals. Web data. http://www.ri.org/wriwr-98-99.

Xiaoyu, W., Xiaofang, Z., Sanglu, L. (2000). Spatiotemporal data modelling and management: a survey, Proceedings of 36th International Conference on

Technology of Object-Oriented Languages and Systems, 2000. TOOLS - Asia : 202-211.

Yates, D. (2005). “WEAP21 – A Demand-, Priority-, and Preference-Driven Water Planning Model Part 1: Model Characteristics” Water International, 30: 487–500.

Yuan, Y., Bingner, R.L., Rebich, R.A., (2001). Evaluation of AnnAGNPS on Mississippi Delta Msea Watersheds, American Society of Agricultural Engineers ISSN 0001–2351 Vol. 44(5): 1183–1190.

6 APPENDICES

6.1 Appendix 1: Abstraction Data

INDEX	OWNER	TYPE OF SYSTEM	ESTIMATED ABST(M3/DAY)	NORTHING	EASTING
1	NGK INTAKE	GRAVITY PIPE	3,456.00	9986708	291467
2	GATUNE WATER PROJECT	GRAVITY PIPE	2,419.20	9986417	290666
3	MURIRU WATER PROJECT	GRAVITY PIPE	864.00	9986881	286350
4	BURGURET WATER	GRAVITY PIPE	2,246.40	9987161	283432
5	MOUNTAIN ROCK HOTEL	FURROW	209.95	9987318	282670
6	BEATRICE MUTHONI	PORTABLE	243.06	9988323	281390
7	O MEARA R B	PORTABLE	2.88	9988429	281352
8	TAMTROUT LTD	PORTABLE	2.70	9988485	281324
9	MUTAMAIYU LTD	HYRAM PUMP	34.57	9990432	280018
10	BABA SAMMY WAGURA	PORTABLE	46.25	9991043	279298
11	FRANCIS WACHIRA	PORTABLE	38.40	9991161	278906
12	BENSON KIIRU	PORTABLE	11.68	9991175	278634
13	GEOFFREY GICHUKI	PORTABLE	578.14	9991175	278634
14	SUSAN WHITEFIELD	PORTABLE	35.25	9991199	276387
15	CYRUS NDERITU KARUGU	PORTABLE	11.56	9991234	278580
16	TIMM HOBBS	FIXED PUMP	907.20	9991236	275893
17	MWANGI KANAMBA	PORTABLE	23.13	9991280	275440
18	MICHAEL THOMAS	PORTABLE	1.92	9991294	276084
19	MACHARIA MWANGI	PORTABLE	23.13	9991318	275405
20	KENNEDY KINOTI	PORTABLE	5.78	9991329	277896
21	RICHARD MWEMA	PORTABLE	18.26	9991420	275358
22	EBRAHIM NDERITU	PORTABLE	23.81	9991472	277730
23	JESSE WARAKI MUCHEMI	PORTABLE	19.20	9991545	275314
24	DAVID KANYIRI	FIXED PUMP	47.89	9991553	275338
25	NEWTON MAINA	PORTABLE	2.89	9991594	277135
26	NGURU	PORTABLE	46.25	9991597	275286
27	MR MUGAMBI	PORTABLE	69.38	9991603	277616
28	JAMES MWANGI TORO	PORTABLE	38.40	9991650	275221
29	MALLIAM W MATHENGE	PORTABLE	23.13	9991725	276376
30	JOHNSON NDEGWA	PORTABLE	2.00	9991732	276369
31	JACKSON NDUNGU	PORTABLE	0.96	9991732	276369
32	TIMM HOBBS	FIXED PUMP	57.81	9991950	276842
33	BENJAMIN KARANJA	PORTABLE	11.56	9992162	275082
34	KAMAU JOHN (TENANT)	PORTABLE	46.33	9992343	275071
35	WAIRIMU	PORTABLE	57.81	9992380	275019
36	ANTONY NGATIA	HYRAM PUMP	23.49	9992707	274743
37	JAMES MAINA	PORTABLE	59.05	9992707	274743
38	FREDRICK MAINA	PORTABLE	17.74	9992707	274743

INDEX	OWNER	TYPE OF SYSTEM	ESTIMATED ABST(M3/DAY)	NORTHING	EASTING
39	NGARI	PORTABLE	46.25	9992786	274637
40	DAVID WACHIRA	PORTABLE	17.34	9992786	274637
41	BENSON MWANGI (TENANT)	PORTABLE	23.13	9992909	274437
42	ROSE WANGUI MIANO	PORTABLE	48.85	9993120	274161
43	MUCHOKI	PORTABLE	23.13	9993177	274119
44	JOSEPH WACHIRA	PORTABLE	23.13	9993177	274119
45	PETER KIIRU	PORTABLE	46.25	9993264	274126
46	ROBERT NGARI	PORTABLE	46.25	9993673	274122
47	SAMSON KIMANI	PORTABLE	11.56	9993677	274218
48	JOSEPH MATU	PORTABLE	23.13	9993714	274181
49	SAMWEL NDERITU	PORTABLE	23.13	9993875	274348
50	JOHN KANYINGI	PORTABLE	57.97	9994008	274338
51	CHARLES MAINA	PORTABLE	11.68	9994008	274338
52	RAHAB MUTHONI	PORTABLE	23.13	9994008	274338
53	MARY MURINGE	PORTABLE	11.56	9994053	274364
54	MARGARET WAIRIMU	PORTABLE	47.29	9994057	274286
55	JOSEPH MUTURI	PORTABLE	59.57	9994153	274097
56	DEMELO (ANASTACIA)	PORTABLE	23.13	9994193	273920
57	BONGO FARM	FIXED PUMP	151.20	9994238	274079
58	NEWTON WACHIRA	PORTABLE	11.96	9994248	273630
59	LAWRENCE MUTHUTHI	PORTABLE	41.03	9994475	273603
60	MARGRET WANJIRA	PORTABLE	11.56	9994475	273603
61	DOUGLAS MUGO	PORTABLE	5.78	9994492	273556
62	JULIUS MUTHUI	PORTABLE	23.13	9994492	2735561
63	ZACHARIA MWANGI	PORTABLE	46.25	9994610	273516
64	MBARUKU KARIAMBAKI	PORTABLE	28.91	9994611	273479
65	KARIUKI MACHARIA	PORTABLE	34.69	9994692	273450
66	MURIUKI MUNYIRI	PORTABLE	29.23	9994745	273441
67	JACKSON KANG'ONG'A	PORTABLE	23.13	9994780	272015
68	JACKSON MATU	PORTABLE	11.56	9994833	273354
69	JOSPHAT KIAMA	PORTABLE	5.78	9994960	273311
70	JOHN GATHARI WANJAU	FIXED PUMP	92.82	9995029	273272
71	JOSEPH KAROKI	PORTABLE	23.13	9995177	273240
72	LAWRENCE MUTURI	PORTABLE	17.28	9995243	273218
73	MICHAEL WACHIRA	PORTABLE	11.76	9995255	273239
74	JAMES KIHURO	PORTABLE	11.56	9995444	273206
75	FELICIAN KAGWANJA	PORTABLE	57.81	9995669	273164
76	JOHN GATHUKU	PORTABLE	69.38	9995669	273164
77	SALOME WAIRIMU	PORTABLE	23.13	9995780	273150
78	MAINA KAHORA	PORTABLE	69.38	9995802	273108
79	CHARLES GATHOGO	PORTABLE	46.25	9996025	273086
80	MAMA WAINAINA	PORTABLE	69.38	9996114	272993
81	AMOS NDUNGU	PORTABLE	1.44	9996309	272969

INDEX	OWNER	TYPE OF SYSTEM	ESTIMATED ABST(M3/DAY)	NORTHING	EASTING
82	STEPHEN NGURE	PORTABLE	46.25	9996355	272930
83	MAINA KIMANI	PORTABLE	47.05	9996489	272750
84	SAMWEL MAINA	PORTABLE	46.37	9996505	272662
85	ITHE WA NGARI	PORTABLE	5.78	9996627	272357
86	WANJIRA KADOGO	PORTABLE	34.69	9996656	272316
87	MAINA IRAJI	PORTABLE	69.38	9996801	272296
88	JULIUS KIBIRI	PORTABLE	46.25	9997018	272009
89	JOSEPH WAHOME	PORTABLE	11.56	9997125	272030
90	JIFFERSON MURUMI	PORTABLE	57.81	9997224	272026
91	JAPHAS WAHOME BAUR	PORTABLE	11.56	9997241	272059
92	JANE WANGUI	PORTABLE	57.81	9997363	271990
93	PETER NJOGU	PORTABLE	5.78	9997540	271986
94	JAMES MWAI	PORTABLE	11.56	9997550	272041
95	MATHENGE	PORTABLE	5.76	9997552	271941
96	MR. NJUKI	PORTABLE	46.25	9997552	271941
97	MR. MUREKIO	PORTABLE	11.56	9997591	271964
98	MR. GITAHI NDEGE	PORTABLE	3.84	9997619	271838
99	JAMES GITHAIGA	PORTABLE	11.56	9997666	271956
100	WILLIAM MATHENGE	PORTABLE	2.88	9997695	271848
101	JOHN KIBANYA	PORTABLE	11.56	9997716	271750
102	CHRISTOPHER KAHOME	PORTABLE	98.54	9997757	271749
103	JOSEPH MUTAHI	PORTABLE	46.37	9997757	271749
104	MAINA KAHORA	PORTABLE	69.38	9997775	271824
105	FRANCIS MUREITHI	PORTABLE	11.56	9998089	271563
106	SWEET WATERS FURROW	FURROW	6,480.00	9998089	271563
107	MAINA KIGENYI	PORTABLE	92.50	9998316	271172
108	THEURI	PORTABLE	46.25	9998460	270811
109	JOSEPH WACHIRA	PORTABLE	11.56	9998589	270676
110	CHARLES MURIUKI	PORTABLE	34.69	9998963	270568
111	KARURI	PORTABLE	2.88	9999319	270460
112	KIROMBE	PORTABLE	11.56	9999683	270197
113	NDIANGUI	PORTABLE	23.13	9999861	269950

6.2 Appendix 2: Information Of Permits, Riperian Vegetation At Point Of Water Use, The Observed River Bank Agricultural Activity

INDEX	OWNER	PERMIT NO / INFO	RIPERIAN VEGETATION	AGRICULTURAL ACTIVITY
1	NGK INTAKE	21948	DENSE	NONE
2	GATUNE WATER PROJECT	YES (NOT PROVIDED)	MEDIUM	NONE
3	MURIRU WATER PROJECT	YES (NOT PROVIDED)	MEDIUM	
4	BURGURET WATER PROJECT	YES (NOT PROVIDED)	DENSE	NONE
5	MOUNTAIN ROCK HOTEL	17998	DENSE	
6	BEATRICE MUTHONI	YES (NOT PROVIDED)		20 M FROM RIVERS
7	O MEARA R B	HAS APPLIED	DENSE	
8	TAMTROUT LTD	7	MEDIUM	NONE
9	MUTAMAIYU LTD	8724		
10	BABA SAMMY WAGURA	NOT KNOWN	POOR	THERE IS AGRICULTURAL ACTIVITY UPTO ABOUT 5 M TO BANK
11	FRANCIS WACHIRA	HAS APPLIED	POOR	AGRICULTURAL ACTIVITIES ABOUT 10 M FROM THE RIVER
12	BENSON KIIRU	YES (NOT PROVIDED)	POOR	AGRICULTURAL ACTIVITY TO THE RIVER
13	GEOFFREY GICHUKI	NOT KNOWN	POOR	
14	SUSAN WHITEFIELD	TO BE INFORMED		
15	CYRUS NDERITU KARUGU	NONE	MEDIUM	AGRICULTURE ABOUT 20M FROM RIVER
16	TIMM HOBBS	NOT KNOWN	POOR	
17	MWANGI KANAMBA	NOT KNOWN	POOR	5 METRES FROM WEIR NAPIER GRASS PLANTED 2

INDEX	OWNER	PERMIT NO / INFO	RIPERIAN VEGETATION	AGRICULTURAL ACTIVITY
				METERS FROM WEIR LINE
18	MICHAEL THOMAS	TO BE INFORMED	DENSE	
19	MACHARIA MWANGI	NONE	POOR	AGRICULTURAL ACTIVITIES 10M FROM RIVER NAPIER GRASS 3 METRES FROM RIVERFEW GREVELLEA TREES RIGHT BANK FACING UPSTREAM
20	KENNEDY KINOTI	NONE	POOR	
21	RICHARD MWEMA	NOT KNOWN	MEDIUM	10 METERS FROM WEIR
22	EBRAHIM NDERITU	HAS APPLIED	POOR	5 M FROM AGRICULTURE TO RIVER BANK
23	JESSE WARAKI MUCHEMI	NOT KNOWN	POOR	10 METERS FROM WEIR KALE AND MAIZE CROP IRRIGATED
24	DAVID KANYIRI	AUTHORIZED		
25	NEWTON MAINA	NONE	POOR	ACTIVITY ABOUT 5M FROM RIVER
26	NGURU	NOT KNOWN	POOR	10 METERS FROM WEIR
27	MR MUGAMBI	NOT KNOWN	POOR	AGRICULTURE 3 M FROM THE BANK
28	JAMES MWANGI TORO	NONE	MEDIUM	10 METRES FROM RIVER5 METRES FROM WEIR (NAPIER GRASS)
29	MALLIAM W MATHENGE	NOT KNOWN	MEDIUM	AGRICULTURAL ACTIVITIES 10 METRES FROM WEIR WILD GRASS,

INDEX	OWNER	PERMIT NO / INFO	RIPERIAN VEGETATION	AGRICULTURAL ACTIVITY
				BUSHES AND FEW TREES ALONG THE RIVER COURSE3/4 SNOWPEAS1/4 GREEN PEPPER IRRIGATION METHOD SURFACE
30	JOHNSON NDEGWA	YES (NOT PROVIDED)		
31	JACKSON NDUNGU MWIHURI	NOT KNOWN		
32	TIMM HOBBS	22077	POOR	
33	BENJAMIN KARANJA	NONE	POOR	ACTIVITY 5M FROM THE RIVER
34	KAMAU JOHN (TENANT)	NOT KNOWN	POOR	
35	WAIRIMU	NOT KNOWN	POOR	
36	ANTONY NGATIA	HAS APPLIED		
37	JAMES MAINA	AUTHORIZED		
38	FREDRICK MAINA	AUTHORIZED		
39	NGARI	NOT KNOWN	POOR	ACTIVITY 5 M FROM THE BANK
40	DAVID WACHIRA	NONE		
41	BENSON MWANGI (TENANT)	HAS APPLIED	POOR	
42	ROSE WANGUI MIANO	HAS APPLIED	POOR	WATERING POINT
43	MUCHOKI	NONE	POOR	RIVER BANK BROKEN BY FLOODS BUT NAPIER GRASS PLANTED
44	JOSEPH WACHIRA	NONE	POOR	AGRICULTURAL ACTIVITIES ABOUT 5 M FROM THE BANK
45	PETER KIIRU	NONE		
46	ROBERT NGARI	NOT KNOWN	POOR	
47	SAMSON KIMANI	HAS APPLIED	POOR	

INDEX	OWNER	PERMIT NO / INFO	RIPERIAN VEGETATION	AGRICULTURAL ACTIVITY
48	JOSEPH MATU	NONE	MEDIUM	ACTIVITY 5M FROM RIVER
49	SAMWEL NDERITU	22152	POOR	
50	JOHN KANYINGI	NOT KNOWN	POOR	NO ACTIVITY NEAR THE BANK
51	CHARLES MAINA	NONE	POOR	
52	RAHAB MUTHONI	NONE		
53	MARY MURINGE	NONE	POOR	
54	MARGARET WAIRIMU	NONE		
55	JOSEPH MUTURI	NONE	POOR	NO ACTIVITY NEAR RIVER
56	DEMELO (ANASTACIA)	HAS APPLIED	POOR	AGRICULTURAL ACTIVITIES 5 M FROM THE RIVER BANK
57	BONGO FARM	27810	POOR	NO ACTIVITY NEAR RIVER
58	NEWTON WACHIRA	HAS APPLIED		
59	LAWRENCE MUTHUTHI	AUTHORIZED	POOR	AGRICULTURAL ACTIVITIES 5 M AWAY FROM THE BANK
60	MARGRET WANJIRA	NOT KNOWN	POOR	
61	DOUGLAS MUGO	NONE	POOR	
62	JULIUS MUTHUI	NONE	POOR	
63	ZACHARIA MWANGI KABARE	NOT KNOWN	POOR	
64	MBARUKU KARIAMBAKI	NOT KNOWN	POOR	
65	KARIUKI MACHARIA	NONE	POOR	
66	MURIUKI MUNYIRI	NONE	POOR	
67	JACKSON KANG'ONG'A	NOT KNOWN	POOR	
68	JACKSON MATU	NONE		
69	JOSPHAT KIAMA	NONE	MEDIUM	RIVERINE WELL PROTECTED. AGRICULTURAL ACTIVITIES ABOUT 20M

INDEX	OWNER	PERMIT NO / INFO	RIPERIAN VEGETATION	AGRICULTURAL ACTIVITY
				AWAY FROM RIVER BANK.
70	JOHN GATHARI WANJAU	HAS APPLIED	MEDIUM	ACTIVITY ABOUT 10 M FROM BANK
71	JOSEPH KAROKI	HAS APPLIED	MEDIUM	NO ACTIVITY NEAR THE BANK
72	LAWRENCE MUTURI	HAS APPLIED	MEDIUM	
73	MICHAEL WACHIRA	NONE	POOR	NO ACTIVITY
74	JAMES KIHURO	NONE	POOR	ACTIVITY 3M FROM BANK
75	FELICIAN KAGWANJA	NONE		NO ACTIVITY NEAR THE RIVER
76	JOHN GATHUKU	NOT KNOWN	MEDIUM	
77	SALOME WAIRIMU	NONE	POOR	
78	MAINA KAHORA	NOT KNOWN	POOR	ACTIVITY 5 M FROM BANK
79	CHARLES GATHOGO	NOT KNOWN	POOR	
80	MAMA WAINAINA	NOT KNOWN	POOR	
81	AMOS NDUNGU	NONE	POOR	
82	STEPHEN NGURE	NOT KNOWN		ACTIVITY NEAR BANK BUT SHE IS PLANTING NAPIER GRASS
83	MAINA KIMANI	YES (NOT PROVIDED)	POOR	ACTIVITY NEAR BANK
84	SAMWEL MAINA	HAS APPLIED	POOR	AGRICULTURAL ACTIVITIES 3 METERS AWAY FROM THE RIVER BANK
85	ITHE WA NGARI	NOT KNOWN	POOR	
86	WANJIRA KADOGO	NOT KNOWN	POOR	
87	MAINA IRAJI	NONE	POOR	
88	JULIUS KIBIRI	NOT KNOWN	MEDIUM	
89	JOSEPH WAHOME	NONE	MEDIUM	
90	JIFFERSON MURUMI	NONE	POOR	ACTIVITY 3M FROM BANK

INDEX	OWNER	PERMIT NO / INFO	RIPERIAN VEGETATION	AGRICULTURAL ACTIVITY
91	JAPHAS WAHOME BAUR	NOT KNOWN		
92	JANE WANGUI	NOT KNOWN	POOR	
93	PETER NJOGU	NOT KNOWN	MEDIUM	
94	JAMES MWAI	YES (NOT PROVIDED)		
95	MATHENGE	NOT KNOWN		
96	MR NJUKI	NOT KNOWN	POOR	5 M FROM BANK
97	MR MUREKIO	NOT KNOWN	POOR	AGRICULTURAL ACTIVITIES 3M FROM BANK
98	MR GITAHI NDEGE	NOT KNOWN	POOR	
99	JAMES GITHAIGA	NOT KNOWN		
100	WILLIAM MATHENGE	NOT KNOWN	POOR	
101	JOHN KIBANYA	HAS APPLIED	POOR	AGRICULTURAL ACTIVITIES 3 M FROM THE RIVER BANK
102	CHRISTOPHER KAHOME	NOT KNOWN	POOR	NO ACTIVITY NEAR
103	JOSEPH MUTAHI	HAS APPLIED	MEDIUM	NO ACTIVITY
104	MAINA KAHORA	NONE	POOR	ACTIVITY 5 M FROM RIVER BANK
105	FRANCIS MUREITHI	NOT KNOWN	POOR	
106	SWEETWATERS FURROW	20173	MEDIUM	
107	MAINA KIGENYI	HAS APPLIED	POOR	
108	THEURI	HAS APPLIED	POOR	
109	JOSEPH WACHIRA	NONE	POOR	
110	CHARLES MURIUKI	NOT KNOWN	POOR	
111	KARURI	NOT KNOWN		
112	KIROMBE	NONE	POOR	
113	NDIANGUI	NOT KNOWN	POOR	