Determination of the Drivers and Impacts of water Diversion and Abstraction in Selected Rivers in the Upper Tana Basin, Kenya

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DECLARATION

I understand that plagiarism is an offence and I therefore declare that this thesis is my own original work and has not been submitted to any other institution for any other award.

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DEDICATION

This thesis is dedicated to my family especially my mum Agnes Mumbe and dad Daniel Mwendwa, sisters Mercy Mwikali and Eunice Makasi and my brother Charles Mumo who have been supportive and encouraging throughout the period I was pursuing PhD studies at South Eastern Kenya University (SEKU).

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA:	Analysis of Variance
ASL:	Above Sea Level
AWSB:	Athi Water Services Board
DAP:	Diammonium Phosphate
DEM:	Digital Elevation Model
DPSIR:	Drivers, Pressures, State, Impacts and Response
EEA:	European Environmental Agency
EIA:	Environmental Impact Assessment
EMCA:	Environmental Management and Coordination Act
GIS:	Geographic Information System
GOK:	Government of Kenya
IFAD:	International Fund for Agricultural Development
ITCZ:	Inter-Tropical Convergence Zone
IWMI:	International Water Management Institute
JICA:	Japan International Corporation Agency
KMD:	Kenya Meteorological Department
KTDA:	Kenya Tea Development Authority
MCIDP:	Murang'a County Integrated Development Plan
NCT:	Northern Collector Tunnel
NWSC:	Nairobi Water and Sewerage Company
NEMA:	National Environment Management Authority
RGS:	River Gauging Station
ROK:	Republic of Kenya
SWUT:	South West Upper Tana Basin
TDS:	Total Dissolved Solids
TNC:	The Nature Conservancy
TSS:	Total Suspended Solids
UN:	United Nations
UNEP:	United Nations Environment Programme
UTaNRMP:	Upper Tana Natural Resources Management Project
WARMA:	Water Resources and Management Authority
WFD:	Water Framework Directive
WHO:	World Health Organization
WRA:	Water Resources Authority
WUA:	Water Users Association
WRUA:	Water Resource Users Association

ABSTRACT

The South West Upper Tana Basin, Kiama, Chania, Kimakia and Thika sub basins, located in the central region of Kenya has been experiencing increased water abstraction and river diversions. However, the causes of this increased water abstraction have not been fully investigated. Several factors that could be responsible to these abstractions; climate change, land cover/land use changes, agricultural practices and changes in streamflow. Previous studies in the region have not determined the contribution of each of these factors in causing water abstraction in the basin. Determination of the drivers of water abstraction is important for sustainable water resource development in the basin. Agricultural intensification in the basin is heavily reliant on water abstraction. This study therefore investigated the drivers and impacts of water abstraction and river diversion in the Basin. The main objective of the study was to determine the causes and impacts of water abstractions/diversions on streamflow in the Basin. Socio-economic data was collected through 120 questionnaires that were equally administered to households in Kiama, Kimakia, Thika and Chania sub basins. Hydrological data, mainly river discharges and rainfall data were obtained from Water Resources Authority (WRA) and Kenya Meteorological Department (KMD). Simple linear regression and logit regression analysis was used to test the relationships between variables. The dependent variable for the study was water abstraction while independent variables were rainfall variability, streamflow, household structure, education, occupation, water abstraction technologies and agricultural practices. The study established that the main drivers of water abstraction are climate change, government policies and strategies and agricultural development. The pressures underlying these drivers are the need for water for irrigation agriculture, domestic use and inter-basin water transfers. There is evidence of increased variability in rainfall due to climate change. The variability of rainfall and streamflow has a strong positive correlation with r value of 0.70 and R^2 0.61. Influence of crop sales (coefficient = 0.78; odds ratio = 22.35; P = 0.01), farm size (coefficient = 0.85; odds ratio = 11.19; P = 0.04) and fertilisers used (coefficient = 0.65; odds ratio = 3.08; P = 0.02) on water abstractions was also significant. The household structure was found not to have a significant influence on water abstraction and streamflow decline. The increased water abstraction has also increased upstream and downstream impacts in the basin. The impacts of water abstraction and streamflow decline include the decline in water levels, changes in turbidity, improved crop yields, siltation and changes in channel morphology. The main responses to these impacts are water use restrictions, policies and legislations and societal guidelines. This study recommends intensified reforestation programs to improve forest cover in the basin since this can potentially improve water yield in the rivers. There is also need for improved monitoring of water abstractions, public awareness creation and the involvement of stakeholders especially water users in the basins. The later is important for sensitizing people on the impacts of over-abstractions. This study will inform the development of policies that will ensure sustainable water abstraction in the SWUT basin.

CHAPTER ONE

1.0 INTRODUCTION TO THE STUDY

1.1 Introduction

This chapter introduces the genesis of the problem on which the study is built on. The objectives of this study, hypothesis, justification, the scope of the study and the conceptual model are presented in this chapter. The chapter also sheds light on the generic drivers and impacts of water abstraction and diversion based on the findings of other previous studies.

1.2 Background to the Problem

Rivers and watersheds are important hydrological systems of the planet earth (Manatunge *et al*., 2008). This is because rivers and watersheds are sources of freshwater which is critical for sustaining life on earth. The freshwater resources are important for supporting socio-economic systems on the earth. However, global fresh water resources spatial-temporal distribution is erratic and unreliable (Saleh *et al.,* 2005). Consequently, man has always tried to exploit the available fresh water resources by diverting river waters for various uses. River water abstraction and diversions have been done in various parts of the world for different purposes such as irrigation, flood control, municipal water supply, hydropower, and environmental management and/or restoration (Jim and Truls, 2005). River water diversions and abstractions are more likely to increase in the coming years (Poff *et al.,* 2003; Finer and Jenkins, 2012) due to the escalating water demands for hydropower, irrigation and domestic purposes (Palmer *et al.,* 2008). In addition, river basins in the world are experiencing many stressors including water over abstraction, infrastructure development such as dams, pollution, land use change and eutrophication (MEA, 2005). These stressors are driven by factors such as industrial growth, population growth, economic development, demand for irrigation water and water for domestic purposes (MEA, 2005).

It is estimated that 60% of rivers in the world are already diverted (IWMI, 2007). Further, water abstraction from rivers and lakes for irrigation, domestic and industrial use has doubled in many parts of the world since the 1960s (MEA, 2005). Also, areas under irrigation worldwide have almost doubled in the previous five decades (Gleick, 2003; FAO, 2009) and it is expected that this upward trend will continue in the coming years (Scanlon *et al.*, 2007). In many river basins, the use of water for agricultural, urban and industrial growth is approaching or in some cases has exceeded the amount of available renewable water (IWMI, 2007). Excessive exploitation of rivers has led to significant hydrological modifications.

The increasing water abstraction including diversion of rivers may be driven by the societal desire to adapt to the changing rainfall patterns and increasing global temperatures that are linked to global climate change (Hisdal *et al.,* 2001; Gibelin and Deque, 2003; Sanchez *et al.*, 2004). Additionally, there is also an increasing per capita demand for energy, for the more than 1.4 billion people globally who do not have connectivity to electricity (UNEP, 2012). As more nations strive to enforce the Kyoto protocol of reducing the use of fossil fuels, the renewable sources of energy such as rivers are becoming more important for hydropower generation. Hydropower contributes approximately 80% of the renewable energy (The World Bank, 2014). The need for adequate supply of drinking water has also forced governments to invest in construction of large water abstraction projects to supply water to large cities (Dahm *et al*., 2013). The impacts of these projects have far reaching consequences locally, regionally and globally (Vorosmarty *et al*., 2004). The consequences that have been documented include but are not limited to conversion of drylands to agriculturally productive regions (Helld_en and Tottrup, 2008), reduction in areal extent of large lake systems (Beeton, 2002), and emergence of broad waterway networks (Acreman *et al.,* 2008). However, it is important to note that at sub-catchment levels, particularly in Africa, the impacts of large water abstraction or diversion projects are largely unknown. This is because, few hydrological studies have been undertaken in Africa to unravel the causes and impacts of increasing water abstraction and diversion of rivers for various purposes.

The impact of any water abstraction project depends on the type of abstraction scheme. For instance, large dams generate more significant hydrological impacts (Poff and Allan, 1995) such as changes in channel morphology (Lobera *et al*., 2015), sediment transport changes (Tena *et al.,* 2011), change in water temperature (Olden and Naiman, 2010) and water chemistry (Friedl and Wuest, 2002). The hydrological changes may in turn impact on the ecosystem processes (Aristi *et al.,* 2014) and riverine biodiversity (Haxton and Findlay, 2008).

In many parts of Africa, only temporary diversions have been constructed to divert river water, since water diversion activities require more extensive engineering works. Additionally, most of the diversion and overexploitation has focused on small rivers. Water may be abstracted directly from the flowing waters in the river channel, or indirectly from wells through pumping of water from aquifers that may be closely connected to rivers. Moreover, water abstraction from rivers may be achieved through inter-basin water transfer schemes.

Despite their prevalent occurrence throughout the world, limited attention has been given to the impacts of water abstraction and river diversion especially through construction of low weirs (<5 m) that do not have the capacity to retain huge volumes of water or fully regulate the downstream flow (Zarfl *et al.,* 2015). Water abstraction schemes can reduce river discharge and their impacts on stream and river ecosystems could somewhat be similar to those of climate change. Therefore, increased water abstraction in rivers has the potential of altering the habitat for aquatic organisms (Boulton, 2003; Ledger *et al*., 2013). This can significantly impact on aquatic biodiversity.

While natural drought normally reduces stream flow in a slow manner and in definite seasons, anthropogenitically driven water abstraction leads to abrupt reductions in streamflow in other seasons. The resulting changes in ambient conditions such as temperature or light penetration could result in different responses to aquatic organisms (Acuna *et al.,* 2005; Von Schiller *et al.,* 2011). In extreme cases, water abstraction/diversion schemes may dry out some sections of streams, hence reducing their longitudinal connectivity (Malmqvist and Rundle, 2002). Even when the change is not dramatic, reduced stream discharge can still result in alteration of river aquatic ecosystem. This can decrease the surface area of in-stream habitats (Fisher *et al.,* 1997). Abstraction could also lead to habitat quality degradation by affecting water temperature (Meier *et al.,* 2003; Bae *et al.,* 2015) and river flow velocity (Death *et. al*, 2009; Matthaei *et al.,*2010), which could impact on biofilm biomass (Mosisch, 2001; Allan and Castillo, 2007).

There have been limited studies on the drivers, pressures and impacts of water abstraction on the functioning of river ecosystems (Dewson *at. al* 2007b; Arroita *et al.,* 2015). In Africa and Kenya, only a few studies have been undertaken to determine the root causes (drivers), pressures and impacts of river water abstraction. Most of the studies on water abstractions have focused on determining the water demands and water supplies particularly in urban centres. There is limited data and information on the root-causes and impacts of water abstraction in tropical river basins and the wider scenario of climate change. This study intends to fill this gap by determining the main drivers and impacts of water abstraction in South West Upper Tana Basin.

In upper Tana basin, there are many low magnitude river water abstractions and diversions that are necessitated by the need to have more water for agricultural use, domestic, industrial, municipal/urban and recreation purposes. However, it is not known which of these uses is dominant or is the main culprit in as far as declining river flows in dry season are concerned. The dynamics of water abstraction in the Upper Tana Basin are not well understood. This is complicated by the fact that most diversions and abstractions are not documented because of poor licensing and monitoring for water abstraction.

These unregulated water abstractions and river diversions bring unintended consequences, largely because there are no data, tools or strategies to address the related cumulative impacts (Jim and Truls, 2005). This study therefore, sought to determine the drivers, pressures and impacts of water diversions and abstractions in South West Upper Tana Basin (Kimakia, Kiama, Chania and Thika Rivers) which is part of the larger Upper Tana Basin. This study is important since increased water abstraction in the basin through the construction of Northern Collector Tunnel (NCT) may increase the impacts of river water diversions and abstractions in the basin. This study was therefore important for promoting integrated water resources management in the sub basins. This is because it provides data and information to guide projects in the basin based on clear understanding of their upstream and downstream impacts. By establishing the main drivers of increased water abstraction and subsequently extreme low streamflows, this study provides an opportunity for designing of strategies of mitigating the adverse impacts. The study also examined the responses to declining low streamflows in the basin.

1.3 Statement of the Problem

The modification of streamflow in many tropical rivers as a result of increasing water demand due to both urban and agricultural development is a matter of concern in developing countries such as Kenya. River water abstractions and the construction of dams and weirs in rivers can change the natural patterns of stream flow. There can be an increase in periods of no flow and or increased low flow. These can inturn lead to many downstream impacts. However, in many tropical river basins, specific impacts are largely undocumented. Also, the root causes and pressures associated with increased water abstraction and river diversion in most tropical river basins are yet to be fully established. The same is true for the South West Upper Tana Basin in Central Kenya. The cumulative impacts of uncontrolled abstractions and diversions have not been established in the previous studies. The cumulative effects of small-scale water diversions and water abstraction projects can be highly significant (Letter *et al.,* 2008). Thus, this study fills this gap by carrying out a comprehensive study of the extent to which water abstraction and diversion has led to extreme low streamflows in the South West Upper Tana Basin in Central Kenya.

In the recent past, there has been an increase in water abstractions/diversions in the South West Upper Tana Basin of central Kenya. This has coincided with declining streamflow in the basin which are leading to degradation of aquatic ecosystem and significant environmental and social-economic impacts (Vitousek *et al.,* 1997; Chapin *et al.,* 2000; Butchart *et al.,* 2010). This decline of streamflow of rivers in South West Upper Tana Basin is not well understood since only a few studies have established the root causes of streamflow decline. This is due to the fact that the rainfall data and other reports show an increasing trend in rainfall in the South West Upper Tana Basin. Furthermore, the impacts of streamflow decline in the dry seasons have not been studied or reported in the previous studies. Most of those studies have largely been speculative based on limited data. Thus, it is important to understand the ways through which human-induced pressures are affecting streamflow in the South West Upper Tana Basin, particularly during the dry seasons. The examination of the extent to which various drivers and pressures cause changes in streamflow in South West Upper Tana Basin as well as how the impacts of these drivers and pressures are addressed is critical for sustainable water resource management and development. This study also attempted to determine the extent to which the causes and impacts interact additively, synergetically or categorically (Piggott *et al.,* 2015).

Rivers in the South West Upper Tana Basin in Central Kenya are important sources of water for the City of Nairobi. Through Ndakaini dam, these rivers supply 84% of water used in Nairobi City. Therefore, decline in streamflow as a result of unregulated exploitation in the South West Upper Tana Basin has potential of causing a major water crisis in Kenya’s capital city, Nairobi.

1.4 Research Objectives

1.4.1 Main Objective

The main objective of this study was to determine the root causes and impacts of water abstractions and diversions in the South West Upper Tana Basin in Central Kenya with a view to attaining sustainable water abstractions.

1.4.2 Specific Objectives

The specific objectives of the study were to:

i. Determine the extent to which rainfall variability is influencing streamflow variability in South West Upper Tana Basin;
ii. Examine the drivers and emerging patterns of water diversion and abstraction in South West Upper Tana Basin;
iii. Determine the influence of agricultural practices and household structure on water abstraction in South West Upper Tana Basin; and
iv. Determine the impacts of water abstractions and diversions in the South West Upper Tana Basin.

1.5 Hypotheses of the Study

The study was guided by the following six (6) hypotheses.

H_o: There is no significant relationship between streamflow variability and water abstractions in the South West Upper Tana Basin.

H_0: There is no significant relationship between streamflow variability and rainfall variability in in the South West Upper Tana Basin.

H_o: There is no significant relationship between household structure and water abstraction in the South West Upper Tana Basin.

H_o: There is no significant relationship between education level, income, employment status and technology used and water abstraction in the South West Upper Tana Basin.

H_0: There is no significant relationship between agricultural practices and water abstraction in the South West Upper Tana Basin.

Ho: The abstraction of river water has no significant downstream and upstream impacts in the South West Upper Tana Basin.

1.6 Justification of the Study

The diversion and abstraction of river water for various activities has been on the increase in Africa in the recent past (Ginster *et al.,* 2010). Many developing countries have increased abstractions of river water in order to improve supply of water for agriculture, urban and industrial development (Kossa *et al.,* 2014). In Kenya, most of the rivers in the Upper Tana Basin have had their waters diverted or abstracted for domestic and agricultural use. This has impacted on the streamflow in these rivers especially during dry seasons. In south West Upper Tana Basin, there has been increased water diversions and abstractions in Kiama, Kimakia, Chania and Thika rivers. However, there are limited studies that have been undertaken in the area to determine the causes and impacts of water abstractions. Most of the studies in the Upper Tana Basin have focused mainly on soil erosion and sedimentation and the impacts of construction of Masinga dam (Ongweny, 1983; Jacob *et al.,* 2007; Kitheka, 2016; Njogu and Kitheka, 2017). Thus, there is limited data and information on the root causes (drivers) of increasing water abstraction and their impacts in Africa as well as in Kenya. This study will generate data and information that can be used for water resources management. The data will also lead to formulation of tailor-made intervention measures, including climate change mitigation measures and monitoring of water abstractions and diversions in South West Upper Tana Basin.

Few studies have applied DPSIR approach in the study of the problem of declining streamflows in African river basins. This study applied DPSIR approach to unravel the drivers, pressures, state, impacts and responses on the increased water abstraction and declining streamflows in South West Upper Tana Basin. There is a raging debate on the exploitation of water resources in the South West Upper Tana Basin between Nairobi and Murang'a County governments. There are also conflicts between the upstream and downstream users of water in the rivers in this basin. Unraveling the root causes/drivers of water abstraction in this area can help in the formulation of strategies for sustainable management of water resources in the study area.

The need to provide water for the increasing population, urbanization and industrialization in the study area can only be addressed through sustainable and integrated water resources management. This study provides data and information that can improve the strategies for water resources exploitation and development. The results of the study are also vital for integrated water resources management in Kenya since the country is classified as water scarce. This study also provides a great contribution to the achievement of Kenya Vision 2030 goal on access to water for all by 2030.

This study is important for development of robust water resources management strategies in the Upper Tana Basin. There is also determination of the suitability or appropriateness of the various responses to the declining streamflows and their impacts. This is important for establishing gaps in existing or current response strategies. Other studies in the Upper Tana Basin will also benefit from the findings of the study as reference points for further research.

1.7 Scope and Limitations of the Study

This study mainly focused on establishing the causes/drivers and impacts of water abstraction in the South West Upper Tana Basin. The study was specifically undertaken in Thika, Chania, Kiama, and Kimakia sub basins in the Upper Tana Basin. The study did not focus on the whole Upper Tana Basin because of its wide geographical extent and also the need to have an intensive study of the smaller sub basins. The main issue addressed by this study is the main causes and impacts of water abstractions/diversions in the sub basins found in South West Upper Tana Basin. However, the study did not deal with impacts of specific diversion projects such as the Northern Collector Tunnel. The focus was mainly on the cumulative impacts of various water abstraction projects in the study area. The fieldwork was conducted in the period between January 2018 and December 2018. This allowed adequate collection of primary and secondary data on water abstraction variations, the driving forces and impacts. The main limitation of this study was the gaps in data obtained from state agencies such as Water Resources Authority (WRA). There were gaps in river discharge data for Kiama and Kimakia rivers while data for Chania and Thika rivers was not updated to 2018. In addition, the study was limited by the lack of comprehensive records on the licensed and unlicensed water abstractors in the study area.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

The chapter provides a review of studies undertaken at local, national, regional and global levels. Attempt was made to provide a critical review in order to establish gaps in the existing literature. The chapter also provides the theoretical basis for the study as per the objectives of the study. It was prepared using data and information from various sources such as books, journals and technical reports.

2.2 Influence of rainfall variability on streamflow variability

2.2.1 Studies done at global level

A number of studies have been undertaken at global level on the influence of rainfall variability on streamflow (Garbrecht *et al.*, 2004; Kabede *et al.*, 2006; Zhang *et al.* 2007; Langobardi and Villani, 2010; Piao *et al.*, 2010; Ghanem, 2011; Zhang *et al.*, 2011; Jain and Kumar, 2012; Meron and Williems, 2012; Bekele, 2013; Da Silva *et al.*, 2015; Chang *et al.* 2016; Machiwal *et al.*, 2016; Zhi and Jiming, 2017; Sharma and Jothiprakash, 2019). Garbrecht *et al.* (2004) established that there are strong impacts of rainfall variations on streamflows since rainfall gives important information for planning and strategic management of water resources in a particular basin. Meron and Williems (2012) identified a high positive relationship between rainfall and streamflow. This study established that the sttreamflow extremes and volumes at El Diem had similar oscillation patterns with those of rainfall in the region. In addition, Kabede *et al.* (2006) observed that the flow of watercourses is mostly influenced by rainfall variability rather than other factors such as human activities in the water catchment. Therefore, it is important to understand the nature and characteristics of rainfall in a particular basin since it plays an important role in the hydrologic cycle (Bekele, 2013).

Sharma and Jothiprakash (2019) determined that decline in total runoff in Tapi River was attributed to rainfall variability as well as anthropogenic factors. Da Silva *et al.* (2015) established that streamflow in the Cabres River Basin in Portugal was decreasing due to the decreasing trends in rainfall in the area. Jain and Kumar (2012) reported a decreasing trend in river flows in India due to decrease in rainfall. Similarly, Machiwal *et al*. (2016) observed a trend of non-normality in rainfall received in Guararat area of India. Rainfall influence on streamflow was also noted in Jordan River (Ghanem, 2011). Langobardi and Villani (2010) studied precipitation trends in Lazio and Campania region in Italy for a period of 81 years and established significant changes in precipitation had influenced streamflows in the regions. Chang *et al.* (2016) established that rainfall variability had the greatest contribution to streamflow in Jinghe basin, Northwest China.

Zhang *et al.* (2007) investigated the changing trends in the annual streamflow in China's six large basins for the past 50 years and reported a downward trend which was attributed to decrease in rainfall amount. Piao *et al*. (2010) studied the runoff changes in Yellow and Yangtze River Basins since 1960 and reported a persistent decline in the annual runoff in Yellow River. Zhang *et al.* (2011) also established a declining trend in streamflow in the Yellow, Pearl, Yangtze, Haihe and Liaohe River Basins in China. Zhi and Jiming (2017) determined that streamflow variability would become greater over most months on a seasonal scale due to the variations in precipitation. These studies do not provide an indepth understanding of the extreme dry season streamflow in a particular region which this study sought to establish.

2.1.2 Studies done at regional level (Africa)

Several studies have been undertaken in Africa to establish the influence of rainfall variability on streamflow (Olivry *et al.,* 1993; Mason, 1996; Servat *et al.,* 1997; Berhanu, 1999; Jury and Engert, 1999; Berhanu *et al.*, 2001; Fanta *et al*. 2001; Cook *et al.,* 2004; Seleshi and Camberlin, 2005; Conway *et al.,* 2009; Descroix *et al*., 2009; Amogu *et al*., 2010; Taye and Willems, 2012; Schewe *et al.*, 2013; Aich *et al*., 2014; Taye and Block, 2015; Odiyo *et al*., 2015; Feyera *et al.*, 2019). Cook *et al.* (2004) observed that, rainfall variability affects water resources and human activities that are reliant on water from rivers. The study emphasized that the region is reliant on agriculture which is highly affected by the changes in rainfall and the subsequent changes in streamflows. Jury and Engert (1999) established that the declining river flows in Namibia since 1970s was a reflection of declining rainfall in the country. Mason (1996), Berhanu (1999) and Berhanu *et al.* (2001) reported a decrease in the mean annual runoff in South African rivers and attributed this to the unrealiable and declining rainfall in the region. Olivry *et al.,* 1993 and Servat *et al.,* 1997 argued that the identified changes in the flow of rivers in Southern Africa were a reflection of the changes in rainfall as observed in West Africa.

Feyera *et al.* (2019) reported that the streamflow in rivers in Ethiopia would have a 25% decrease by 2080. In Luvuvhu River Catchment, South Africa, it was established that the variability of rainfall and streamflow had increased over a period of 86 years (Odiyo *et al*., 2015). Fanta *et al*. (2001) investigated the river flow variability for 502 river gauging stations in Mozambique, Angola, South Africa and Zambia. The study noted that there was a declining trend in run-off in those rivers. Rainfall-runoff relationships in Africa vary from region to region with a strong but non-stationary relationship in West Africa, relative stability in East Africa, weak and almost random in Southern Africa and medium variation in Central Africa (Conway *et al.*,2009). The expected changes in rainfall patterns are likely to influence hydrological extremes in the Blue Nile basin (Taye and Block, 2015). The temporal variability of streamflow extremes in the region have been linked to Pacific Decadal Oscillations and the Atlantic Multi-decadal Oscillations (Taye and Willems, 2012). In Ethiopia and Sudan, extreme hydro-climate events are very common. These events are directly related to precipitation extremes in the highlands and areas around Khartoum (Seleshi and Camberlin, 2005).

There is high inter-annual rainfall variability in Africa (Hulme *et al.*, 2001). This influences streamflows with a notable decrease in streamflows in Sudanian Rivers and increasing discharge in the Sahel region (Descroix *et al*., 2009; Amogu *et al*., 2010). In the last two decades, flood events have increased in the Niger Basin (Aich *et al*., 2014) while in Ghana, Cote d'ivore and Southern Nigeria, a 10-30% decrease in annual run-off was reported (Schewe *et al.*, 2013).

2.3 Drivers and Emerging Patterns of Water Diversion and Abstraction

2.3.1 Global studies

A number of studies have been undertaken at global level on the root causes of water abstraction and diversion (Reinfelds *et al*., 2006; Pieter *et al.,* 2008; Mattias, 2015; United Nations, 2016; Voulivoulis and Giakoumis, 2016; Pletterbauer *et al.,* 2017; Chu *et al.*, 2018). UN (2016) established that the demands for water abstraction from surface and groundwater sources have been increasing rapidly as a result of increase in global population, urbanization, industrialization and climate change. Mattias (2014) in a study of Gallikos River Basin, North Greece, identified intensive agriculture, urbanization, industry along the coastal part of the basin, and to a minimal extent animal breeding along the mountainous region, as the main driving forces affecting the river. The quantification of these driving forces was based on population density and the spatial distribution of agricultural land, industry and animal breeding units (Mattias, 2014). The study also established that the main pressures on water resources in the basin to be degradation of water quality, overexploitation of aquifers, and decreasing river discharge. Increasing demands for irrigation water and industrial growth coupled with uneven distribution of rainfall throughout the year was identified as another major pressure to Gallikos Basin.

Voulivoulis and Giakoumis (2016) identified the root causes of water abstraction as all economic activities that have significant impact on a river basin. These include; agriculture, fisheries and aquaculture, energy both hydropower and non-hydropower, industry, forestry, tourism and recreation, urban development and transport. Pletterbauer *et al*. (2017) added that the drivers also include adaptive social processes such as development in technology, climate change, population changes, drought management and flood control.

Study by European Environmental Agency (2015) emphasized the need for all economic activities, social processes and drivers of change in ecosystems to be properly understood at different temporal and spatial scales. The study established that the rate of drinking water demand, a critical driver for water intake depends, among other factors, on the population size, the number of households and family income (European Environmental Agency, 2015). The study emphasized the need for analysis of factors such as households using water from a particular source, irrigatioin surface, crops planted and development plans in order to determine why and how drinking water provision, irrigated agriculture could be sustained or not, depending on local ecosystems availability and the efficiency with which these services are used (EEA, 2015).

Study undertaken by Reinfelds *et al.* (2006) in Bega River in Australia established that the main drivers for water abstraction in the basin were irrigation, town water supplies, farmstead use and livestock watering. The authors reported that, agriculture in the basin accounted for 65% of water abstractions/diversions. The highest volumes (91%) of water were diverted from Bega River in summer during the period of low flows for irrigation. Chu *et al.* (2018), in their study undertaken in Canada's freshwater rivers established that the root causes of water abstraction in 2013 were electric power generation, industrial development, domestic use, agriculture and mining which accounted for 68%, 10%, 9%, 5% and 3%, respectively. The study also identified climate change as a major factor affecting the flow of rivers which had contributed to the establishment of invasive species in rivers (Chu *et al.*, 2018).

Climate change as a major driver of water abstraction was further emphasized by Pieter *et al.,* (2008) in their study on the impacts of upstream water abstractions on reservoir yield. This study established that the decrease in rainfall, increased the need for irrigation water and the periods with low flows have the highest water abstraction rates for irrigation (Pieter *et al.,* 2008). Smakhtin *et al.* (2006), noted that upstream rainfall variability and water abstractions/diversions for irrigation are important aspects in comprehending low flows in rivers. Besides climate change, human activities including soil and water conservation practices, water diversion and water conservancy projects are the main causes for decrease and inter-annual variations of water discharge and sediment load into the sea (Wang *et al.*,2006; Peng and Chen, 2009). However, Wilk and Hughes (2002) had a contrary finding that increase in agricultural activities increased river discharge in south India. Their findings, however, were only for small scale increases in agricultural lands. Hence, these findings may change when large areas are converted to agricultural land uses. These studies have identified agriculture, water for household use, urbanization and rainfall variability as the root causes of water abstraction/diversion in different parts of the world. However, the relationships between water abstraction and streamflow, water abstraction and agricultural practices and water abstraction and water quality have not been well addressed. This study sought to establish these relationships that led to determination of the key drivers of water abstraction/diversions in the South West Upper Tana Basin.

2.3.2 Regional studies (Africa)

A number of studies (Matekole**,** 2003**;** Basson, 2005; Ginster *et al.*, 2010; Mromba, 2012; Kossa *et al.*, 2014; Mwadini, 2016; Botha, 2017) have been undertaken at the regional level to determine the drivers and pressures of water abstraction and river water diversion. Basson (2005) established high variations in river flows in South Africa based on water abstraction and the design of water abstraction structures. These variations in streamflow could last for years especially during droughts (Basson, 2005). Study by Ginster *et al.* (2010) established that unlawful abstractions along the Liebenbergsvlei River, South Africa were driven by the increase in population and industrial development in Gauteng province, South Africa. These unlawful abstractions were also done to avail water for irrigation, households use and the municipal water supply (Ginster *et al*., 2010).

The results of this study are consistent with those of Botha (2017) who identified that population growth, climate change and urbanization as the main drivers of water abstraction/diversion in South Africa. The study noted that the increasing demand for water was due to the rapid population growth in the country. This situation is worsened by the increase in frequency of below average rainfall and the expansion of urban areas such as Cape Town metropolitan (Botha, 2017). Similar findings were reported by Brooks and Brandes (2011) who identified population growth as the root cause of water abstraction for irrigation in a river basin. Mromba (2012) also identified the rise in irrigation activities as the root cause of water over abstraction in Kilideda sub catchment. This over abstraction led to decline in river flows in the sub catchment (Mromba, 2012). Chiwa (2012) noted a 13.3% increase in the land under cultivation in the Kilideda sub catchment between the years 2000 and 2009. This led to subsequent increase in demand for water for irrigation. Studies by Matekole (2003) and Mromba (2012) established that the irrigation technologies used were the main drivers of water abstraction. The studies further showed that these drivers cause pressures on the demand and supply of water resources in the basin. The drivers also caused conflict for the available water resources (Mromba, 2012). These findings are similar to those of Ramirez *et al*., (2008) who established that water abstraction technologies used, farm size, farm ownership, farm position and type of crop grown were the main drivers of water abstraction. Similarly, a study by Botha (2017) established that in South Africa, water abstraction is guided by demand guidelines such as stand size, water price, household income, type of development and the available pressure.

2.4 Impacts of water abstractions/diversion

2.4.1 Studies done at global level

Several studies have been undertaken to establish the upstream and downstream impacts of water abstraction and diversion globally (Boulton, 2003; Doyle *et al*., 2003; Larranaga *et al*., 2003; Reinfelds *et al*., 2006; Miller *et al*., 2007; James *et al*., 2008; Mattias, 2014; Arroita *et al*., 2017; Chu *et al*., 2018). Reinfelds *et al*. (2006) established that water abstractions in Bega basin, Australia, increased the frequency and duration of low flows in the river and magnified the impacts of drought. These impacts of water diversions on daily flows differed from year to year but were mostly realized during the dry season. The hydraulic response to water diversion/abstraction is mostly seen in running water mesohabitats such as reduction in the wetted area, riffles, average velocity and depth. These hydraulic changes also alter the assemblage of microinvertebrate directly through the loss of habitats for organisms as well as reduction in biodiversity (Reinfields *et al*., 2006). Indirect impacts to microinvertebrate occur through changes to water chemistry related to the long periods of low flows including increase in water temperature and conductivity and decrease in dissolved oxygen (Boulton, 2003; Miller *et al.,* 2007). These results are consistent with those of other studies (Rader and Belish, 1999; McIntosh, Benbow and Burky, 2002; James *et al.,* 2008) that reported increase in water temperature and pH and decreased dissolved oxygen concentration due to water abstraction.

Chu *et al*. (2018) established that water abstraction in Canadian rivers caused a decrease in water quantity and quality in the rivers by increasing the concentrations of contaminants, stunted growth of species, reduced ranges of species and change in the proportion of species. In addition, study undertaken on Gallikos River Basin, North Greece (Mattias, 2014) established that water diversion/abstraction for intensive agricultural production where use of fertilizers is highly popular, led to nitrate pollution and increased phosphorus compounds in surface and ground water.

Overpumping of water from boreholes resulting in groundwater level drawdown and decrease of reserves was also identified as a major impact of water abstraction in this basin. These results were consistent with the findings of Sinclair (1999), who noted that the impact of water diversion for irrigation had the potential to significantly impact on stream flow particularly under low flow conditions on the downstream users. In a similar study, Arroita *et al.* (2017) established that water abstraction reduce discharge in the impact reach to an average of 35%. The study also noted that water abstraction did not affect water quality but it reduced the biomass and the nutrient uptake rate, and the distance travelled by organic matter. A strong relationship between water abstraction and the river ecosystem functioning was established by this study (Arroita *et al*., 2017).

Other studies established a strong relationship between water abstraction and hydromorphology, leading to a much narrower wetted channel, shallower water column and slower flow velocity (Ehrman and Lamberti, 1992; Larra~naga *et al.,* 2003). Reduced discharge results in narrower depth and width, and smaller hydraulic power, thereby increasing retentiveness of coarse particulate organic matter (Ehrman and Lamberti, 1992; Larranaga *et al.,* 2003). These results are consistent with Stanley *et al.* (1997) and Sweeney *et al.* (2004)

who established that the most evident effect of water abstraction as the reduction of the total amount of benthic stream ecosystem per unit of channel length. Therefore, even if water abstraction would not affect in-stream processes on a per-surface-unit basis, these physical changes could significantly compromise in-stream ecosystem functioning on a per-unit-of channel- length basis similar to those in streams narrowed due to forest clearing.

Wilcock *et al*. (1996) and Pitlick (1992) had similar findings in their study on the Trinity River in California USA where water diversion led to simplification and narrowing of the channel by 40%. Other studies in river Colorado (Van Steerer and Pitlick, 1998; Pitlick and Cress, 2000) showed a reduction in the main river channel from 1937 to 1993 by approximately 10% while the area of secondary channels decreased by 20-30 %. The narrowing of the river channel simplified the channel, reducing the amount of side-channel and back water habitat in the river (Pitlick and Cress, 2000). Studies in China also showed that water diversion is one of the main causes of decrease and inter-annual variations of water discharge (Yu *et al*., 2011). Similarly, studies by Defersha *et al.* (2012) showed that water abstraction and river diversion increased 2turbidity in the river. Through increased turbidity, sunlight penetration decreased, resulting in restricted photosynthesis and consequently the plant survival and dissolved oxygen content decreased (Ven, 2011). However, the sediments could also encapsulate particles; for example, nutrients, heavy metals and pesticides that originate from agricultural fields and hence pollute the receiving water bodies (Hulsman, 2015).

2.4.2 Responses to water abstractions/diversions

Responses are the actions taken by the government, community or non-state actors to deal with the impacts generated by water abstraction/diversion. A number of studies (Defra, 2013; Randle *et al*., 2015; Sharkov, 2016) have been undertaken at the global level to determine the responses to increasing water abstractions and river diversions. Sharkov (2006) established that water abstraction charges were the main tool adopted by the Bulgarian government to curb increased water abstraction rates in the country. The author reported that the introduction of those charges helped in preserving water resources and enhanced sustainability in the use of the resources. These results are consistent with Defra (2013), who established that water licensing system in the United Kingdom (UK) was the best tool for managing water abstractions. According to the study, the licenses and permits are issued to people based on their peak water abstraction in the past 10 years to factor in climate variability. The author also found out that the permits also have restrctions to the amount of water to be abstracted in low flows to maintain environmental flows. In the United States of America (USA), Randle *et al.* (2015) established that some river diversion projects, especially those using canals needed redesigning after a period of time to restore their efficiency. The authors noted that redesigning projects improves water intake, removes high sediment concentration in diversions and prevents possible increase in flooding during the wet season (Randle *et al.,* 2015).

2.4.3 Impacts of water abstractions and diversions in regional level (Africa)

Several studies (Lahlou, 1996; Basson, 2005; Ginster *et al.,* 2010; Kossa *et al.,* 2014) have been done in Africa to establish the impacts of water abstraction and river diversion. Study done by Ginster *et al.,* (2010) established the existence of transboundary conflicts in Southern Africa. In addition, it was noted that there was a conflict between water users and regulators in the Upper Vaal region as a result of water abstraction. This study also noted that the upstream abstraction affected the downstream users negatively (Ginster *et al.,* 2010). In a similar study, Kossa *et al*., (2014) established that there existed a conflict between upstream and downstream farmers in Mkoji Sub Basin, Tanzania. The author added that the improved water intakes in the sub basin were diverting more water hence depriving access to the downstream users especially in dry season (Kossa *et al.,* 2014). The study also noted that the region was highly dependent on dry season irrigated agriculture as the main source of livelihood. As a result, this increase in the demand for water led to persistent conflicts in the region. In the study, it was also established that 80% of downstream water users believed that the increase in irrigation farming upstream of Mkoji Sub Basin was the main cause of water shortages and drying up of rivers during dry season (Kossa *et al.,* 2014). The study also noted that the increase in river diversions led to low streamflows and ecosystem degradation.

Lahlou (1996) established that diversion of water for agricultural activities led to degradation of water quality through eutrophication process. The author noted that increased use of nitrogen and phosphorous rich fertilizers in farms affected the water quality when these nutrients found their way into the river channel (Lahlou, 1996). Another study by Basson (2005) established that the diversion of water from the Marromeu complex to Cahora Bassa dam led to reduced river channel with marked reduction of in-channel habitat (Basson, 2005). These reductions in the magnitude and frequency of flood plain inundation caused isolation of secondary channels leading to the dominance of one main channel. The study also noted that there was increased siltation leading to isolation of secondary channels from the main channel. This also resulted in loss of biodiversity since the connectivity of wetlands to the main river channel was disrupted.

2.4.4 Responses to water diversions and abstractions at regional level

Several studies have been undertaken on the responses to increased water abstractions on river basins in Africa (Basson, 2005: Inocencio *et al*., 2007; Ginster *et al*., 2010; Nakano and Otsuka, 2010; Ward, 2010; Komaketch *et al*., 2012; Kossa *et al*., 2014; Mwadini, 2016; Botha, 2017). For instance, Ginster *et al*. (2010) established that the main responses given to water abstraction in the Vaal Basin, South Africa were licensing, granting of water rights and legislation. The authors noted that in the Axle and Liebenbergsvlei river district, farmers were following their allocation rights when abstracting water from the river. However, the institution in charge of enforcing water legislations was not effective in ensuring the other regions were following the water rights guidelines (Ginster *et al.*, 2010). Similar responses to increase in water abstractions were identified by Kossa *et al.* (2014) where water abstraction rights and legislations were the main tools used in Mkoji Sub Basin to regulate abstractions. These water rights spelt out the amount and the period when water could be abstracted from the sub basin. It was, however, noted that some farmers who abstracted water using canals defied the provisions of their water rights and abstracted water even in the low flow period. The study recommended regular auditing and assessments of the canals and water abstracted by the farmer viz. their abstraction rights.

A similar study by Mwadini (2016) in Kiladeda Sub Catchment, Tanzania, established that there was a system for the allocation of water rights in the sub catchment. The rights were issued by the Pangani Basin Water Office to all people abstracting water in the basin except those abstracting water for domestic and livestock watering (Mwadini, 2016). The water rights were allocated to a certain amount of flow depending on the general understanding of the demand and supply of water within the basin. This study also noted that proper implementation of regulations and policies on the allocation and use of water resources would ensure a prudent water resource management. A similar study by Botha (2017), reported that the best response to water abstraction is the adoption of alternative sources of water such as water harvesting. Additionally, this study recommended the use of predictive statistical models to estimate the water demands for irrigation and water supply in a river to help strike a balance between demand and supply (Botha, 2007).

Study by Komaketch *et al.* (2012) established that the formation of Water Users Associations (WUAs) in Pangani River Basin, Tanzania minimized the conflicts between water users in the basin. The WUAs provided for a well-structured water allocation framework which solved the conflicts that were existing among different groups (Komaketch *et al.,* 2012). A similar study in Uganda by Nakano and Otsuka (2010) established that water abstractors in Doho irrigation scheme had organized themselves into water management groups. These groups ensured equitable allocation of water resources to avoid conflicts (Nakano and Otsuka, 2010). These results are also consistent with those of Inocencio *et al.* (2007) and Ward (2010) who noted that the establishment of effective WUAs in a river basin is the most effective way of ensuring equity and efficiency in water resources allocation.

Basson (2005) established that there was a need to design the diversion structures in a way that would not compromise their functionality and the amounts that would be diverted from the river channel. The study recommended the optimal locations of intake as the location where the flow path did not wander (Basson, 2005). In all these studies, none of the responses had been demonstrated to have worked perfectly in controlling the water abstraction rates. This study sought to identify the best ways of controlling water abstractions and river diversions to ensure that it is done in a sustainable way.

2.5 Review of Studies done in Kenya

2.5.1 Drivers and pressures of water abstraction and river diversion in Kenya

A number of studies have been done on water abstraction and river diversion in Kenya (Mutiga *et al.,* 2010; Musau *et al.,* 2015; Mueni, 2016; De Jong, 2011; Manohar *et al.,* 2017). A study by Mutiga *et al.* (2010) established that the high demand for irrigation water was the root cause of water abstraction in the Upper Ewaso Ng'iro North Basin. This study noted that the increase in water abstraction gave rise to low river flows, water shortages and conflicts among water users in the basin (Mutiga *et al.,* 2010). In a similar study Mukhwana (2016) established that water abstractions in Ewaso Ng'iro basin was driven by the rapid population growth as a result of immigration from neighbouring areas, agricultural development and land use changes in the basin. Horticultural farming in the basin had gained popularity because of the realization that it was profitable (Mukhwana, 2016). The study also noted that climate change in the basin had contributed to the increased abstractions since farmers rely entirely on the water abstracted from the river for crop production. Increase in drought cycles in the basin led to low river flows which placed more pressure on the river to provide enough water for irrigation (Mukhwana, 2016). Ngigi *et al.* (2007) had similar findings that population increase and intensification of agriculture in Ewaso Ng'iro basin was the root cause of increased abstractions.

A study by Mueni (2016) established that climate change and population changes were the main drivers of water abstractions and river water diversions in Kenya. This is similar to the findings of Musau *et al.* (2015) who noted that population growth and climate change were a major threat to the availability of water resources in Kenya. Manohar *et al.* (2017) had similar results identifying agricultural activities and population growth led to increased demand for water from Yatta diversion canal which increased siltation in the canal. The study also cited poor farming and irrigation methods, infiltration of agrochemicals and rainfall variability were the root causes of low flows and changes in water quality in the canal. In another study, De jong (2011) established that water resources in the Lake Naivasha basin were facing increased pressure because of the increase in water demand and limited availability of water resources. The study identified illegal water abstractions and over abstraction of water from River Malewa as the key drivers of low flows in the river. A study undertaken in Nairobi River by Kithiia (2006) established that land use changes were the root causes of low flows and reduced infiltration rates.

2.5.2 Impacts of water abstraction and river diversion in Kenya

A study by Mukhwana (2016) identified several impacts of water abstraction in the Ewaso Ng'iro Basin. The study established that there were vegetation changes in the basin between the years 2000 to 2015 with a 58% and 51% decrease for moderate and dense vegetation respectively (Mukhwana, 2016). The study also established that there were low flows which altered the channel morphology and affected the proportion of benthic microinvertebrates. The crocodile and hippotamus population were also reported to have decreased as a result of the low flows. Low flows in the river had also caused increase in water temperature and changes in dissolved oxygen in the river water. Invasion of alien species was also noted due to the low flows which cause changes in dry and wet cycles (Mukhwana, 2016). This study established that water abstraction for intensive agriculture in the upper parts of the basin had increased since horticultural farming became profitable in 1980s. Ngigi *et al.* (2007); Aeschbacher *et al.* (2005) established that there were inter-communal conflicts in the Ewaso Ng'iro basin because of the low flows and competition for the scarce water resources.

In addition, the increase in water abstraction has been magnified by the increase in population which has placed more demands on water resources (Ngigi *et al.*, 2007). It is estimated that 60 to 90% of the Ewaso Ngir'o river flow is abstracted during the dry season since agricultural production in the basin is mainly based on water abstraction from the river (Gichuki *et al.* 1998; Ericksen, 2011). In their study, Leeuw *et al.* (2012) found out that there was an increasing trend in water abstractions in the basin from 1960 to 2010. However, the estimates in this study were only based on the legal abstractions. Most of the abstractions (90%) are illegal (Ericksen, 2011). The study also established that the increasing abstractions in the basin have led to decline in river flows and this decline is aggrevated by the increasing frequency of droughts in the region. Liniger *et al.* (2005), examined three sub basins, Burguret, Likii and Timau, and established that the low flow trends were mainly as a result of water abstractions for agriculture. However, it is important to note that studies aimed at unraveling the root causes and impacts of water abstraction and diversion are very limited in Kenya and Africa at large. In their study of the Yatta canal, Manohar *et al.* (2017) noted that diversion canals were prone to eutrophication in dry season. The alterations have environmental and economic impacts like water scarcity and could also increase the risk of water borne diseases.

2.6 Review of Studies done in the Upper Tana Basin

Most of the studies conducted in the Upper Tana Basin have been on soil erosion, sedimentation, changes in riparian vegetation, climate change and river discharge among others (Ongwenyi, 1983; Jacob *et al.*, 2007; Bunyasi *et al.*, 2013; Njogu and Kitheka, 2017). In their study, Jacobs *et al.* (2007) established that the expansion of agricultural production and unregulated deforestation in the basin had resulted to erratic downstream flows, and reduced ecosystem function (Jacobs et al., 2007). Similar study by Ongwenyi (1983) cited Poor land-use practices in the rich agricultural Upper Tana basin to have contributed to increased soil erosion and a large quantity of sediments in reservoirs annually. Njogu and Kitheka (2017) identified land use and the type of soil as the major determinants of sediment supply to Masinga reservoir. This study had similarities with Bunyasi *et al.* (2013), who identified forest cover loss as the main cause of Masinga reservoir sedimentation. In all these studies, there is no study of water abstractions and river water diversion, the drivers, pressures and impacts despite the growth in concerns about increased water abstraction in the Upper Tana Basin. This study will determine the drivers, pressures impacts of water abstraction and responses to deal with increased water abstraction.

2.7 Research Gaps

On the basis of literature review, the following are the key gaps that justify this study;

i. Most of the studies in Africa and Kenya on water abstraction have not applied DPSIR approach. The interaction between drivers, pressures, impacts and responses have not been examined in most studies.

ii. Most of the studies show that impacts on streamflows show significant geographical differences. The differences between regions have not been studied.

iii. Most of the studies in Upper Tana Basin have been on soil erosion, sedimentation and the impacts of land use changes on Masinga dam (Ongwenyi, 1983; Jacob *et al.*, 2007; Bunyasi et al., 2013; Njogu and Kitheka, 2017). Thus, there are hardly any studies on drivers and impacts of water abstraction and diversion in this basin.

iv. The causes and impacts of extreme low flows in dry seasons have not been examined in detail in most of the studies. In the Upper Tana, the situation is unique in that, while there is increasing variability of rainfall and river discharge (and increasing trends), the streamflow in dry season are extremely low. The root causes of these extreme low flows have not been established.

2.8 Conceptual Framework

This study was guided by a conceptual model derived from the DPSIR framework (Figure 2.1). According to DPSIR framework, there is chain of causal relationships beginning with the "driving forces" (economic sectors, human activities) through "pressures" (emissions) to "states" (physical, chemical and biological changes) and "impacts" on ecosystem, human health and ecosystem functions. This eventually leads to "responses" which include political responses such as prioritization, target setting and indicators (DPSIR Framework, 2018).

The driving forces for water abstraction could be population increase, climate change, land use changes and need for water for irrigation. These driving forces lead to pressures such as damming of the rivers, inter-basin water transfers and infrastructural change to improve rural-urban water supplies. The pressures leave the river at a state that could be reduced river channel, eutrophication and increased turbidity. This state generates several impacts including; reduced streamflow, socio-economic impacts and ecological impacts. This neccistates responses to deal with the impacts which could include legislations, government policies, community interventions and non-state actors interventions. The study in the South West Upper Tana Basin adopted this approach in establishing the causes and impacts associated with increased water abstractions and river diversion. This approach was also used to determine the "state" of water resources (rivers) and the measures undertaken by government (National and County) and other actors to address the problem of over-abstraction of river water in the sub basin.

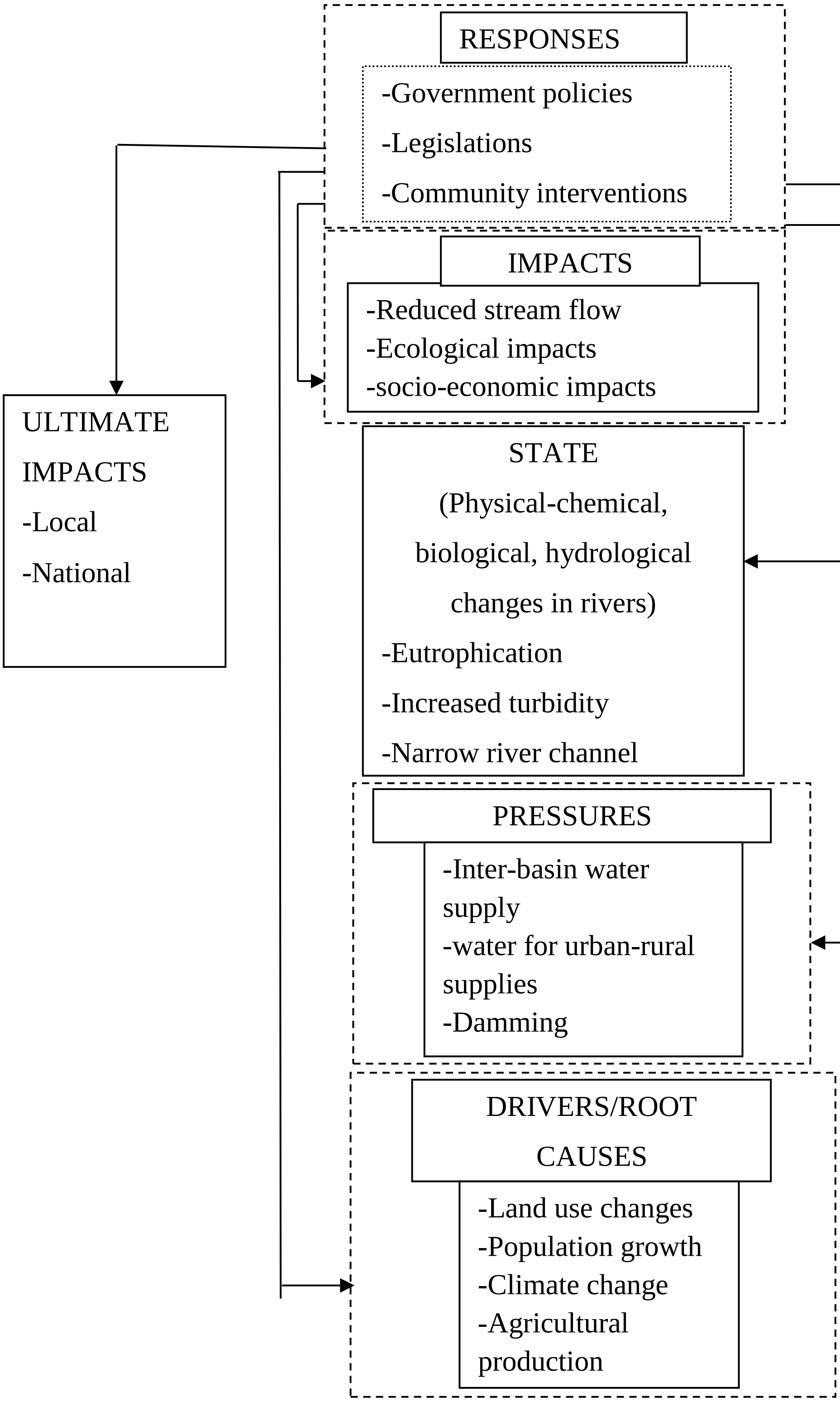

Figure 2.1: The conceptual model used in this study (Source ; Mwendwa, 2018)

CHAPTER THREE

3.0 METHODOLOGY

3.1 Introduction

This chapter introduces the study area and the approaches used in collecting and analyzing data. It presents details on the climatic conditions, hydrology and drainage, topography, geology, vegetation, biodiversity, land use, population and socio-economic activities in the study area. This information enabled the determination of the key geographic characteristics of the study area and the extent to which changes in these characteristics could affect water abstraction and streamflow.

3.2 The Study Area

The study area encompasses sub basins drained by Thika, Kiama, Kimakia and Chania Rivers in central Kenya highlands. The data and information for the study area was obtained from published and unpublished sources such as technical reports and journals prepared by various governmental and non-governmental agencies.

3.2.1 Location of the Study Area

The South West Upper Tana Basin (SWUT) is located in Murang'a County and partly in Kiambu County, in Central region of Kenya (Figure 3.1). The study area covers a total surface area of 2,558.8Km^2 and lies between latitudes 0^o 34' South and $1^0$7' South and Longitudes 36^o East and 37^o 27' East. It lies between 1,340m above sea level (ASL) in the East and 2,190m above sea level (ASL) along the slopes of the Aberdare Mountains in the West (Murang'a County Integrated Development Plan, 2014).

3.2.2 Climatic Conditions

The climatic conditions in the South West Upper Tana Basin vary widely. The region is influenced by the Inter-Tropical Convergence Zone (ITCZ) and also considerably by the relief of the Aberdare mountain Ranges (MCIDP, 2014*)*. The data and information on climatic conditions in the study area was obtained from Kenya Meteorological Department (KMD) and other published reports from the Upper Tana Basin (Njuguna *et al*., 2011; Onduru and Muchena, 2011; Leisher, 2013). In the following sections, details are provided on the key climatic variables such as rainfall, temperature, evaporation and relative humidity.

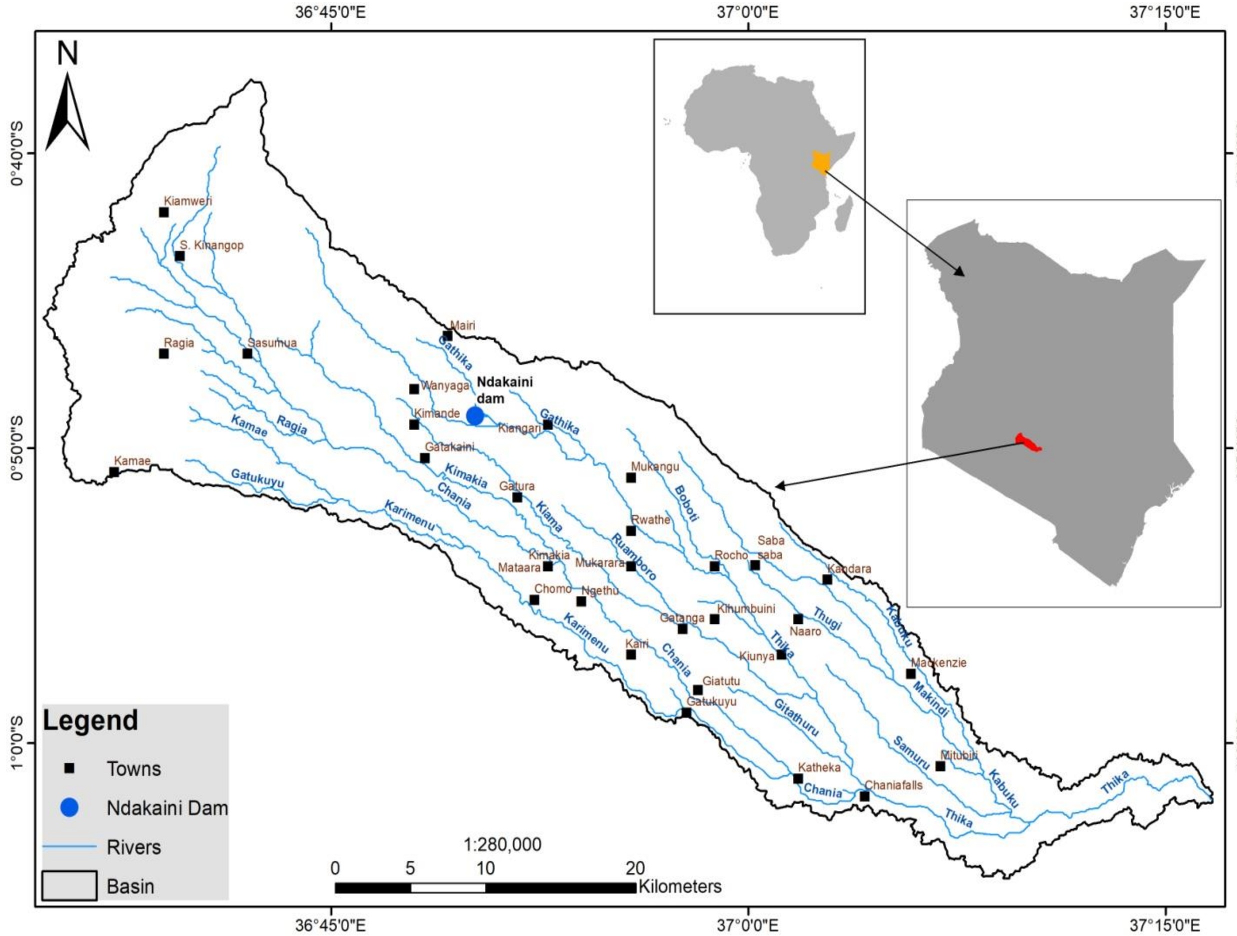

Figure 3.1: Location of South West Upper Tana Basin in Kenya (Source ; Mwendwa 2018)

3.2.2.1 Rainfall

The rainfall in the South West Upper Tana Basin is controlled by monsoon winds that blow from the Indian Ocean and the relief factors of Aberdare Mountain ranges (Njuguna *et al*., 2011). The monsoon winds blow through the region twice a year leading to the two rain seasons, between October and December (Short rain season) and between March and May (long rain season) (Okoola, 1996; Onduru and Muchena, 2011). In between the two seasons, there are intervening dry seasons which are a result of monsoonal systems that bring dry air masses (Figure 3.2). The persistent North Easterly monsoons bring clear sunny weather conditions with occasional showers from December to March. From June to October, the South easterly monsoon is characterised by a rather cool and dull weather with occasional drizzles which are more common in higher elevations. The highest annual rainfall in the area is 1800 mm. This is experienced on the higher elevations of the Aberdare mountain ranges while the mid Aberdare ranges receive between 1000 to 1800 mm/yr (Otieno *et al*., 2000). Areas with elevations <1000 m above sea level receive <700 mm/yr (Otieno *et al*., 2000). However, the mean annual rainfall in the study area is 679 mm/yr (JICA/GOK, 1992).

3.2.2.2 Temperature

The temperatures in the study area vary with altitude with the eastern lower altitude areas experiencing maximum temperature of 26^o C. The highest temperature in the Aberdare Mountains range is 18^o C while the minimum temperature can be as low as 6^o C (MCIDP, 2018). Temperatures are moderate in medium potential areas. In most parts of the study area, the lowest monthly mean temperatures are experienced in the period between July and August while the hottest months are March and October (Leisher, 2013). In the June-August period, the temperature ranges from 18^0 C to 24^0 C while during the hottest period (January-March) the temperatures range from 25^o C to 26^o C (Figure 3.2).

3.2.2.3 Evaporation

The Mean annual free water surface evaporation is highest in the piedmont zone (about 1800 mm per annum) and lowest (about 1400 mm per annum) in the Aberdare Ranges (The Nature Conservancy, 2012). The free water evaporation in the high altitudes is estimated to be 75% of rainfall while in the lower altitudes the evaporation rate is about 80% of rainfall (TNC, 2012). Evaporation rates are highest in the dry months of January-March and lowest in June-August months. The study area has a mean annual Potential evaporation of between 1200 mm per year in the Aberdare Mountains and 2300 mm in the lower altitude areas of the basin (Leisher *et al*., 2016).

3.2.2.4 Relative Humidity

In the lower elevations, the mean annual relative humidity is estimated at about 65% while in elevations above 2000 metres the mean annual relative humidity rises to 80% (Leisher *et al*., 2016). Humidity is greatest at dawn (70%) and lowest in the early afternoon (45%) when the temperature reaches the diurnal maximum (Leisher *et al*., 2016). There are high seasonal variations in relative humidity in the study area with the highest rates recorded in March-June period and September-December period while the lowest rates are recorded in January-February period and August-September period (Onduru and Muchena, 2011).

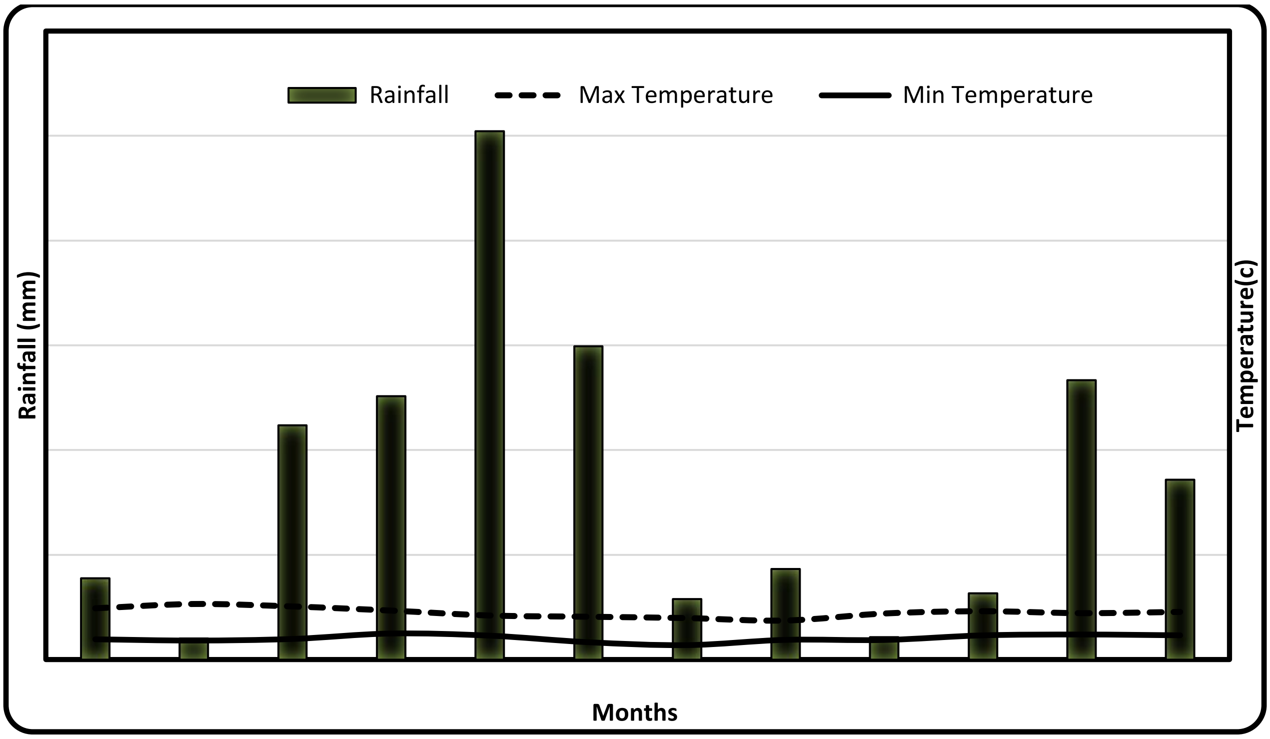

Figure 3.2: Monthly average temperature and rainfall in the study area (Source ; Kitheka *et.al.* 2019)

3.2.3 Hydrology and Drainage

The main rivers in the study area which are subject to this study are Kiama, Thika, Kimakia and Chania. These rivers flow from the west and deeply dissect the topography in the area. The rivers flow in a south eastward direction to join Tana River. The rivers originate from the moorlands and forests of the Aberdare Mountain Range. The upper drainage of this area occurs within the Aberdare National Park and comprises undulating moorland with swamps and a few areas with Ericaceous heath and Hagenia woodland (Athi Water Services Board, 2014). Kimakia, Thika, Kiama and Chania rivers flow from the high-altitude moorland in the Aberdares into deeply incised valleys within Kimakia and Aberdares Forest Reserve surrounding the Aberdares National Park (AWSB, 2014). These rivers intersect with each other at some point down slope. Kimakia River joins Chania River at Ngethu where water is tapped for supply to Nairobi County (Kimenju, 2018). Kiama joins Thika River downstream after Ndururumo then the four rivers join downstream after Bluepost hotel to form Thika River (Figure 3.3) which flows to River Tana. The rivers experience low flows during the dry months of January-March and August-October periods.

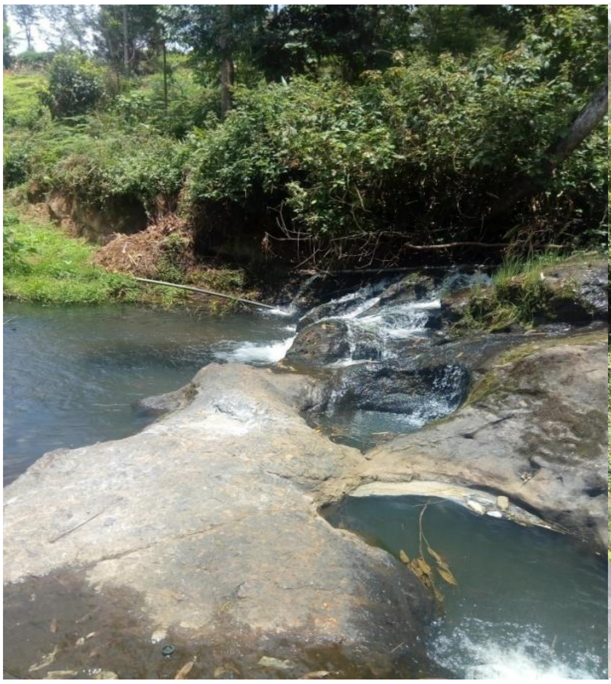

Plate 3.1: Kimakia river in dry season

Plate 3.2: Chania river in dry season

Plate 3.3: Thika river in dry season

Plate 3.4: Kiama river in dry season

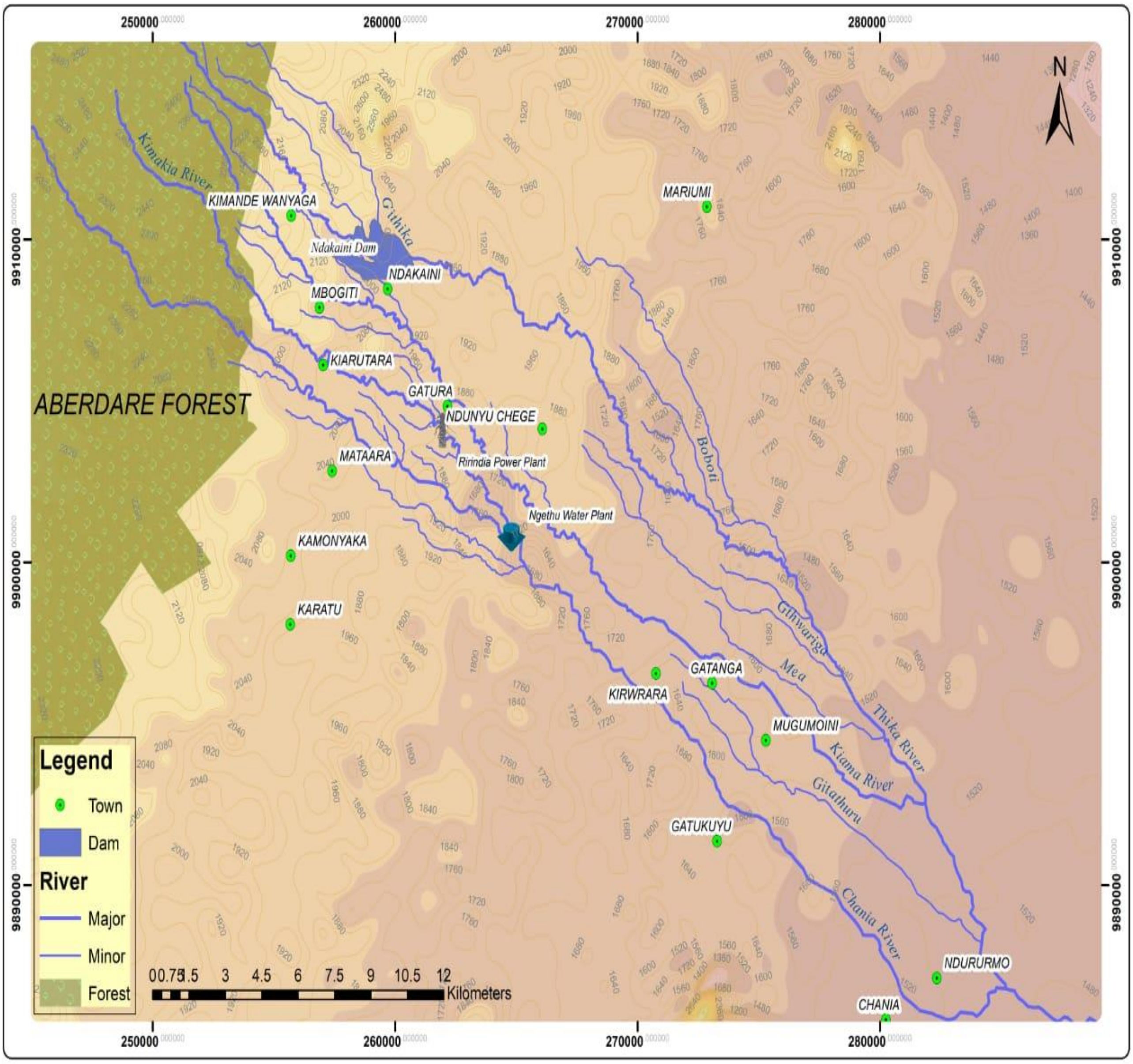

Figure 3.3: Location of Kiama, Kimakia, Chania and Thika Rivers in the South West Upper Tana Basin (Mwendwa, 2018)

3.2.4 Topography

The study area is dominated by the presence of mountain ranges which stretch a distance of about 160 km and rise to altitude of about 2190 m above sea level. The mountain range is heavily dissected and characterized by steep slopes roughly at an elevation above the 2100 m contour (Kimenju, 2018). Notable slopes are also observed in the transition between the volcanic and basement rock systems. Other topographical features in the study area include foot ridges, plateaus and valleys (Leisher, 2013). The foot ridges occur due to the down cutting of rivers in the area. These ridges rise to considerable heights of 30-120 m above the surrounding land. In the upper reaches of the Aberdares, some of the U-shaped valleys have widths of up to 1 km and drop to more than 300 m below the surrounding high grounds. These features provide good opportunities for construction of water storage reservoirs (Onduru and Muchena, 2011).

3.2.5 Soils and Geology

The geology of the study area consists of volcanic rocks of the Pleistocene age and basement system rock of Achaean type (AWSB, 2014). Volcanic rocks occupy the western part of the study area extending into the Aberdare ranges while rocks of the basement system are found in the lower eastern part. Porous beds and disconformities within the volcanic rock system form important aquifers (AWSB, 2014). On the upper slopes (1800m to 2190m above sea level), dark surface horizon soils that are rich in organic matter are found. These soils have low bulk density since they are formed from pyroclastic rocks. They include hitosols, regosols and andosols. In the lower slopes (<1,800 m above sea level), soils are greatly influenced by the amount of rainfall received. For instance, forested areas that receive high rainfall have red soils with traces of clay (Kimenju, 2018).

The main soils in this area include cambisols, nitosols and andosols. The lower zones are mainly covered with basement rocks with sediments deposited from upper volcanic zones in some of the areas (Kimenju, 2018). In Aberdares, the basement system is exposed up to higher altitudes (MCIDP, 2018). The study area is overlain with an ancient core of crystalline rocks of the Basement Complex which underlies the greater part of the plateau areas of Africa (Leisher *et al*., 2016). These rocks have been affected by the extensive faulting, displacement and volcanic activity associated with the Rift Valley System. The eroded surface of the pre-Cambrian basement rocks, outcrops only on the southern and eastern margins of the area. Elsewhere it is overlain by a variable thickness of volcanic and pyroclastic rocks of Tertiary age (Leisher *et al*., 2016). Uplifting and concentration of volcanic activity at the margins of Rift Valley has resulted in a general alignment of lava flows and associated surface deposits in a south easterly direction (TNC, 2012).

3.2.6 Vegetation and Biodiversity

Since the upper parts of the study area receive good rainfall and the soils are fertile, there is extensive vegetation cover. The main vegetation types are both indigenous and planted vegetation. The upper parts of the study area are predominantly forest reserves (Kimakia and

Gatare Forests). There are 778 vegetation and plant species in these forests because of high elevation and high rainfall experienced in this region (AWSB, 2014). The main tree species in the forests are Cedar, Podo, Campor and Hegenia (KIFCON, 1994). In the lower altitudes, different indigenous species of trees including fern, *Tabernaemontana stapfiana* (Mwerere), *Vernonia auriculifera* (Muthakwa), *Ochna Holstii* (Mungirima), *Syzgium Guineense* (Mukoe) and *Prunus africanum* (Muiri) are found. However, the dorminant tree species in the study area is Eucalyptus which is planted in farms and along the rivers (AWSB, 2014).

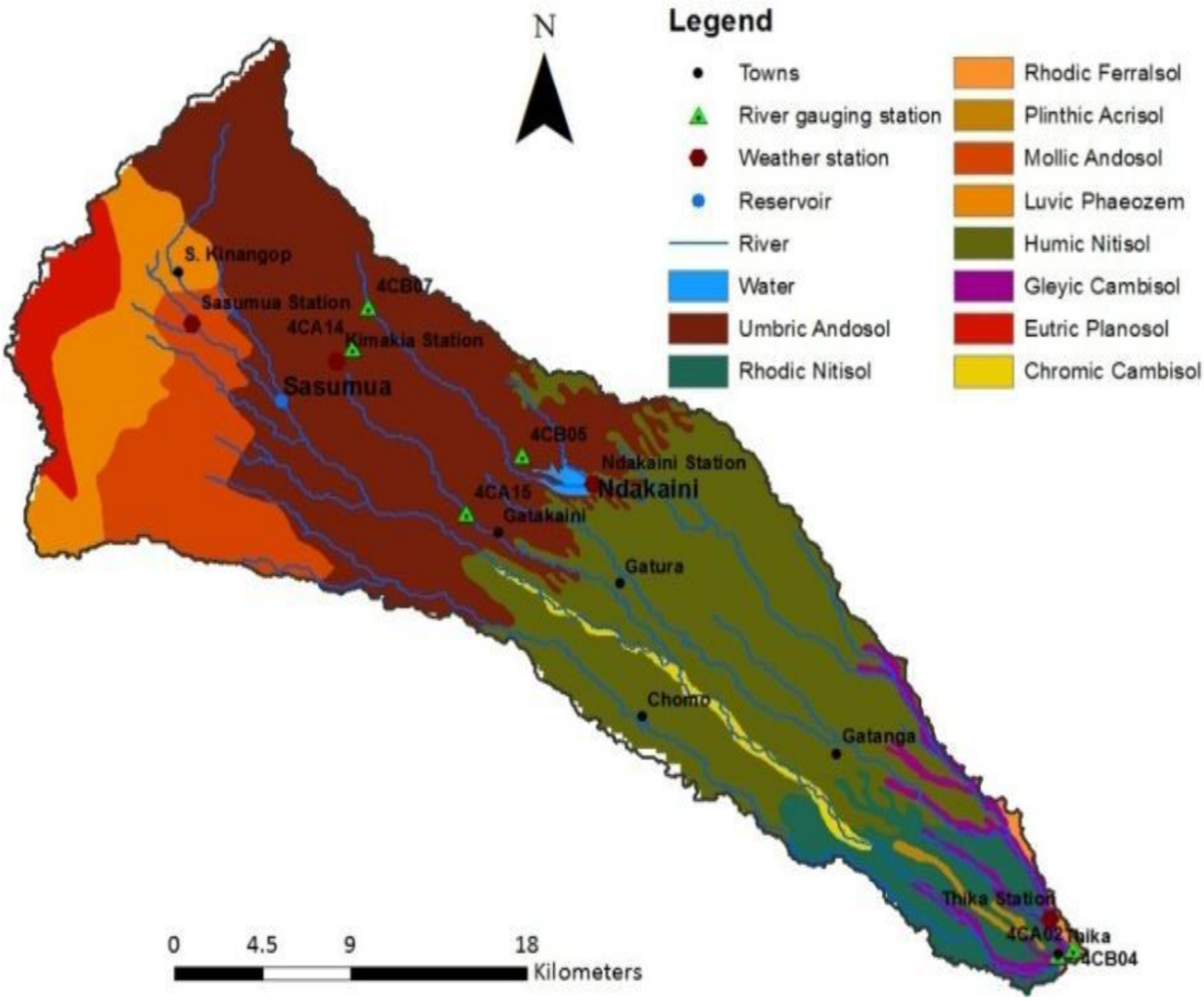

Figure 3.4: The soil types and their distribution in the South West Upper Tana Basin (Mwendwa 2018)

Table 3.1: Vegetation Types and their spatial coverage in the study area

Vegetation Type	Coverage (km^2)	Coverage (%)
Closed Natural Forest	459	33
Montane Forest / Bamboo Mix	282	19
Bamboo	196	13
Exotic tree plantations.	166	11
Forest / Scrub Mix	110	8
Moorland	49	3
Grassland	33	2
Scrub/Grassland Mix	27	2
Cultivated Land	65	4
Other	15	1
Total	1,460	100

Source: KIFCON (1994).

3.2.7 Land Use

High rainfall and well aerated volcanic soils in the study area enabled exploitation of the Central highlands of Murang'a County (Njuguna *et al*., 2011). Crop farming is the most dominant agricultural activity with about 98% of farmers growing cash crops such as coffee and tea and subsistence crops (TNC, 2015) (Figure 3.5). Horticultural crops and flowers, rice and food crops such as cereals, bananas and potatoes are also produced in various parts of the study area. Livestock production is also practiced for milk, beef and mutton while pig farming in the basin is widespread (Hirji *et al*., 1996; Agwata, 2005b). Other economic activities within the area include wildlife in the forests on the mountains in the upper parts of Aberdare such as Kimakia forest, Kieni forest and Aberdares forest that serve as important wildlife conservation sites with several game parks (Agwata, 2006). Due to the increasing population, about 72% of the people own a plot of land of 2 acres or less while less than 1% of the population own more than 20 acres (TNC, 2015).

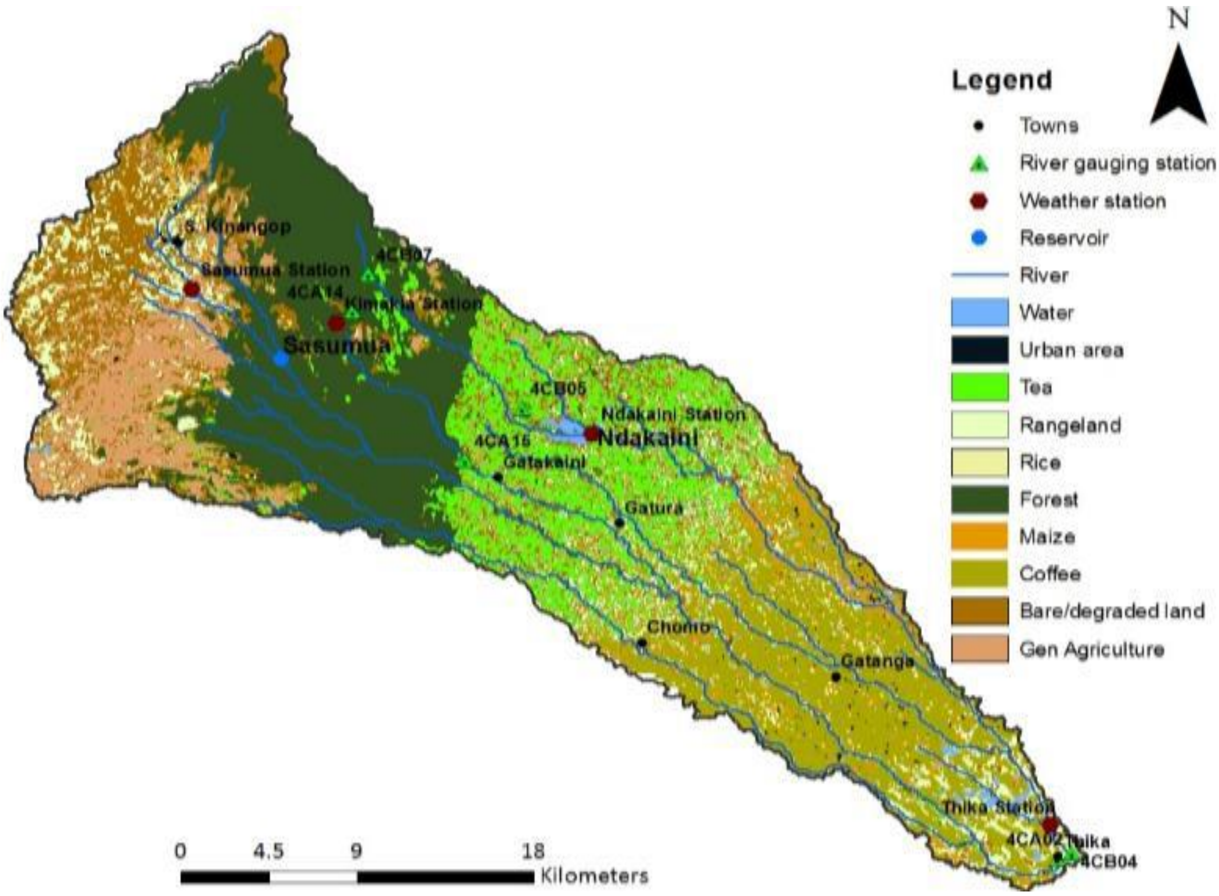

Figure 3.5: Land uses in SWUT Basin (Source ; Mwendwa, 2018)

3.2.8 Population

The total population in the study area is estimated to be 163,597 people (KNBS, 2009) which translate to 276 people per Km^2. This is more than the national average population density which is estimated at 66 people per Km^2. The female population in the study area is slightly higher (82,610) than the male population (80,987). The high female population in the study area is attributed to the high emigration rates of male population to towns in search of employment opportunities (MCIDP, 2018). The Aberdare forest area has the least population density of 0.06 people per km^2. Settlement patterns in this area are determined by climatic conditions, infrastructure, food availability and proximity to urban centres. However, there are also protected areas where settlements are not permitted. These include the forested areas and the national parks. Other areas with minimum settlement are the large-scale farms notably Delmonte and Kakuzi. The human development index in the study area (HDI) is estimated to be 0.56 while the literacy rate is 70.1 % (MCIDP, 2018). It is estimated that 36 % of the population in the study area live below poverty line with the area contributing 0.8 % to the national poverty level (MCIDP, 2014).

3.2.9 Socio-Economic Activities

The study area is one of the most productive areas for agriculture in Kenya, and it provides water to key national parks, water for hydropower production of the country, and supplies 84% of Nairobi's water demand (Githinji *et al*., 2015). It is estimated that more than 80% of the people in this area depend on agriculture (Kimenju, 2018). Key cash crops include Coffee and Tea in the high elevation areas while cereals, fruits such as mangoes and pineapples are grown in the low altitude areas (Leisher *et al*., 2016). Numerous food and horticultural crops including cabbages, kales, potatoes, carrots, tomatoes among others are also produced in these areas (Leisher *et al*., 2016).

3.2.10 Water Supply and Uses

The study area is an important source of water for the city of Nairobi. The water is supplied by Nairobi Water and Sewerage Company (NWSC) through the Ndakaini dam, drawing water from Kiama, Kimakia, Chania and Thika rivers (Kimenju, 2018). For instance, Gatanga Water Community is the main water supply scheme in the study area, supplying directly to households in the study area (MCIDP, 2018). Further downstream, the rivers in the study area are also important for hydropower generation since they are tributaries of River Tana. The main hydropower reservoir, Masinga, is located downstream of the study area (Leisher, 2013). In the upstream of the Masinga reservoir, there are a number of small hydropower facilities, including the Tana power station (20 MW) and Ndula power station (2.0 MW) which draw water downstream of the rivers in the study area.

3.3 Research design

The study approach used in this study was based on methodologies that have been applied in similar studies (Kossa *et al*., 2014; Botha, 2017; Mwadini, 2016; Kimenju, 2018).

3.3.1 Determination of the relationship between water abstraction, rainfall and stream flow

The determination of the relationship between water abstraction and streamflow involved collection of data for the river discharge, rainfall data, water abstraction data and the analysis of seasonal and inter-annual variations in streamflow and water abstraction. Attempt was made to determine if there were any changes in rainfall and streamflow and if water abstraction had any effect on streamflow in rivers found in the study area.

3.3.1.1 Location of River Gauging Stations and rainfall stations

The details on the location of the river gauging stations and the rainfall stations are provided in the following sections.

3.3.1.2 River Discharge Data

River discharge data for Kiama, Thika, Kimakia and Chania Rivers were collected from Water Resources Authority (WRA) regional offices in Embu. The river gauging stations where this data was collected are RGS 4CB5 for Thika River, RGS 4CA15 for Kimakia River and RGS 4CA19 for Chania River. The data used in this study was for a period of 15 years from 2000 to 2015. The data was to determine changes in stream flow as well as the influence of water abstractions and river diversions.

The river discharge (Q) data is based on measurements undertaken by WRA and was based on the application of the velocity (V) and cross-sectional area (A) method. In this approach, a river cross-sectional area is multiplied by velocity to give river discharge. The daily instantaneous river discharge (Q) was determined using the following equation;

$$Q_i = \sum_{i=1}^{n} (A_i)(V_i) \quad \text{......equation 3.1}$$

Where; Q_i is the river discharge measured at cross-section i, A_i is the cross-sectional area of the river section i, and V_i is the mean velocity for section i. The total daily river discharge (Q_t) at a river gauging station is therefore a sum of all cross-sectional area discharges $Q_{i.}$

$$Q_t = \sum_{i=1}^{n} Q_i \quad \text{......equation 3.2}$$

The monthly river discharges (Q_m) were computed by summing of the daily instantaneous river discharges (Q_t) using the following equation;

$$Q_m = \sum_{i=1}^{n} Q_t \quad \text{......equation 3.3}$$

The annual river discharge (Q) is the sum of all monthly river discharges (Q_m) and was calculated as follows;

$$Q = \sum_{i=1}^{n} Q_m \text{……………………………………………………………equation 3.4}$$

3.3.1.3 Rainfall Data

Rainfall data for this study was obtained from the Kenya Meteorological Department (KMD), Nairobi. Data was collected for four stations, namely; Kimakia forest station, Thika Meteorological Station, Gatare Forest Station and Thika dam station. This data was used to determine if changes in streamflow could be attributed to seasonal and inter-annual changes in rainfall patterns in the basin. The data was also important in determining if increase in water abstractions in South West Upper Tana Basin (SWUT) was driven by the changes in rainfall patterns.

Mean annual rainfall values were computed from the mean monthly rainfall values. The later were computed from daily rainfall values for each of the four rainfall stations. Determination of the positive and negative trends in rainfall was accomplished by subtracting the mean monthly rainfall from each of the monthly rainfall data.

$$\bar{R}_{fm} = \sum_{i=1}^{i} R\frac{fm}{n} \text{……………………………………………………………equation 3.5}$$

Where; $\bar{R}_{fm}$ is the mean monthly rainfall and R_{fm} is the monthly rainfall values which are sum of daily rainfall values at each of the rainfall station.

3.3.1.4 Water abstraction Data

Information on water abstraction in the study area was obtained from the field using questionnaires where in each sub-basin, a total of 15 households and 15 households in the upstream and downstream, respectively, were randomly selected for interviews. Water abstraction data from these households were recorded on a daily basis for 12 months, monthly and annual abstraction rates were then calculated. Similar methods were also used by Kossa *et al*. (2014) and Botha (2017). The mean monthly abstraction rates were calculated as follows;

$$\bar{Q}_{abs(m)} = \sum_{i=1}^{i} Q_{abs(d)} \text{……………………………………………………equation 3.6}$$

Where; $\bar{Q}_{abs(m)}$ is the total monthly water abstraction rate (in litres) and $Q_{abs(d)}$ is the daily water abstraction rate.

The annual water abstraction rate was the sum of the monthly water abstraction rates $\bar{Q}_{abs(m)}$ calculated as follows;

$$\bar{Q}_{abs(a)} = \sum_{i=1}^{i} \bar{Q}_{abs(m)} \quad \text{.............equation 3.7}$$

Data on water abstraction was also obtained from records of Water Resources Authority (WRA) in Embu. However, it was noted that the data did not include abstractions from unlicensed users of river water.

3.3.1.5 Analysis of seasonal and inter-annual variations of streamflow, rainfall and water abstraction

The analysis of the seasonal and inter-annual variations in streamflow, rainfall and water abstraction was accomplished by using time series analysis to establish the key trends (Pallant, 2011). The daily and monthly data for the period between 2000 and 2015 was plotted using excel and the key patterns studied. Simple linear regression analysis was used to determine whether the trends observed in rainfall and river discharge were significant. The coefficient of determination R^2 describing the proportion of the variance in measured data was also computed (Pallant, 2011).

3.3.2 Determination of the relationship between water abstraction and water turbidity

The determination of the relationship between water abstraction and water turbidity in the study area was accomplished through field-based measurements, observations, questionnaire survey and review of the findings reported in other similar studies (Manohar *et al.*, 2017; Makhoha, 2017). Additional information on water quality was obtained from Water Resources Authority (WRA) in Murang'a.

Turbidity level was determined by asking the respondents to indicate the possible scale ranging from 0 to 1500 NTU which corresponds to the NTU turbidity units ranging from 0 to 1500 NTU. Siltation was determined by calculating the sediment settling rates per given period of time per unit area ($Kg/m^2/yr$). Nitrate concentrations were determined by asking the respondents to indicate a possible scale ranging from 0.1 to 20 mg/l. The relationship between water turbidity, nitrate concentration and water abstraction were established through simple linear regression. Data obtained from WRA was compared with the data obtained through questionnaire surveys.

3.3.2.1 Analysis of seasonal and inter-annual variations in water turbidity

The analysis of seasonal and inter-annual variations in water turbidity was accomplished using time series analysis to establish the key trends. Monthly data was plotted using excel and the key trends examined (McFedries, 2018).

3.3.3 Determination of the influence of household characteristics on water abstraction

The determination of the relationship between household characteristics and water abstraction was achieved mainly through the use of questionnaire survey (see also Roberts, 2004; Mwadini, 2016; Botha, 2017).

3.3.3.1 Questionnaire surveys

Questionnaire survey was used to determine the influence of household characteristics on water abstraction. The designing of the questionnaire was guided by the specific objectives of the study. The questionnaires were administered to households that are near or those that abstract/divert water from the rivers. Data collected through questionnaires included; age, household size, marital status, occupation, technology used to abstract water and settlement period. A total of hundred and twenty (120) household questionnaires were administered in the study area. The sample size was determined using equation 3.8. The questionnaires were administered randomly along four (4) transects identified in the field. The four transects were mainly the four sub basins (Kiama, Kimakia, Thika and Chania) in the study area. Four (4) research assistants administered the questionnaires randomly in each of the four sub basins. Thirty (30) questionnaires were administered in each sub basin, fifteen (15) in the upstream and fifteen (15) in the downstream of the rivers. This methodology is consistent with the suggestion of Kothari (2004), for proportional allocation in selecting the sample size. Mwadini (2016) used a similar approach in the study on the management practices of irrigation water and their effects on water allocation among farmers. With a sample size of 150, the proportional allocation method was used to collect data from three transects with 50 respondents from each transect (See also Roberts, 2004 and Roberts, 2012).

3.3.3.2 Target population size and sample size

The population for this study consisted of households that abstract or have been affected by the river water abstractions and diversions in the South West Upper Tana Basin. Fifteen (15) households on the upstream and fifteen (15) households downstream of each river were selected. The study population also involved institutions and large irrigated farms in the study area. Officials from institutions such as Water Resources Authority (WRA), National Environment Management Authority (NEMA), Nairobi City Water and Sewerage Company (NCWSC) and Murang'a County government also formed part of the study population and subsequently the questionnaires were also administered to them.

The sample size was determined according to Cochran formula as follows (Pallant, 2011):

$$n = \frac{z^2\,pq}{e^2} \text{..equation 3.8}$$

Where; n is the sample size, P is the estimated proportion of an attribute present in the population (0.5), q is1-p, z^2 is abscissa of the normal curve that cuts off an area α at the tails (value of z obtained from the statistical table). With a margin of error of 10%, the sample size for this study was found to be 116.04 which is equivalent to 120 households. This number of households was found to be representative of the total number of households in the study area.

3.3.3.3 Collection of primary and secondary data on household characteristics

The primary sources of data included the data that was collected from households in the study area, resource persons and relevant institutions such as Water Resources Authority (WRA), Nairobi Water and Sanitation Company (NWSC), Ministry of water and irrigation, County Government ministries (Natural Resources, Environment and Water, Planning), industries abstracting water from the rivers, Non-governmental organizations and the Private Sector. In addition to collection of primary data in the field through questionnaire surveys, secondary data was also collected from various other sources. The main secondary data sources for this study included; publications, annual/quarterly reports, journals, development plans, periodicals and existing spatial information like maps of the study area.

3.3.3.4 Analysis of socio-economic data

Socio-economic data collected through questionnaire surveys were subjected to simple linear and logit regression analysis as detailed in section 3.3.10. The data for each variable (age, household size, marital status and settlement period) was analysed using excel statistical package. Comparisons on water abstraction and each of the variables were done and simple regression curves plotted using excel statistical package. The mean for each of the variables were calculated to show the variations in frequency for each of the sub basin (See section 3.3.10.1).

3.3.4 Determination of the influence of education, occupation and technologies on water abstraction

The determination of the extent to which education level, occupation and technologies influence water abstraction in the study area was made through questionnaire surveys, field-based observations and review of reports and published data. Four research assistants were each assigned a sub basin where 15 questionnaires were administered on the upstream and 15 questionnaires on the downstream of each river to make a total of 30 questionnaires per sub basin and 120 for the whole study area. Secondary data on education and occupation was obtained from government reports such as economic surveys, Kenya National Bureau of Statistics (KNBS) and the Murang'a County Integrated Development Plan (MCIDP). Data collected through questionnaire survey was analysed through excel statistical package. Simple linear regression analysis was used to determine the extent to which each variable influence water abstraction. Measures of central tendency such as mean, mode and median of the responses were calculated to show the variables with the highest variations (see section 3.3.10.1).

3.3.5 Determination of the influence of agricultural practices on water abstraction

Determination of the extent to which agricultural practices are influencing water abstraction in the study area was through questionnaire surveys, review of secondary data and field based observations. Data collection on agriculture for farm sizes, types of crops grown, income from crop sales and best period for sales was collected from primary and secondary sources. Primary sources mainly included questionnaires where 30 questionnaires were administered in each sub basin. Secondary data sources included data from the Muranga County Integrated Development Plans (MCIDP) 2014 and 2018. Excel statistical package was used to generate regression coefficients to determine the relationship between each of the variables and water abstraction. Logistic regression was run to determine the degree to which agricultural practices influence water abstraction and subsequent decline in streamflow.The mean of the responses given in the questionnaire survey were calculated and standard deviation to show the variations from the mean. This enabled this study to determine the reliability of those responses.

3.3.6 Determination of land use/land cover change

Six (6) land cover/use classes were selected in image classification. Before image classification, satellite images were processed through a sequence of operations that involved geometric corrections, atmospheric correction, image registration and masking for irrelevant features (Barnsley and Barr, 1997; Beaubien *et al.,* 1999; Lu and Weng, 2007). The images were also geo-referenced and corrected for sensor irregularities. The study area was extracted using the masking tool after the two Land Sat images were imported to the Arc GIS. The image was transferred to ENVI 4.7 for image classification and land use changes analysis. After compositing, training sites were identified so that image classification tool in ArcGIS tool could be used to identify areas with same signature in the image. Areas with similar signature represented various land cover/landuse. Further information on the catchment landuses was acquired by ground truthing where various land covers were identified in the field. The study examined the land use changes for a period of 34 years from 1984 to 2018.

3.3.7 Analysis of the downstream and upstream impacts of water abstraction

The determination of the upstream and downstream impacts of water abstraction and river diversion in the study area was based on questionnaire survey, field-based measurements, observations and review of the findings of other studies in the area. Data collected using questionnaire survey was analysed using excel statistical package. Mean and the standard deviation were calculated to determine the variations in responses and reliability. Logistic regression was run to determine the influence of water abstraction on the various impacts noted in the rivers in the SWUT basin.

3.3.8 Determination of the influence of water abstraction/diversion projects on streamflow

The determination of the extent to which water abstraction and water supply projects have influenced streamflow in the study area was done through questionnaire surveys, field observations and review of published reports and reports of other similar studies. Data for streamflow obtained from Water Resources Authority (WRA) and water abstraction data from the field was used to show trends in the two variables. Simple linear regression analysis was used to show the strength and nature of relationship between streamflow and water abstraction and or diversion in the study area.

3.3.9 Determination of Drivers, Pressures, State, Impacts and Response

The determination of Drivers, Pressures, State, Impacts and Responses (DPSIR) was done according to the standard DPSIR framework (Kristensen, 2004). This framework describes a chain of causal links starting with the drivers of a certain activity in the environment for instance water abstraction, pressures brought by those drivers, the state of environment following the activity, impacts on the ecosystem, biodiversity, human health and environmental functions, eventually leading to responses to those impacts (Mukhwana, 2016). Driving forces are the needs or the root causes of water abstraction/ river diversion for instance need for irrigation water and household consumption. The driving forces lead to human activities in the sub basins that result in pressures on the water resources for instance over abstraction, pollution and land use changes among others. State of the environment encompasses physical, chemical and biological conditions of the sub basins after the pressures have been applied to them, for instance, the state of the water quality, streamflow, riparian vegetation and river morphology (Kristensen, 2004). The changes in the state of water resources have economic, ecosystem, human and hydrological impacts on the water resources. These undesired impacts are addressed through responses that could be developed by policy makers or the society (Mukhwana, 2016). Primary data for DPSIR analysis were obtained through questionnaire survey and focus group discussions with key stakeholders including officials from national and county government ministries and departments. In addition, information was also sought from private sector stakeholders and individual farmers. Secondary data was also used to analyse the drivers, pressures, state, impacts and responses. Further, secondary data from Water Resources Authority (WRA), Kenya Meteorological Department (KMD), Kenya National Bureau of Statistics (KNBS) and Muranga County Statistics Department was also used in analysis.

3.3.10 Statistical methods of data analysis

The statistical methods of analysis used in this study were descriptive statistics, parametric tests and regression analysis.

3.3.10.1 Descriptive statistics

The descriptive statistics that were used in this study include mean, percentages, cross tabulation and standard deviation. These statistics were generated from data collected from the field and responses obtained from questionnaires. Descriptive statistics were used to analyse and present data on household characteristics, socio-economic, abstraction technologies and agricultural characteristics of the study area (see also Chirchir, 2014 and Mwadini, 2016).

3.3.10.2 Regression analysis

Regression analysis is a statistical technique that explains the relationship between two or more variables (McFedries, 2018). A linear model is normally used to explain the relationship of two or more variables using a straight line. In regression models, the independent variable is denoted as x while the dependent variable is denoted as y. In this study both simple and logistic regression models were used (McFedries, 2018). The simple linear regression analysis was based on the following equation;

$$Y = a + bX + e \qquad \text{equation 3.9}$$

Where; Y is the dependent variable, a and b are the numerical constants, X is independent variable and e is the error term. Simple linear regression analysis was used to establish the relationship between two variables, for instance the relationship between water abstraction (dependent variable) and streamflow (independent variable) (see also Chirchir, 2014).

From the simple linear regression model, results on correlation coefficient (r), coefficient of determination (R^2), adjusted R^2 and beta value were obtained. The r value shows the strength and direction of relationship and ranges from 0 to 1. A result with r=1 was taken to indicate a perfect positive relationship between the variables while r=-1 meant a perfect negative relationship. A value of 0 meant that there is no relationship between the two variables. R^2 indicated the proportion of the variance in the independent variable that could be used to explain the dependent variable (water abstraction and river diversion). For instance, a result of 50% meant that the model could account for 50% of the variations in the dependent variable (Pallant, 2011). The Beta value indicated the strength of influence of each independent variable on water abstraction. Variables with high Beta value were taken to have a greater influence on water abstraction and river diversion (see also Tabachnick and Fidell, 2007; Chirchir, 2014; Mwadini, 2016).

Table 3.2 : Description of the simple linear regression variables

Variable	Description	Expected sign
Y (dependent variable)	Water abstraction from the river (litres)	
X (independent variable)	Streamflow (m^3/s)	+

The logistic regression analysis is used to determine the relationship between one dependent variable and several independent variables (Tabachnick and Fidell, 2007). This statistical technique was chosen because there are several predictor variables in water abstraction. For instance, the household characteristics that may influence water abstraction and river diversion could be marital status, age, settlement period and household size. Also, in agricultural practices influencing water abstraction, we can have farm size, types of crops grown, amount of fertilizer used and income from crop sales as predictor variables. The model was used because of its ability to ascertain the best set of variables that influence a particular process (Pallant, 2011). A similar method was used by Mwadini (2016) to determine the best set of socio-economic factors that could be used to determine irrigation water demand in Kiladeda sub basin, Tanzania. The logistic regression analysis was carried according to the following equation;

$y=\beta o+\beta_1 X_1+\beta_2 X_2+\cdots+\beta_k X_k+\varepsilon$ ……………………………………………………equation 3.10

Where Y is the dependent variable (water abstraction), βo is the Y- intercept, β_1- β_2... are the set of coefficients to be estimated X_1, $X_2 \ldots X_k$ are the explanatory variables while ε, is the random error which is taken to be a random variable with variance (σ^2) and mean 0. Table 3.3, table 3.4 and table 3.5 presents the description of explanatory variables.

Table 3.3: Description of explanatory variables used to predict influence of agricultural practices on water abstraction

Variable	Description	Expected sign
*Y	Water abstraction from the river in litres (Yes=1, otherwise 0)	
X_1	Income from crop sales from irrigated farms (Kshs)	+
X_2	Farm size of each household (Acres)	+
X_3	Amount of fertiliser used in the irrigated farms (Kgs)	+

***Dependent variable**

Table 3.4 : Description of explanatory variables used to predict influence of household structure on water abstraction

Variable	Description	Expected sign
*Y	Water abstraction from the river in litres (Yes=1, Otherwise=0)	
X_1	Household size (number of family members in the household	+/-
X_2	Age of the household head (number of years)	+/-
X_3	Marital status of the household head (1=married, 0=not married)	+/-
X_4	Settlement period (Duration of stay in the current home)	+
X_5	Income of the household head (Ksh)	+/-
X_6	Education level of household head (number of schooling years)	
X_7	Technology use in abstracting water (1=Yes, 0=No)	+
X_8	Employment status of household head (1=employed, 0=not employed)	+

***Dependent variable**

Table 3.3 : Description of explanatory variables used to predict impacts of water abstraction

Variable	Description	Expected sign
Y*	Water abstraction from the river in litres (Yes=1, otherwise 0)	
X_1	Reduced water levels (m)	+
X_2	Decreased turbidity (NTU)	+
X_3	Improved yields (1=Yes, 0=No)	+
X_3	Nitrate concentration	+
X_4	Conflicts (1=increased, 0=reduced)	+/-
X_5	Degradation of vegetation (1=Increased, 0=reduced)	+/-
X_6	Change of river morphology	+/-
X_7	Reduced Siltation (1=reduced, 0=increased)	+/-

***Dependent variable**

CHAPTER FOUR

4.0 RESULTS OF THE STUDY

4.1 Introduction

This chapter presents the results of the study, based on the data collected through the questionnaires, interview schedules and field observations as well as analysis of secondary data collected from various sources. The chapter also presents the results of statistical analysis of data including the results based on DPSIR analytical framework.

4.2 Determination of the influence of rainfall on stream flow

There is a signigficant relationship between rainfall and streamflow in the South West Upper Tana Basin. The results show that the streamflow increases during the periods of high rainfall and decreases during drought periods. The results also show that the abstraction of water from the rivers only significantly affects streamflow during low flow conditions, particularly during the dry periods.

4.2.1 Seasonal and inter-annual variability in river discharge and rainfall

There is a significant seasonal and inter-annual variation in river discharge and rainfall in the study area. The results indicate that the maximum river discharge in the period between years 2000-2015 was 353 m^3/s while the mean river discharge was 64 m^3/s. The mean annual rainfall in the sub basin was 91 mm while the maximum rainfall recorded was 719 mm. The occurrence of low river discharge was more frequent than the high flows since the low flows occurred 75% to 85% of the time. The highest river discharges were recorded during the wet months between March-May and October-December while the lowest river discharges were frequent during the dry season in the period between months July-October and December-January.

The frequency of occurrence of below average river discharge between years 2000-2015 decreased by -23% while above normal river discharges increased by 19%. The frequency of occurrence of above average rainfall in the same period increased by 10% while that of below average rainfall decreased by -33% (Table 4.1). The results in this table indicate that the frequency of occurrence of above mean rainfall and river discharge is increasing while the frequency of occurrence of below mean rainfall and river discharge is decreasing. The peak river discharges showed a decreasing trend from 2000-2009. From the years 2009-2015, rainfall increased as well as the peak river discharges. These variations are expounded in the following sub sections.

Table 4.1: The frequency of occurrence of above and below normal rainfall and river discharge in the period 2000-2015

Period	Rainfall Deficit		Discharge Deficit	
	Above Mean	**Below Mean**	**Above Mean**	**Below Mean**
2000-2004	14	46	17	43
2005-2009	20	53	30	42
2010-2015	24	31	21	33
% Change	10	-33	19	-23
Trend	Increase	Decrease	Increase	Decrease

Source: Kitheka *et al.* (2019)

4.2.1.1 Kiama sub basin

Figure 4.1 shows the seasonal variations of the discharge and rainfall in Kiama River. The maximum rainfall occurs between March and May during the long rains and between October and November during the short rains. The maximum river discharges ranging between 4.4 m^3/s and 5 m^3/s also occur in the same period. The results are an indicator that rainfall exerts a major influence on streamflow as evidenced by the results in the simple linear regression analysis between rainfall and river discharge in the basin.

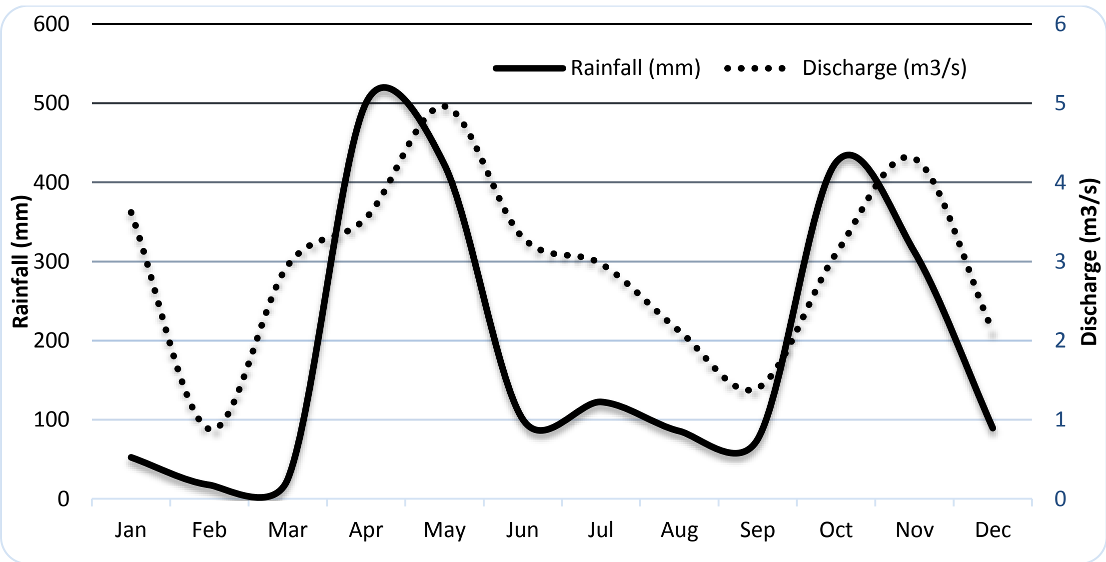

Figure 4.1: Seasonal variability of rainfall and discharge in Kiama Sub basin

Figure 4.2 illustrates the inter-annual variations in rainfall and river discharge in Kiama sub basin between the the period 2000 and 2015. It is evident that there is a significant inter-annual variation in rainfall that subsequently causes significant variability in river discharge. Rainfall and river discharge in the sub basin show significant variability and increasing trend. The magnitude and frequency of occurance of extreme river discharge and rainfall events has also increased. This can be attributed to climate change (See also Matondo *et al.,* 2004; Hagg *et al.,* 2007; Kingston *et al.,* 2011). There is a significant relationship between rainfall and streamflow as the simple linear regression model gave a correlation coefficient (r) of 0.57 and the coefficient of determination (R^2) of 0.54 (figure 4.3). These were statistically significant at 95% confidence level (P=0.05).

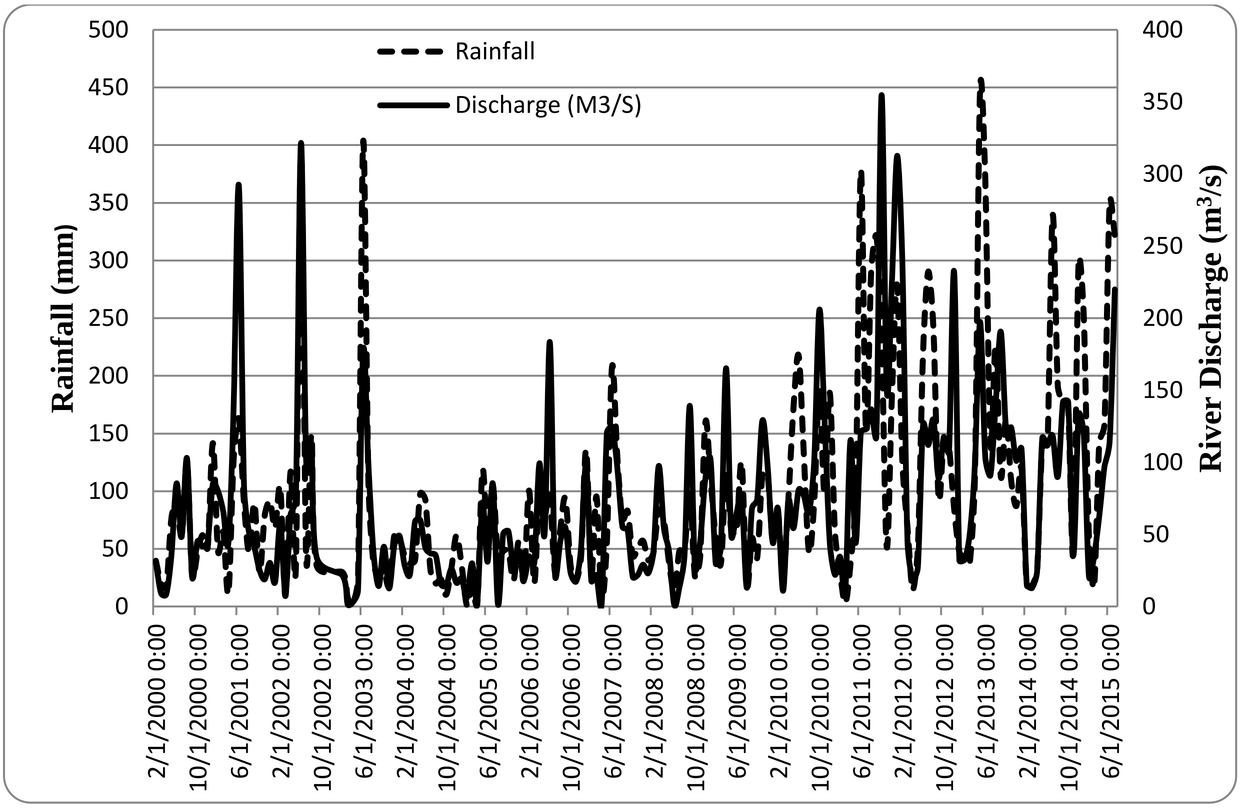

Figure 4.2: Seasonal variability of rainfall and discharge in Kiama Sub basin

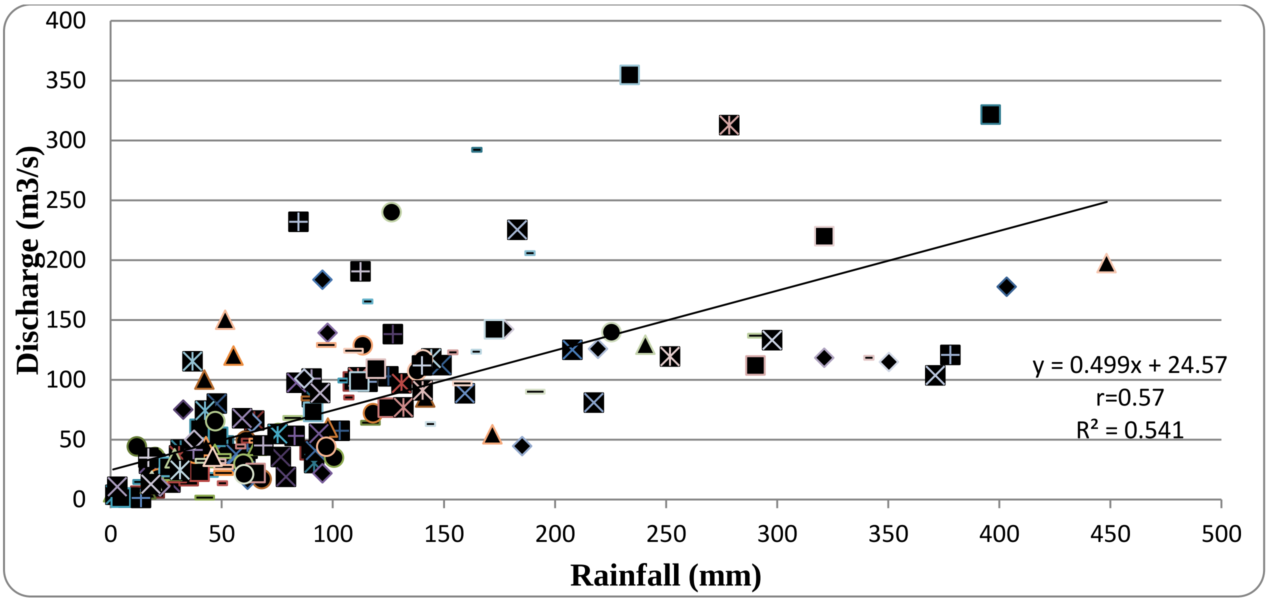

Figure 4.3: The relationship between rainfall and river discharge in Kiama sub basin in the period between 2000 and 2015

There is a significant variation in the water level in Kiama River. The water level in the river declines from 0.31 m to 0.2 m in the months of December to February. This trend changes in March with the onset of long rains where the water level in the river increases to 0.35 m. The level then decreases from 0.35 m to 0.29 m in September (Figure 4.4). The water level decrease could be attributed to the amounts abstracted each month from the river. The water levels in the river were also low during the periods of high-water abstraction. The maximum water abstraction rate of about 95,500 litres/day occurred in January during the period of low water level of 0.2 m. There is also a peak in August (95,300 litres/day) during a period of low flow when the water level was 0.3 m. Water abstraction rates were high during the dry seasons due to the increased use of water for irrigation since farmers need more water for crop production during this period. The analysis of the relationship between water abstraction and river water level yielded a correlation coefficient r of 0.50 and the coefficient of determination (R^2) of 0.45 both of which are significant at 95% confidence level (P=0.05).

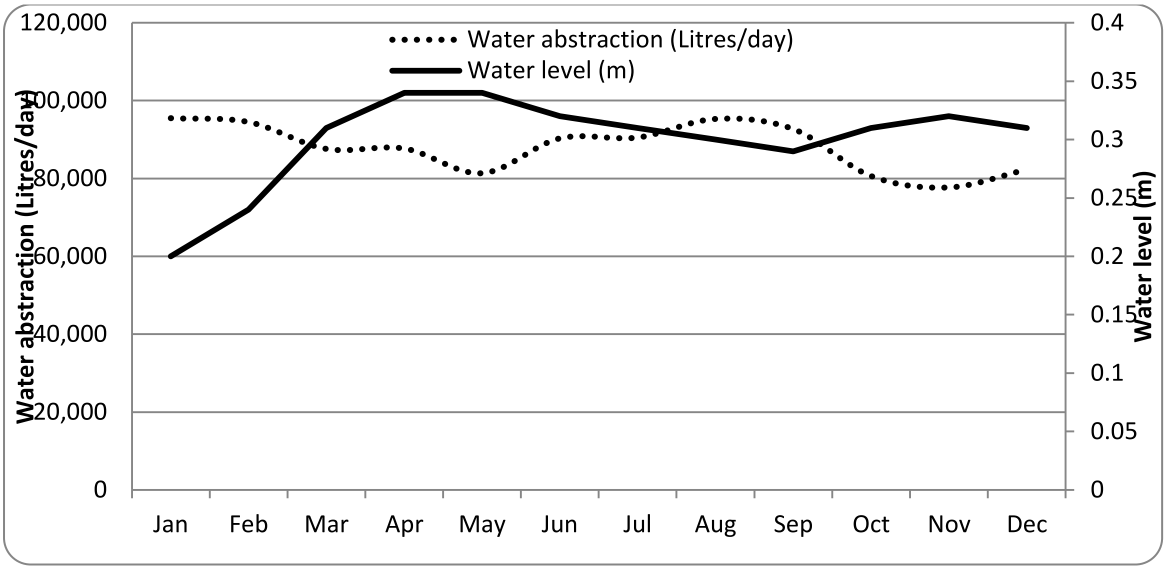

Figure 4.4: Seasonal variability between water abstraction and water level in Kiama sub basin in 2018

4.2.1.2 Thika sub basin

Figure 4.5 shows the seasonal variations of the discharge and rainfall in Thika River. The maximum rainfall occurs in the period between March and June during the long rains and in the period between October and November during the short rains. The maximum river discharges ranging between 3.5 m^3/s and 5.5 m^3/s also occur in the same period. These results show that rainfall exerts a major influence on streamflow as evidenced by the results in simple linear regression between rainfall and river discharge in the basin.

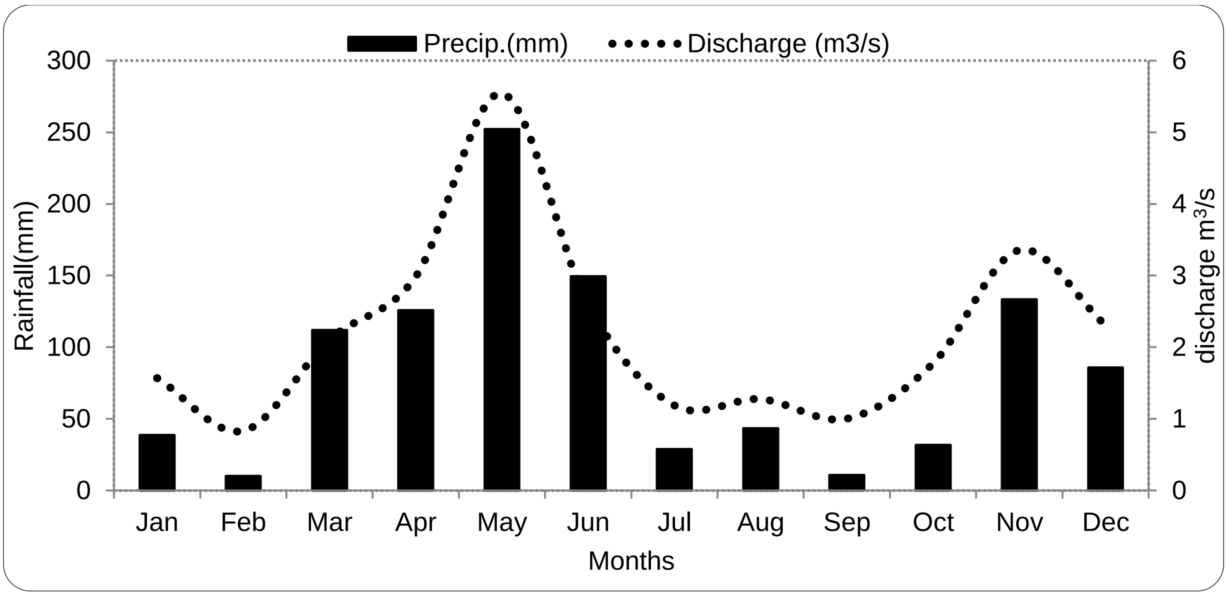

Figure 4.5 : Seasonal variability of rainfall and discharge in Thika Sub basin

Figure 4.6 shows inter-annual variations in the rainfall and river discharge in the period between 2000 and 2015. There is a significant inter-annual variation in rainfall which subsequently causes significant variability in river discharge. Both rainfall and river discharge show significant variability and increasing trend (Figure 4.6). There is also an increase in the magnitude and frequency of occurrence of extreme rainfall and river discharge events. There is a significant relationship between rainfall and streamflow as the simple linear regression gave correlation coefficient (r) of 0.75 and the coefficient of determination (R^2) of 0.56 (figure 4.7). These were statistically significant at 95% confidence level, P=0.05.

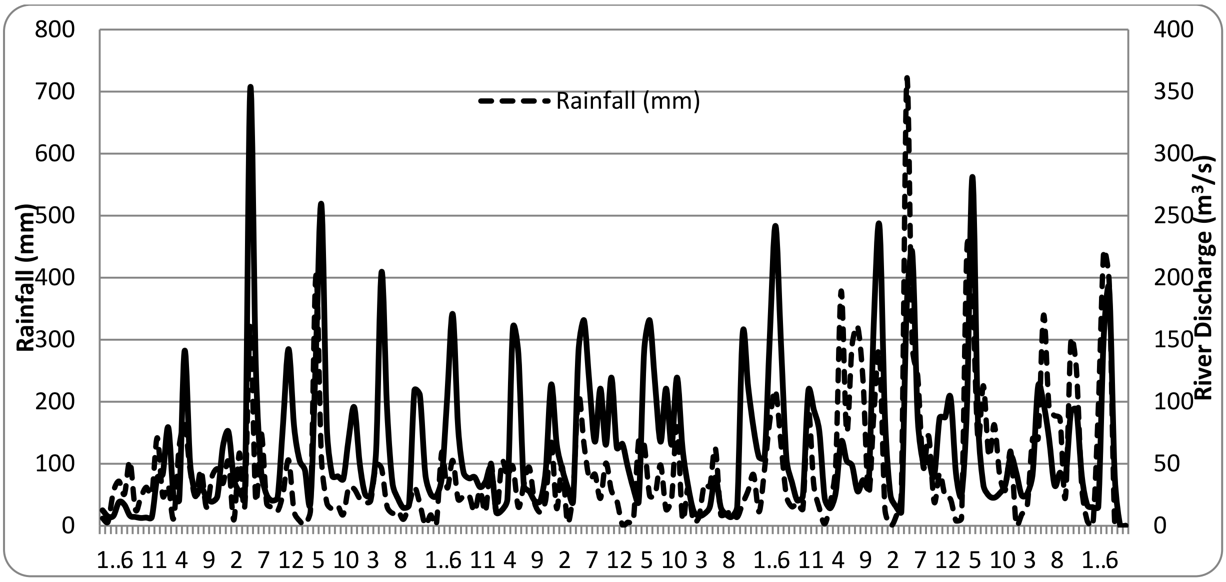

Figure 4.6 : Inter-annual variability of rainfall and river discharge in Thika Sub basin

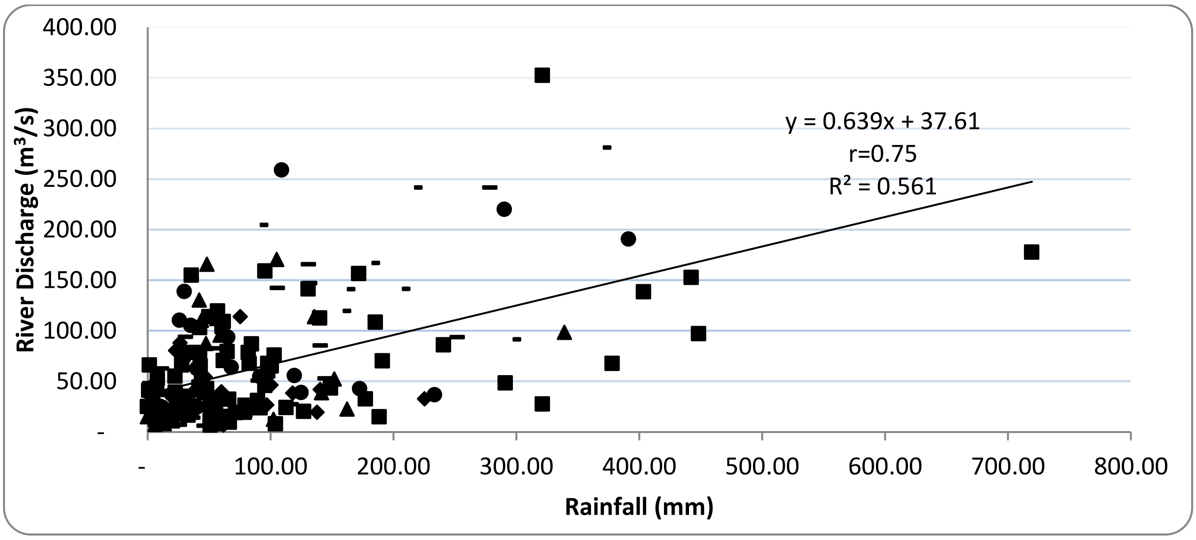

Figure 4.7: The relationship between rainfall and river discharge in Thika sub basin in the period between 2000 and 2015

There is a significant variation in the water level in Thika River. Increase in water level is in the period between September and December (0.25 m to 0.8 m) during the S.E monsoon and about the period between February and April. Decrease in water level is in the period between April and September when river water level declines from 0.75 m to 0.25 m. The period of maximum water abstraction is in the month of January (107,200 litres/day) and also in the period between June and September during the dry period. The period of maximum water abstraction is mainly during dry periods (Figure 4.8). It is during this period that the pressure on the river increase considerably. The analysis of the relationship between water abstraction and river water levels yielded a correlation coefficient (r) of 0.48 and the coefficient of determination (R^2) of 0.45 both of which were significant at 95% confidence level (p= 0.05).

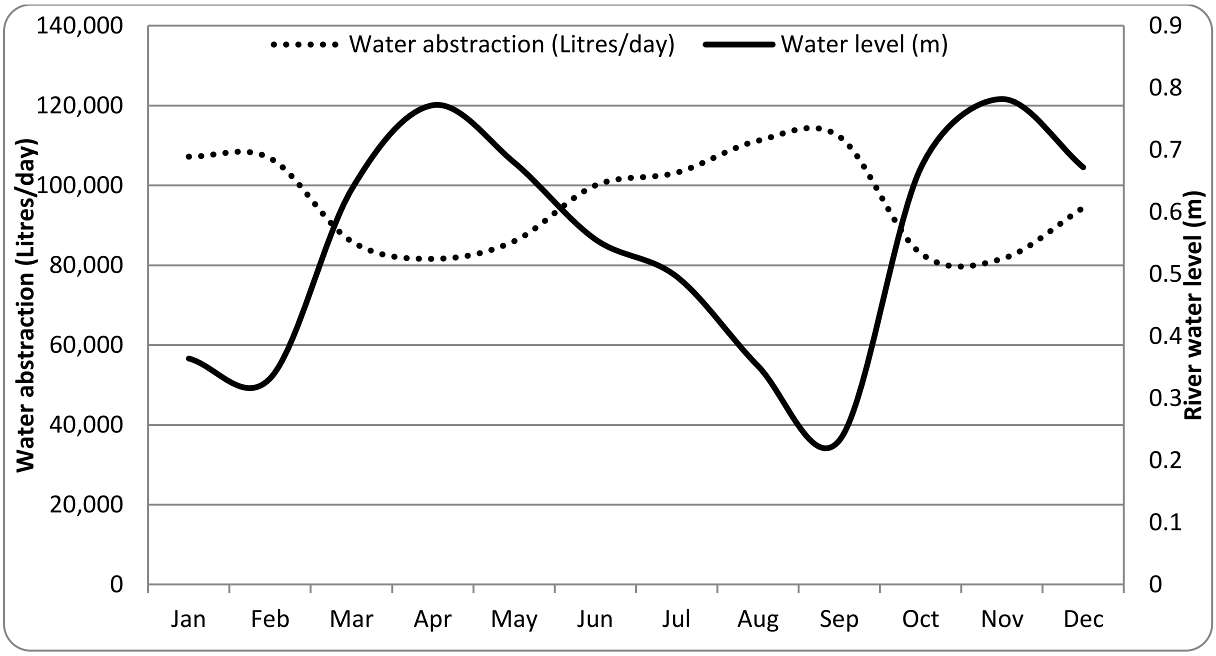

Figure 4.8: Seasonal variability between water abstraction and water level in Thika sub basin

4.2.1.3 Kimakia Sub basin

Figure 4.9 shows the seasonal variations of the discharge and rainfall in Kimakia River. The maximum rainfall occurs in the period between March and May during the long rains and in the period between October and November during the short rains. The maximum river discharges ranging between 3 m^3/s and 5.3 m^3/s also occur in the same period.

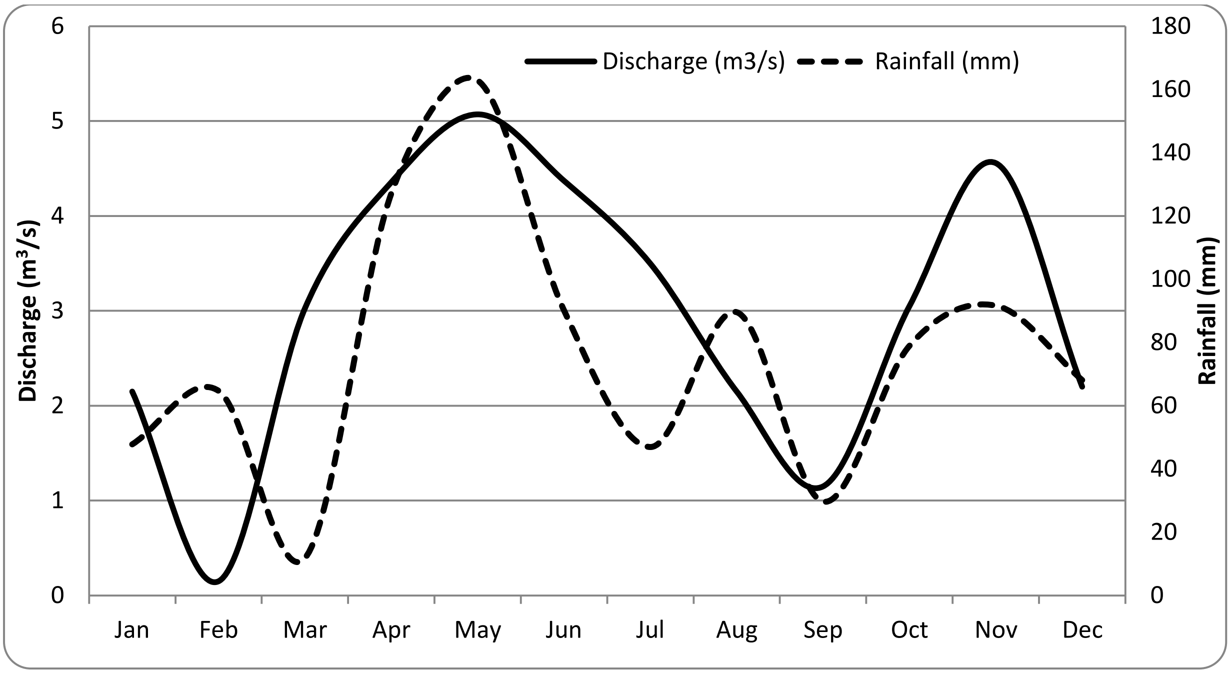

Figure 4.9: Seasonal variability of rainfall and discharge in Kimakia Sub basin in 2018

Figure 4.10 shows inter-annual variations in the rainfall and river discharge in Kimakia river in the period between 2000 and 2015. There is a significant inter-annual variation in rainfall which subsequently causes significant variability in river discharge. Both rainfall and river discharge show significant variability and increasing trend. There is also an increase in the magnitude and frequency of occurrence of extreme rainfall and river discharge events.

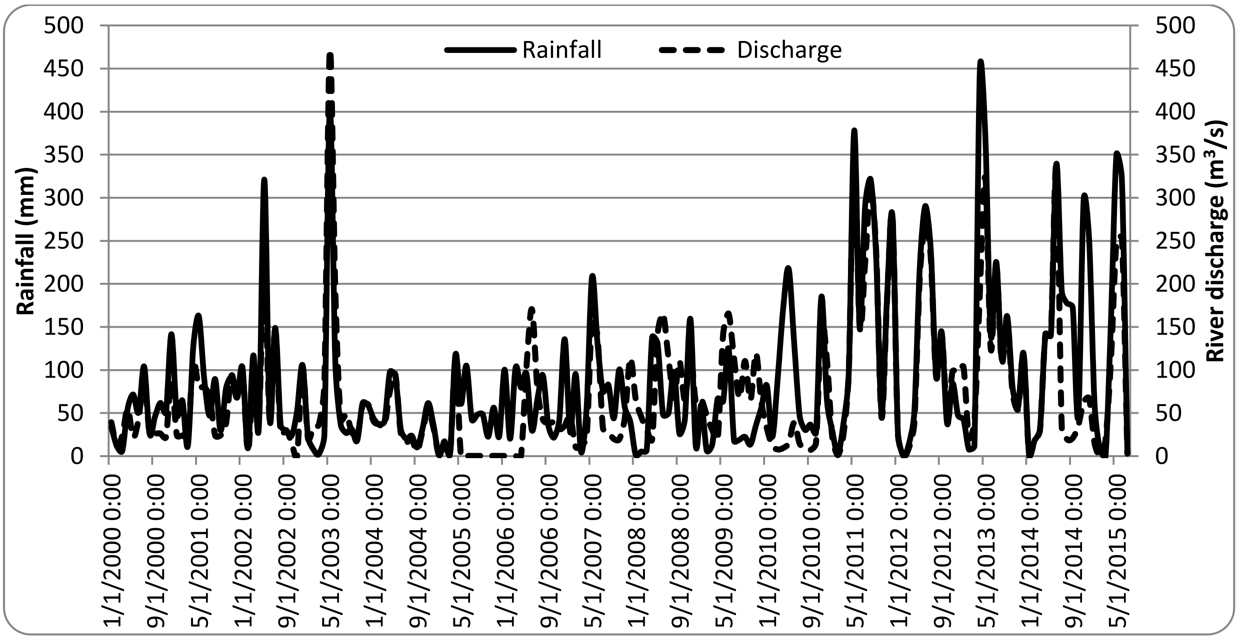

Figure 4.10: Inter-annual variability of rainfall and river discharge in Kimakia Sub basin

These results show that rainfall commands a major influence on streamflow as evidenced by the results in the simple linear regression analysis between rainfall and river discharge in the basin (Figure 4.11). There is a significant positive relationship between rainfall and streamflow as the regression coefficient (r) was 0.9 and the coefficient of determination (R^2) was 0.80. These were statistically significant at P=0.05.

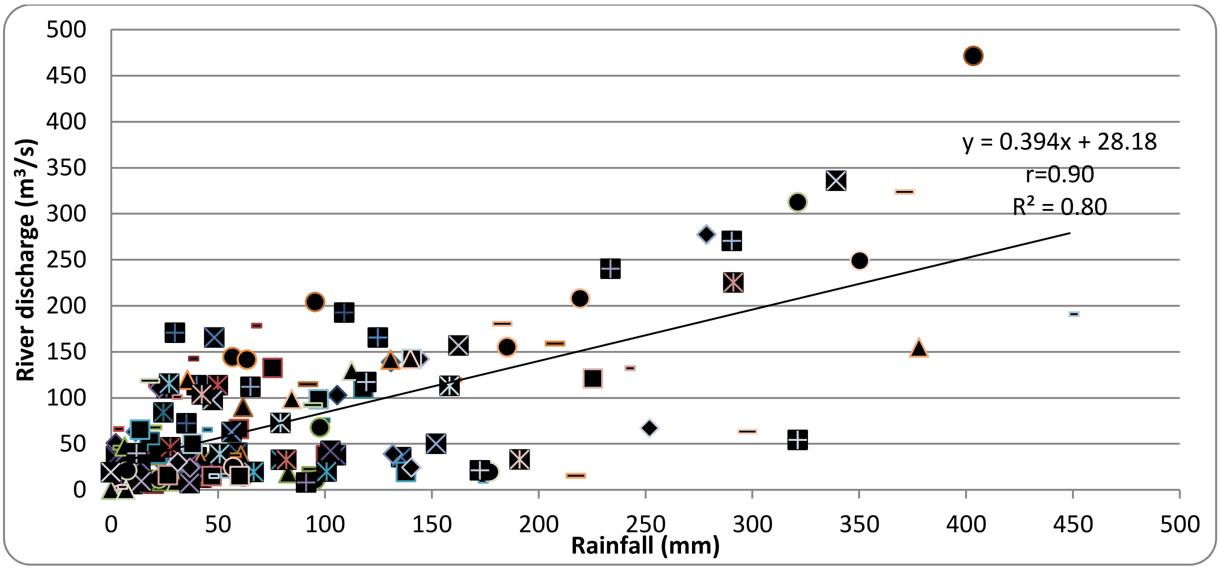

Figure 4.11: The relationship between rainfall and river discharge in Kimakia sub basin in the period between 2000 and 2015

There is a significant variation in the water level in Kimakia River. The lowest water level in the river decreases from 0.6 m to 0.4 m in the months of December to February. This trend changes in March to April with the onset of long rains where the water level in the river increases to 0.87 m. The water level then decreases from 0.87 m to 0.39 m (lowest) in September. The maximum water level is 0.9 m in October (Figure 4.12). The water level decrease in the river can be attributed to the amounts abstracted each month from the river. The water levels in the river are also low during the periods of high-water abstraction. The maximum water abstraction rate of about 69,300 litres/day occurred in February when the flow level was 0.39 m. There is also a peak in September (66,900 litres/day) during a period of low flow when the flow level was 0.5 m. Water abstraction rates are high during the dry seasons due to the increased use of water for irrigation since farmers need more water for crop production during this period. The simple linear regression analysis of the relationship between water abstraction and river water level yielded a correlation coefficient r of 0.55 and the coefficient of determination (R^2) of 0.47 both of which are significant at 95% confidence level (P=0.05).

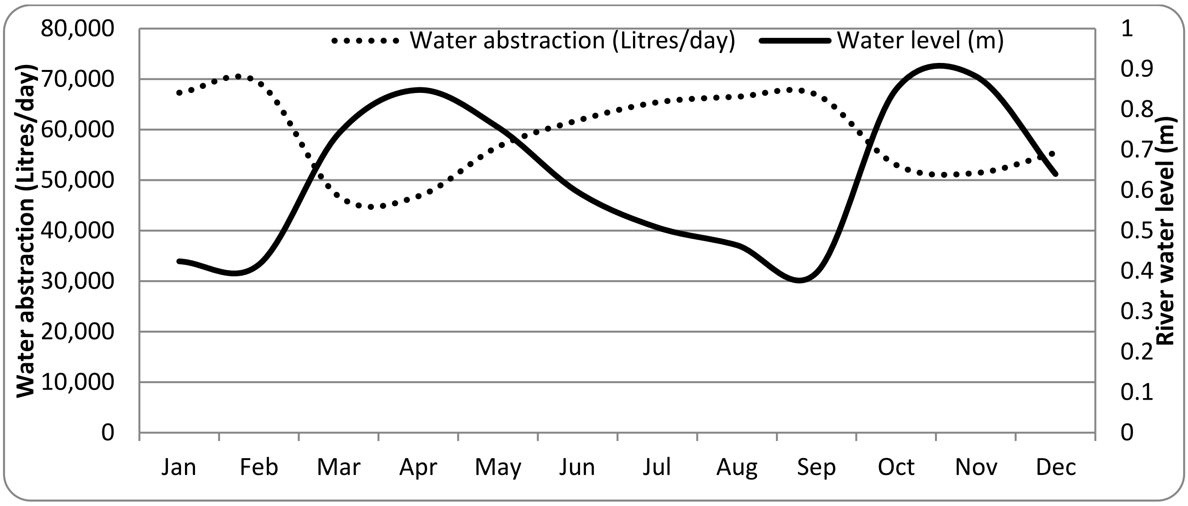

Figure 4.12: Seasonal variability between water abstraction and water level in Kimakia sub basin

4.2.1.4 Chania sub basin

Figure 4.13 shows the seasonal variations of the discharge and rainfall in Chania River. The maximum rainfall occurs between March and May (410 mm) during the long rains and in the period between October and November (300 mm) during the short rains. The maximum river discharges ranging between 4.9 m^3/s and 5.3 m^3/s also occur in the same period. River discharge and rainfall decrease from 5.3 m/s to 2 m/s and 410 mm to 25 mm respectively between May and September.

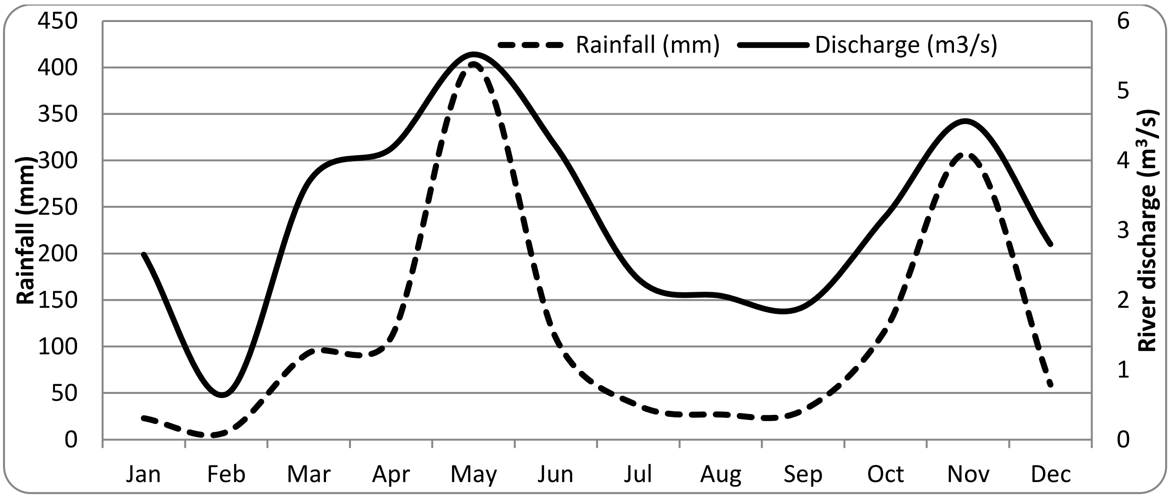

Figure 4.13: Seasonal variability of rainfall and discharge in Chania Sub basin

Figure 4.14 shows inter-annual variations in the rainfall and river discharge in Chania river in the period between 2000 and 2015. There is a significant inter-annual variation in rainfall which subsequently causes significant variability in river discharge. Both rainfall and river discharge show significant variability and increasing trend. There is also an increase in the magnitude and frequency of occurrence of extreme rainfall and river discharge events.

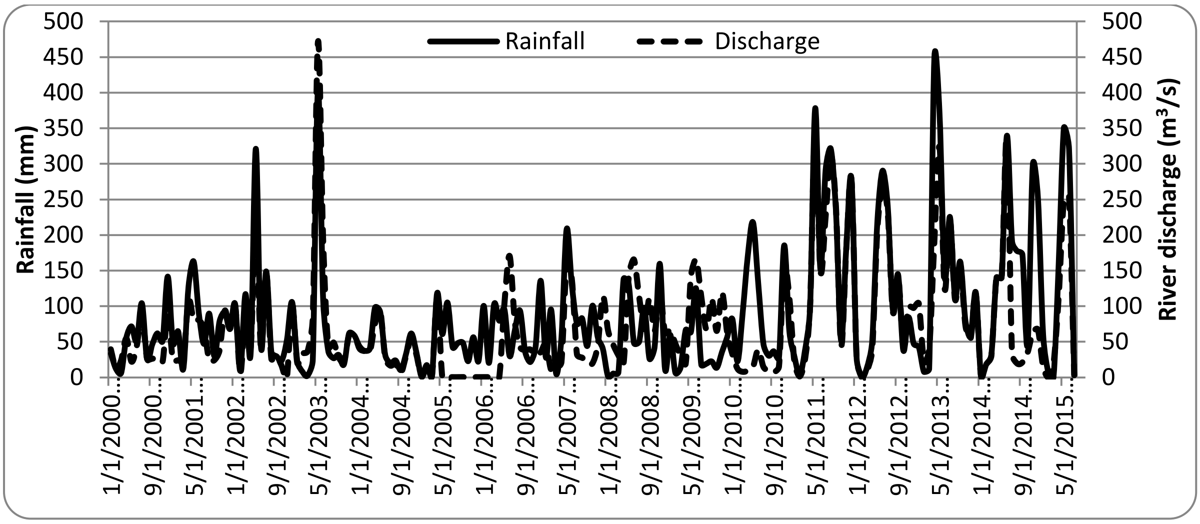

Figure 4.14: Inter-annual variability of rainfall and river discharge in Chania Sub basin

These results show a significant relationship between rainfall and streamflow as evidenced by the results of the simple linear regression analysis between rainfall and river discharge in the basin (Figure 4.15). There is a significant relationship between rainfall and streamflow as the simple linear regression coefficients of r 0.69 and the coefficient of determination (R^2) 0.54 indicated. These were statistically significant at 95% confidence level (P=0.05).

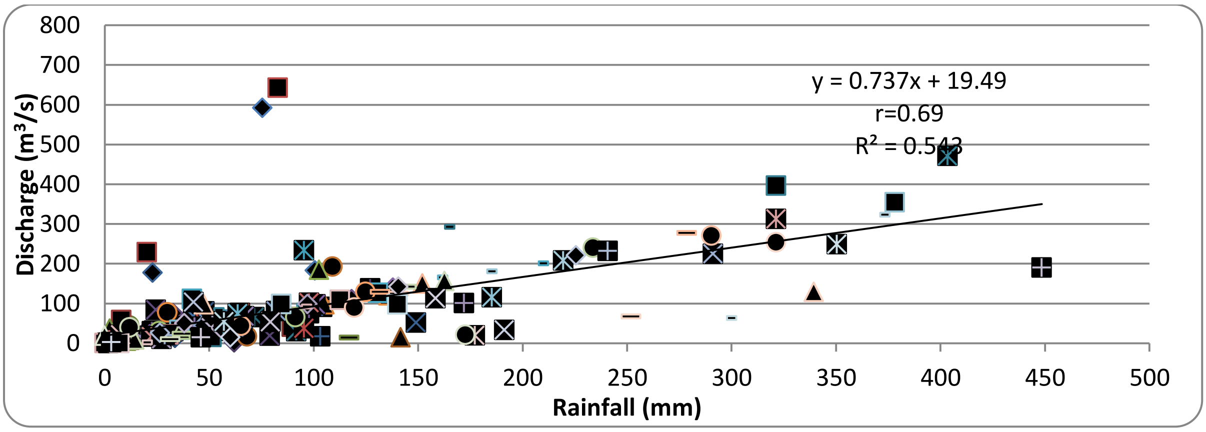

Figure 4.15: The relationship between rainfall and river discharge in Chania River in the period between 2000 and 2015.

There is a significant variation in the water level in Chania River. Increase in water level is in the period between September and November (0.4 m to 1 m) during the S.E monsoon and about the period between March and May (0.41 m to 0.9 m). Decrease in water level is in the period between May and September (0.7 m to 0.4 m). Increasing water abstraction is in the period between March and September, until the peak which is in September. The period of maximum water abstraction is in September (63,400 litres/day) and also in the period between December and February during the N.E monsoon (dry period). The period of maximum water abstraction is mainly during dry periods (Figure 4.16). It is during this period that the pressure on the river increase considerably. The simple linear regression analysis of the relationship between water abstraction and river water levels yielded a correlation coefficient (r) of 0.52 and the coefficient of determination (R^2) of 0.46 both of which are significant at 95% confidence level (p= 0.05).

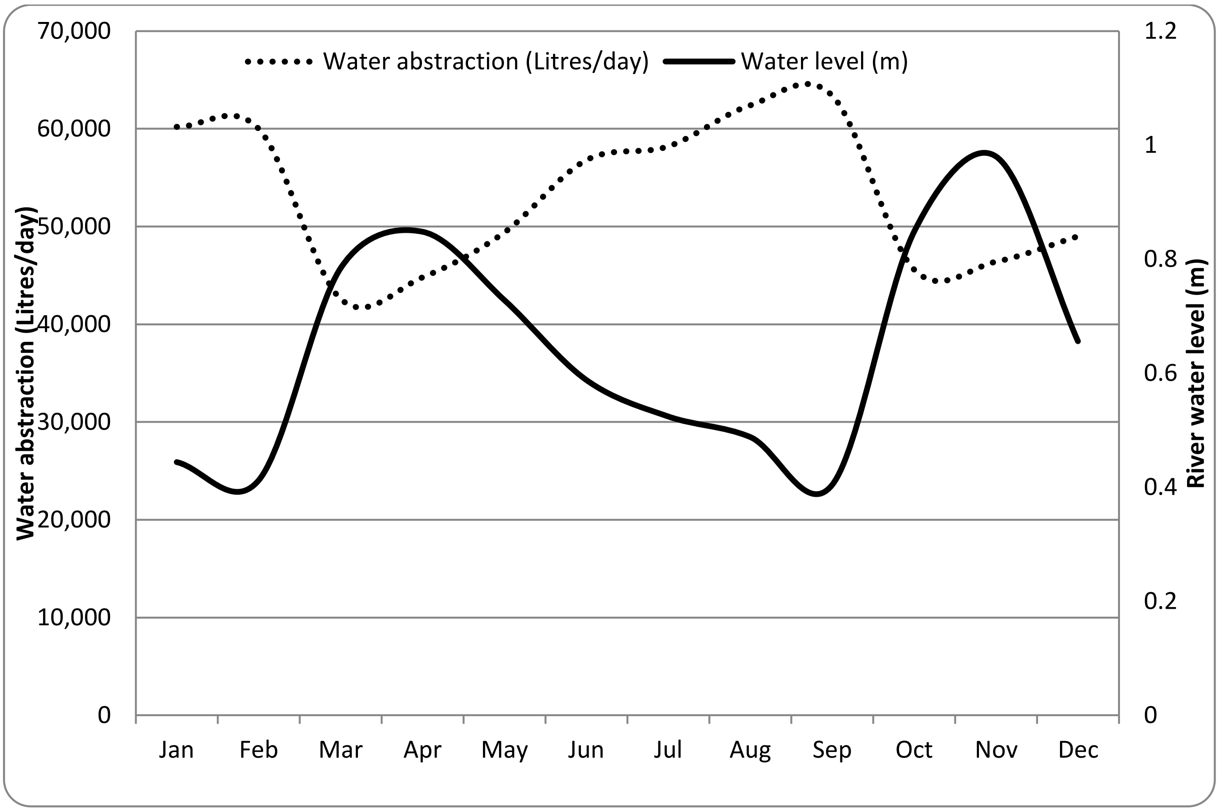

Figure 4.16: Seasonal variability of water abstraction and water level in Chania sub basin

4.2.1.5 Comparison of seasonal and inter-annual variability in river discharge and rainfall in the four sub basins

Figure 4.17 shows the inter-annual variations of rainfall in South West Upper Tana Basin from 2000-2015. Increase in rainfall occurred between 2001 and 2004 and between 2009 to

2015.The maximum rainfall occurred in 2003 (about 1300 mm) in Kiama sub basin. There is also a peak in 2012 (about 1190 mm) in Chania Sub basin. It was observed that the rainfall decline was between 2003 and 2008. The lowest rainfall recorded was in 2005 (About 50 mm) and in 2008 (about 20 mm). The periods of increase in rainfall (2001-2004) coincide with the periods of increase in river discharge in the sub basins. The river discharge in the study area increased between 2001 and 2003 and between 2010 and 2015. Generally, there has been a systematic increase in river discharge since 2010. The maximum river discharge of about 460 m^3/s was in 2003 in both Kimakia and Chania Rivers. There was also a peak in 2011 of about 360 m^3/s in Chania River. The periods of low river water discharge were between 2004 and 2006 and between 2007 and 2009.

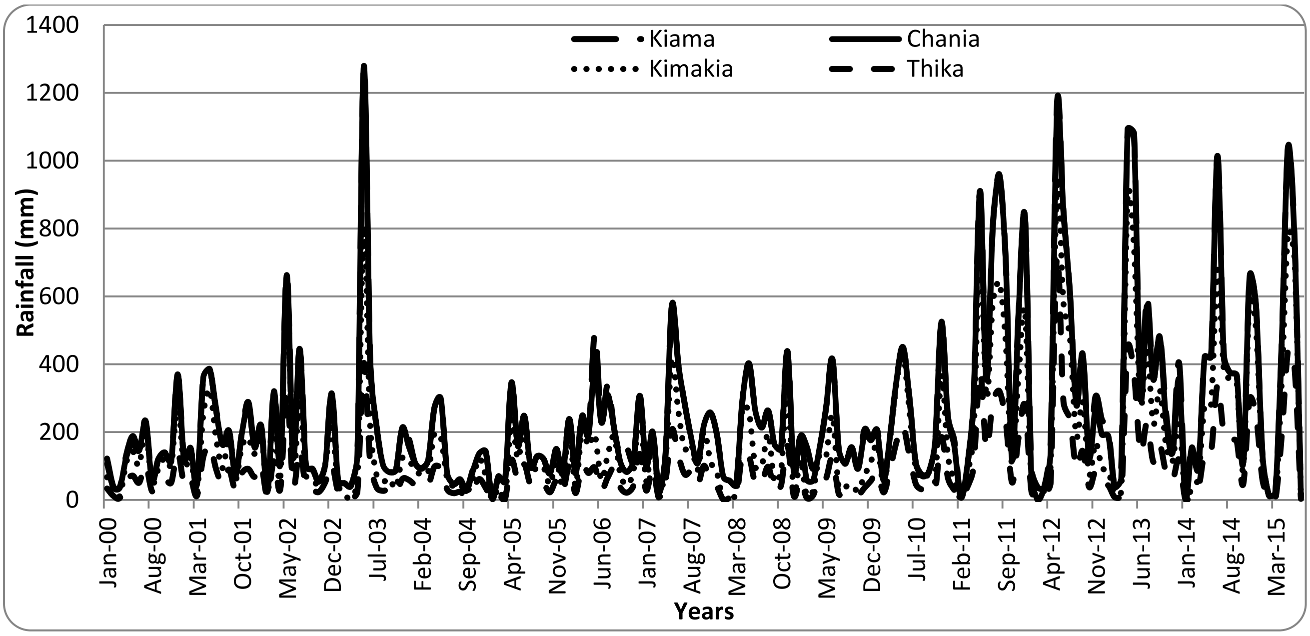

Figure 4.17: Inter-annual variations in Rainfall in South West Upper Tana Basin between 2000 and 2015

The lowest river discharge of about 5 m^3/s was in 2005 in Thika River (Figure 4.18). This is the same period when rainfall in the sub basin decreased. This relationship between rainfall and river discharge yielded a simple linear regression coefficients r of 0.70 and coefficient of determination (R^2) of 0.68. These were statistically significant at 95% confidence level (P=0.05) (See also Kingston and Taylor, 2010 and IPCC, 2014).

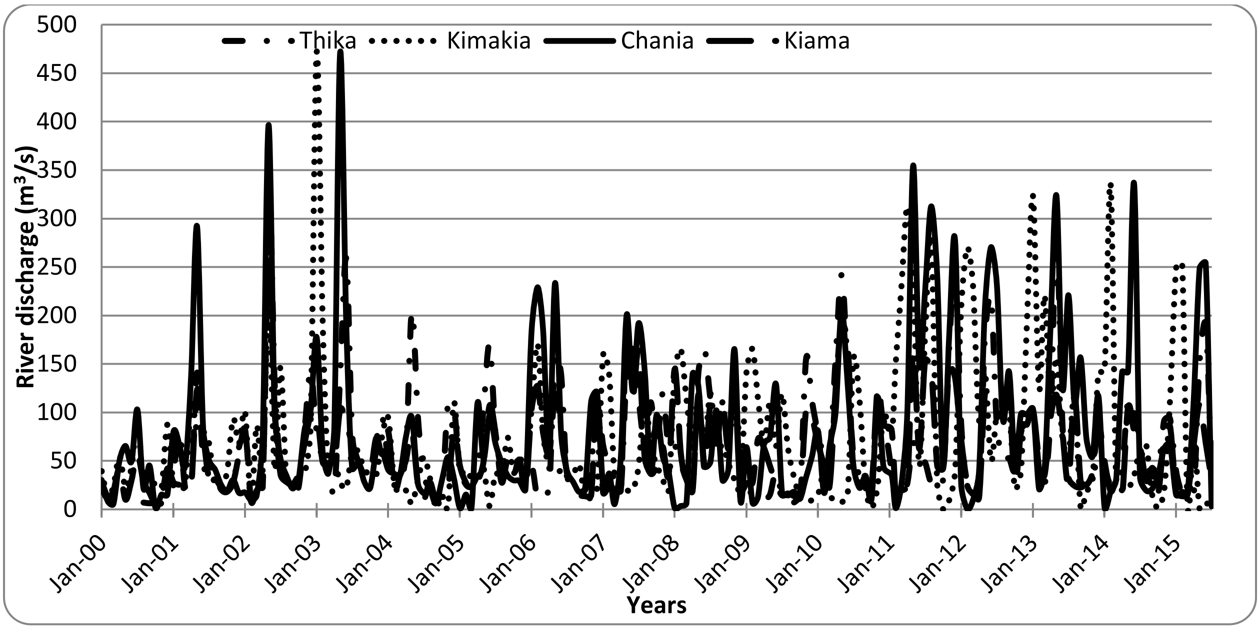

Figure 4.18: Inter-annual variability in river discharge in South West Upper Tana Basin between 2000 and 2015

The patterns of variations of water levels in the four sub basins are similar. Water levels in the four sub basins decreases between April and September from 1.01 m to 0.5 m, 0.78 m to 0.24 m, 0.83 m to 0.4 m and 0.83 m to 0.41 m in Kiama sub basin, Thika sub basin, Kimakia sub basin and Thika Sub basin, respectively. The decrease is also evident between November and February from 1.5 m to 0.58 m, 0.79 m to 0.38 m, 0.89 m to 0.41 m and 0.99 m to 0.41 m in Kiama sub basin, Thika sub basin, Kimakia sub basin and Chania sub basin, respectively. These are the periods when water abstraction rates are also high in the four sub basins. Maximum water levels in the four sub basins are in the period between February and April being 1.01 m, 0.78 m, 0.83 and 0.83 m in Kiama sub basin, Thika sub basin, Kimakia sub basin and Chania sub basin, respectively. Maximum water levels are also evident in the period between September and November being 1.5 m, 0.79, 0.89 m and 0.99 m in Kiama sub basin, Thika sub basin, Kimakia sub basin and Chania sub basin, respectively (Figure 4.19). This coincides with the periods of high rainfall in the study area March-May (long rains) and October-December (short rains). Kiama sub basin has the highest water levels in the study area while Thika has the lowest water levels. This low water level in Thika River could be attributed to the high abstraction rate in the sub basin as compared to the other three sub basins (Figure 4.19).

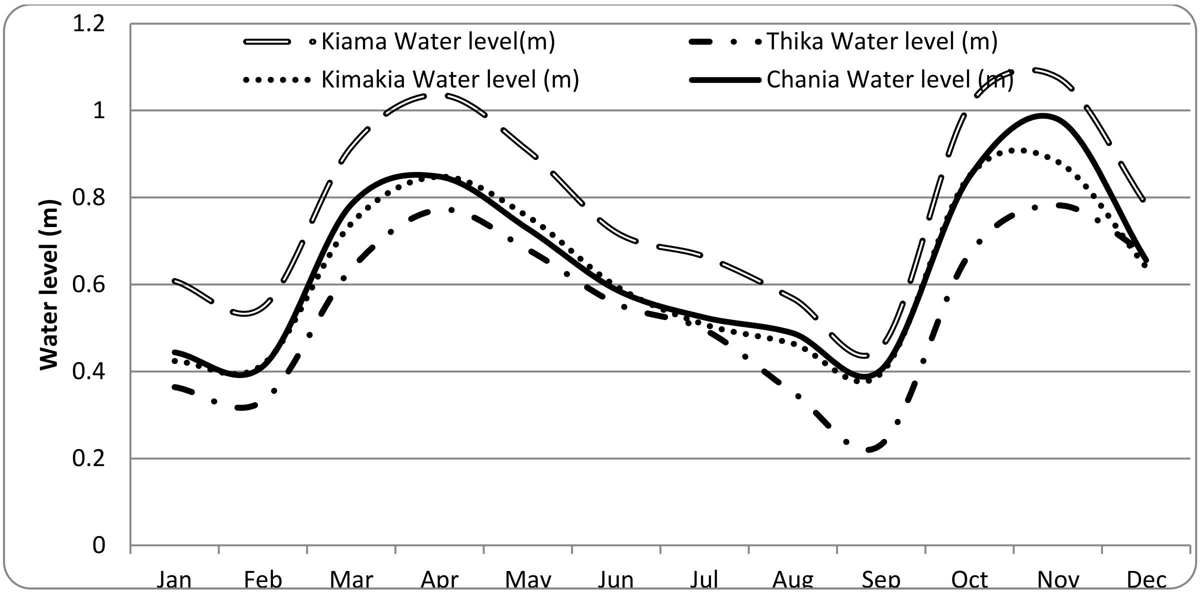

Figure 4.19: Water levels in Thika, Kiama, Chania and Kimakia sub basins in 2018

Figure 4.20 shows water abstraction rates in the four sub basins. The maximum water abstraction rate of about 95,500 litres/day, 107,200 litres/day, 66,900 litres/day and 63,400 litres/day in Kiama, Thika, Kimakia and Chania sub basins respectively are in the month of September and January. It is during this period that the pressure on the rivers increases considerably since farmers need more water for crop production. These are the same periods with low water levels, April to September and December to February. The analysis of the relationship between water abstraction and river water levels yielded a correlation coefficient (r) of 0.51 and the coefficient of determination (R^2) of 0.46 both of which are significant at 95% confidence level (p= 0.05).

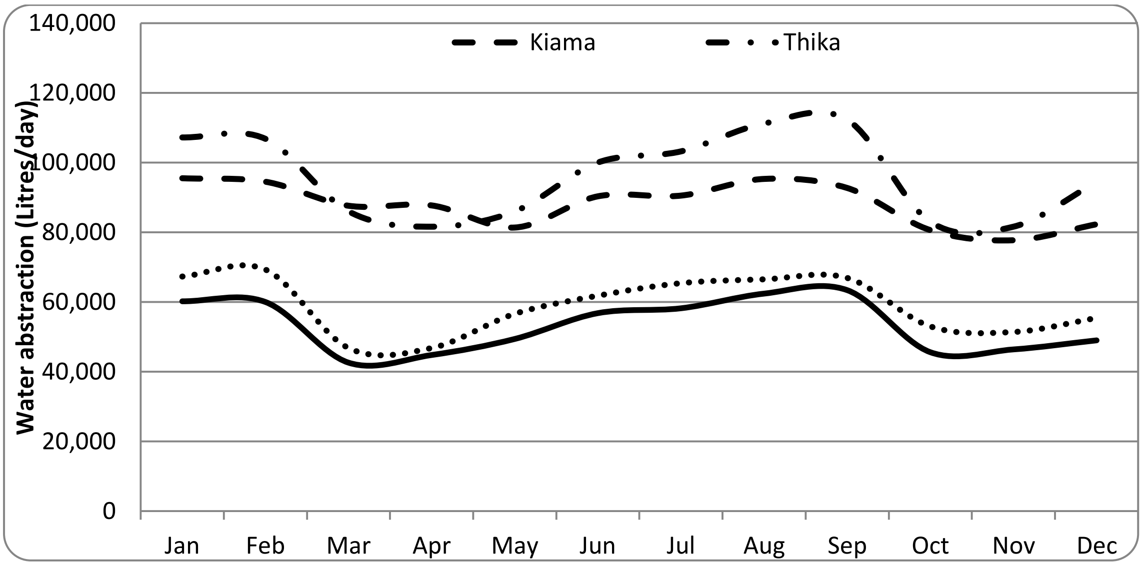

Figure 4.20: Water Abstraction rates in Thika, Kiama, Chania and Kimakia sub basins in 2018

4.3 The relationship between household characteristics and water abstraction

Attempt was made in this study to determine the extent to which household characteristics influence water abstraction in the study area. 120 respondents were interviewed using questionnaires. The household characteristics were analysed based on the age, sex, marital status, household size and the residence time of the respondents in the study area. The results of the study showed that most of the people abstracting water in the study area are between the ages of 25-55 years. This could be attributed to the fact that, in that age bracket, most of them have children who they have to take care of. Thus, they abstract more water to improve their yields and get more income from their farms. The reliance of rainfed agriculture seems to be on the decline due to the unreliability of rainfall in the study area.

4.3.1 Kiama sub basin

In Kiama sub basin, 95% of the respondents indicated that they had stayed in the sub basin since they were born. Thus, the land they occupy is their ancestral land. However, 5% of the respondents have migrated to the area from other places in central Kenya. The main reason for their migration was mainly to be in an area where they could access water for irrigation. Others have moved to the area in search of informal employment opportunities in the tea farms and at market centers. Women form the highest percentage (56%) of those abstracting water from Kiama sub basin. This could be attributed to the fact that there are many single mothers headed families in the sub basin. Most of the respondents (63%) in the study area are married and therefore have families. Only 33% of respondents were single with most of them being women. This explains why women form the highest number of the people abstracting water from the basin (see also Institute of Economic Affairs-Kenya, 2008; Kimani and Kombo, 2010).

Most of the people abstracting water from the basin are of the productive age between 25-50 years. The abstraction of water for this age bracket is of the order of 1000 litres to 2000 litres per day. The reason for this could be that these respondents have already gained more experience in farming thus the need to abstract more water in order to have more yields. The increase in abstractions could also be attributed to more income in the people in that age group which enables them to buy more farm implements and use water abstraction technologies like water pumps. For those above 50 years, the abstraction is less than 500 litres per day. This could be attributed to the fact that most of the people in this age have relatively young families and thus they have to abstract more water to increase crop production in order to obtain more money to take care of their families. In addition, respondents aged 50 years and above rarely abstract water from the river. This could be attributed to the fact that most people at this age and above no longer have children to take care of and also do not see the need for engaging in the tasking job of abstracting water from the river. These results are consistent with (Ramirez *et al.,* 2008) who established that the decisions made by farmers in regards to water abstraction differ greatly depending on the age factor. Ahmed *et al*., (2012) noted that age influences the quality of decision that the farmer will make regarding the adoption of a new irrigation water use innovation. A study by Owilla (2010) established that there was a negative relationship between farmers age and water abstraction in Mwea irrigation scheme. A study by Mwadini, 2018 established that age was not a major factor influencing water abstraction for irrigation in the sub basin (Mwadini, 2018).

This study established that 36% of the households in Kiama sub basin were found to have a total of 5 members. Households with 3 and 4 members formed 20% and 24% of the respondents, respectively. Households with more than 6 members formed less than 20% of the total population.

4.3.2. Thika Sub basin

In Thika sub basin, 88% of the respondents indicated that they had been staying in the area since they were born. This means that most of the people in the area live in their ancestral land. However, 12% of the respondents have migrated to the sub basin from other places. The immigration is mainly to obtain land where they could access river water for irrigation. Others have moved to the area in order to look for informal employment in the tea farms and in market centers. In this sub basin, 52% of the people abstracting water are women as compared to 48% who are men. This high proportion of women abstracting water from the sub basin can be attributed to the fact that in the basin, there are more families that are headed by women. This is consistent with (Institute of Economic Affairs- Kenya, 2008) who established that there were 30.8% female household headed families in Central Kenya. Thus, women have to be involved more in farming in order to cater for the needs of their families. This higher percentage of women could also be attributed to the fact that they are the main users of water for domestic purposes. Thus, they abstract water for household chores such as cooking and washing. This is consistent with Kimani and Kombo (2010) who established that women perform the most work in farms to enhance food production in rural areas in Kenya. The study also showed that 71% of respondents in the study area are married and only 29% of the respondents were single. Most of these respondents were women, possibly explaining the reason why women form the largest percentage of those abstracting water from this basin.

Majority of the people abstracting water in Thika sub-basin are in the age bracket of 25-40 years. The maximum water abstraction rate in Thika sub basin was found to be 4000 litres/day and this was mainly undertaken by farmers aged above 40 years. The youthful farmers aged 25 to 45 years abstract upto 1000 litres/day. However, beyond the age of 60 years, the water abstraction rate reduces drastically to only 500 litres/day. Most of the people in that age bracket have young families to take care of and also educate, and hence they engage in abstraction of water to produce more yields in their farms in order to earn more money. The percentage of the people abstracting water declines from 50 years because in most of those families, the water needs reduce since the children move from their homes either to look for jobs or settle in their own families.

The study established that respondents above 45 years abstracted more water as compared to those in the lower age groups. This was attributed to the fact that respondents 45 years and above earn more income and are therefore able to buy expensive equipment for abstracting water such as water pumps. It could also be attributed to the fact that at that age, these farmers have gained experience, thus the need to abstract more water to get more crop yields. These findings are consistent with those reported by Adeoti (2009) who established a negative relationship between age of farmers and the adoption of irrigation technology that has an impact on water abstraction. Mwadini (2018) noted that young people were more involved in abstracting water for irrigation as compared to old people. However, this study established that the male farmers were more dominant in abstracting water for irrigation in Kiladeda Sub basin, Tanzania. Other similar studies by Ahmed *et al.* (2012) and Ahmed *et al.* (2013) established that there was a negative correlation between irrigation water use and farmers age.

It was found that, 41% of households in the study area have 5 members. Households with 3 and 4 members are 22% while those with 6 and 8 members are 11 % and 4% of the respondents, respectively. Majority of the households in Thika sub basin abstract less than 1000 litres per day. Some smaller households abstract more water than larger households by employing casual labourers or procuring water abstraction technologies such as water pumps. Also, they adopt more efficient irrigation practices for their relatively large farms.

4.3.3 Kimakia Sub basin

In Kimakia sub basin, 90% of the respondents were born in the sub basin and therefore they live in their ancestral land. However, 10% of the respondents have migrated into the area from other areas to work as casual labourers in the tea farms and also secure employment opportunities in the nearby markets. In this sub basin, 60 % of the people abstracting water from the river are women and men consist of only 40%. The higher number of women abstracting water can be attributed to the fact that there are many families that are headed by women in the sub basin. Thus, women have to be more involved in abstracting water in order to cater for the needs of their families. The higher percentage for women abstracting water could also be attributed to the fact that they are the main users of water domestically. These findings are consistent with Kimani and Kombo (2010) who established that women are the main workers in farms in rural areas and are instrumental in the crop production process. Most of the respondents (76%) in the study area are married and therefore have families. Only 24% of respondents were single with most of them being women. This explains why women form the highest number of the people abstracting water from the basin. This is consistent with the (Institute of Economic Affairs- Kenya, 2008) who found that 30.8% of the households in Central Kenya were headed by women.

Most of the people abstracting water from the basin are in the productive ages between 25-50 years. The abstraction of water for this age bracket is of the order of 500 litres per day to 1000 litres. For those above 55 years, the abstraction is less than 500 litres per day. This could be attributed to the fact that most of the people in 25-50 years age bracket have relatively young families and thus they have to abstract more water to increase crop production in order to obtain more money to take care of their families. The youthful population (25-50) years could also be lacking meaningful employment. However, as age increases, there are very few people abstracting water. For instance, people in the age bracket 46-50 years formed only 6% of the total number of people abstracting water from the river. In addition, respondents aged 50 years and above rarely abstract water from the river. This could be attributed to the fact that most people at this age and above no longer have children to take care of and also do not see the need for engaging in the tasking job of abstracting water from the river. However, respondents between ages 40-50 years abstract more water. The reason for this could be that these respondents have already gained more experience in farming thus the need to abstract more water in order to have more yields. The increase in abstractions could also be attributed to the increased income that the people in that age group have. The income enables them to buy more farm implements and acquire water abstraction technologies like water pumps.

Attempt was made to determine the influence of household size on water abstraction. For Kimakia sub basin, 40% of the households in the sub basin were found to have a total of 5 members. Households with 3 and 4 members formed 25% and 24% of the respondents, respectively. Households with more than 6 members formed only 11% of the total population.

4.3.4 Chania Sub basin

In Chania sub basin, 87 % of the respondents indicated that they have stayed in the sub basin since they were born. Only 13% of the respondents were immigrants from other places in Central Kenya. Most of the immigrants work in the tea farms while a few migrated to the area to obtain land where they could access water for irrigation. In this sub basin, 56% of the people abstracting water are women as compared to 44% of the population who are men. The high proportion of women in water abstraction could be attributed to the fact that there are many homes that are headed by women in this sub basin. Thus, women have to be more actively involved in water abstraction to improve income from crop production to enable them cater for the needs of their families. Women are also the main users of water for domestic chores. 71% of the people in the sub basin were married people while only 29% of the population were single. Most of the single respondents were women which could be the reason why women form the highest number of those abstracting water from this sub basin (see also Kimani and Kombo, 2010).

Majority of the people abstracting water from this sub basin concentrated in the age bracket 30-50 years and they abstract up to 4000 litres per day. Most of the people in this age bracket have young families to take care for, hence they engage in water abstraction to improve farm yields in order to earn more money. Those aged 50 years and above have very low daily water abstraction rate of less than 500 litres per day since people at that age no longer have many children to take for since most of them will have completed their studies or moved from their homes to look for jobs elsewhere. Attempt was made to determine the influence of household size on water abstraction in this sub basin. It was established that, 47% of the households have 5 members while 35% of the households had 4, 7 and 8 members. About 6% of the households were composed of 3 members. Households with 2 to 4 members abstract more water with a daily water abstraction ranging from 1200 litres/day to 4000 litres/day. Those with 3 to 6 members have a daily water abstraction rate of about 750 litres/day.

4.3.5 Comparison of the influences of household structure on water abstraction

In South West Upper Tana Basin (SWUT), 90% of the people indicated that they have been staying in the study area since they were born. This means that most of the people in the study area live in their ancestral land. However, 10% of the respondents have migrated to the sub basin from other places. The immigration is mainly in search of informal employment in the markets and tea plantations in the area. Others migrated into the area in order to obtain land near rivers to access water for irrigation. In this area, 56% of the people abstracting water were women as compared to 44% who were men. This high proportion of women abstracting water from the sub basin can be attributed to the fact that in the sub basin, there are more families that are headed by women. Emigration of male to the nearby urban areas such as Thika and Nairobi in search of employment opportunities has also limited their numbers in water abstraction (MCIDP, 2014). Significant positive influence of the gender of household head on water abstraction was also noted in a study by Belay and Bayene (2013). Women also are the main users of water domestically. This is consistent with (Institute of Economic Affairs-Kenya, 2008) who established that there were 30.8% female household headed families in Central Kenya.

Water abstraction priorities between men and women differ, while men prefer to abstract water for cash crop irrigation, women abstract water for home gardening and domestic uses (International Fund for Agricultural Development, 2012). Similarly, Kimani and Kombo (2010) noted that women are the main workers in farms in rural areas and are instrumental in the crop production process, hence are more likely to be involved in water abstraction than men. Sultana (2012) established that gender exert influence in water abstraction and irrigation policy. However, some studies have had contrasting results; Zwarteveen (2006); Adeoti (2009) established that water abstraction for irrigation is mainly a male dominated affair with high percentage of male abstracting water for irrigation in Ghana. The study established that 71% of people in the study area are married and therefore have families. Only 21% of respondents were single with most of them being women while 1% of the people in the study area are divorcees. This could be the reason why women form the highest number of the people abstracting water from the basin.

Attempt was made to determine the influence of household size on water abstraction in South West Upper Tana Basin (SWUT). It was determined that 40% of households in the study area have 5 members, 25 % of the households had 4 members while 20 % of the households had 3 members. Only 15% of the households in the study area had more than 5 members. Majority of the households in SWUT basin abstract less than 10,000 litres per day. Households with the highest water abstraction rate (15,000 litres/day to 40,000 litres/day) have 2-6 members. These findings are consistent with those by Mwadini (2018) who established that most of the households in Kiladeda Sub Basin had an average of 5 people. Some small households abstract more water than larger households by employing casual labourers or procuring water abstraction technologies such as water pumps. Also, they adopt more efficient irrigation practices for their relatively large farms. This contradicts results of Aseyehegn *et al*. (2012); Zhang (2013) who noted that there was a positive correlation between household size and water abstraction.

Majority of the water abstraction fall in the age bracket 25 to 55 years abstracting upto 40,000 litres per day. Those aged above 55 years abstract less water as the abstraction rate is of the order 500 litres per day. Increase in water abstraction in age bracket 25 to 55 years could be attributed to the fact that most of the people in this age bracket have young families to take care for hence they engage in water abstraction to improve farm yields in order to earn more money. The low water abstraction rates among those aged 55 years and above could be attributed to the fact that people at that age no longer have many children to take care of since most of them will have completed their studies or moved from their homes to look for jobs elsewhere. These findings are consistent with Mwadini (2018) who noted that 84% of those abstracting water for irrigation from Kiladeda sub basin were in the 20-51 age bracket. Ramirez *et al.* (2008) established that age plays a significant role in water abstraction decisions. It influences the decision of the farmer on the water abstraction technology to use (Ahmed *et al*., 2012).

4.4 The influence of education, income level, occupation and water abstraction technologies

The extent to which education, occupation and water technologies influence water abstraction was determined through questionnaire survey and review of literature. It was found that these factors influence water abstraction and water use in various ways.

4.4.1 Kiama Sub basin

In Kiama sub basin, 42% of the respondents indicated that the main reason for water abstraction was to obtain water in order to improve crop yields and income from the farm. Water abstraction is also done in order to improve crop productivity through supplementary irrigation which accounted for 17% of the reasons given by respondents. About 27% of the respondents noted that they abstract water for domestic uses and 12% noted that they abstract river water due to reduction in rainfall which has made rainfed agriculture unsustainable in the recent past. There is a significant seasonal variation in the volume of water abstracted from Kiama River. The periods for the maximum water volume abstraction (ranging from 16,000 litres per day to 19,000 litres per day) are mainly in the dry periods between the months of June and September and also the period between December and February. The periods of the lowest water volume abstractions (<16,000 litres per day) are mainly the rainy season months of March-May and October-November. The low water abstraction in the period March- May and October-November could be attributed to the fact that during long rains and short rains there is adequate water to support early growth of crops and also for the users. After May, water abstraction volume increases again and hits peak in August-September during the dry season. During this period, the water level in the river declines significantly due to over abstraction.

In Kiama sub basin, majority of people abstract water from the sub basin for domestic uses (38%). This was mostly attributed to the fact that most people do not have piped water supply in their homes. It was also found out that 34% of the respondents abstract water from the sub basin for irrigation. This can be attributed to the fact that most of the respondents in the study area are farmers. The increased abstraction of water could also be attributed to the fact that the rainfall patterns have changed in the last 20 years. About 13% of the respondents indicated that they abstract water for dairy farming, 11% for business use while 4% is abstracted for commercial purpose by water vendors. The results of the study showed that a significant number of respondents (47%) use 20 litre buckets or jerricans to abstract water from this sub basin. Descriptive statistics showed that the mode, mean and median for water abstraction technology used was 1, the code for buckets and jerricans in the analysis. This could be attributed to the fact that most of the farms are small in size and thus farmers can simply irrigate their farms by drawing water from the river using buckets. It could also be attributed to the fact that buckets are relatively cheap to acquire and easy to use in abstracting water. The study established that 32% of respondents indicated that they use water pumps, 14% use diversion canals or weirs while 7% use siphons. Most of the respondents who use water pumps have considerably large farms that need more water for irrigation and abstract upto 40,000 litres of water per day. These results are consistent with Adeoti (2009) who established that adoption of improved irrigation technologies in developing countries is mostly dependent on the income of the farmer. Similarly, Jansen and Schulz (2006) noted that farmer's income is the main determinant of the water technology used in irrigation and water management processes in the farm.

An attempt was made to determine the extent to which educational level influence how people abstract water in the sub basin. It was found that the level of education plays an important role in determining who engages in water abstraction in the sub basin. The number of respondents with college and university education in Kiama sub basin was 28% and 4%, respectively. About 68 % of the respondents who are the majority of respondents have only obtained secondary school education. The fact that majority of the respondents have low level of education could be the reason why most of the respondents are engaged in farming activities since they cannot secure formal employment. The main occupation of 49% of the respondents is farming and only 20% of the respondents are engaged in business while teaching, informal sector, civil service and county government employ 8%, 8%, 10% and 5%, respectively. The high number of respondents engaged in farming activities could therefore be attributed to low education levels. These results are consistent with Chebil *et al.* (2012) who established that educational level had a significant influence on the water use efficiency of the farmer. The study noted that farmers with higher education qualification were more likely to practice water conservation and management practices thus abstracting less water than the uneducated farmers. Similarly, Alufah, (2010); Rockaway *et al.* (2011); Getacher *et al.* (2014) established that education enables farmers to adopt suitable water management practices to reduce irrigation water usage. In addition, Rockaway *et al.* (2011) noted that educational qualifications contributed to sustainable water abstraction and prudent decision making to reduce irrigation water. In this sub basin, 67% of the respondents who are employed earn between Kshs 5000-15,000. These low-income levels have driven some of those employed in formal sector to water abstraction since what they earn is not enough to cater for their needs.

4.4.2 Thika sub basin

In Thika sub basin, 52% of the respondents in the sub basin indicated that the main reason for water abstraction was to obtain water in order to improve crop yields and income from the farm. Water abstraction is also done to improve crop production through supplementary irrigation which accounted for 35% of the reasons given by the respondents. About 10% and 3% noted that they abstract water from the river due to reduction in rainfall which has made rainfed agriculture unsustainable and for domestic uses, respectively. There are significant seasonal variations in the volume of water abstracted from Thika River. The periods for maximum water volume abstraction (ranging from 16,000 litres per day to 22,000 litres per day) are between August-September and December-January while March-May and October-November are the periods of the lowest water volume abstractions (<16,000 litres per day). The low water abstraction in the period between March- May and October-November could be attributed to the onset of long rains and short rains in those periods, respectively, which support early growth of crops. After May, water abstraction volume increases again and hits peak in August-September. Water abstraction volume is highest in the dry season (August-September). During this period, there is a significant decline in river water level attributed to over abstraction. In this sub basin, 80% of the respondents indicated that they abstract water from the river for domestic and irrigation uses. Increase in water abstraction for irrigation could be attributed to the changing rainfall patterns in the last 20 years (See also Gibelin and Deque, 2003; Sanchez *et al,* 2004). In addition, the increased water abstraction for irrigation could be attributed to the fact that increase in water abstraction leads to increase in crop yields while water abstraction for domestic use could have increased because most of the respondents do not have supply of piped water in their homes.

It was established that, 46% of the respondents in this sub basin use 20 litres buckets or jerricans to abstract water from the river. This could be due to the fact that buckets and jerricans are cheap to acquire, easy to use and readily available. It is also convenient for the small farms. 30% of the respondents use diversion canals or weirs. These are common in farms that are nearest to the river since the canal can easily direct water into the farm through gravity. Water pumps were used by 15% of the respondents. These are common with large farms or institutions such as schools and tea factories since they can pump huge amounts upto 4000 litres/day required in those areas. The pumps are also expensive to maintain for the smaller farms. These findings are consistent with Mwadini (2018) who established that farmers in Kiladeda sub basin, Tanzania relied on plastic buckets and diversion canals to abstract water for irrigation from the river. Diversion canals or furrows were common among farmers licensed to abstract water from the sub basin while plastic buckets were used by the unlicensed farmers. Similarly, Wagnew (2004) noted that diversion canals or furrows were a common irrigation water abstraction technology in Awash River, Ethiopia. This is also in agreement with Mattias (2010) who noted that farmers in the Kilimajaro region used diversion canals to abstract irrigation water.

In Thika sub basin, 22% of the respondents indicated that they had only attained primary school education while 35% had attained secondary education. Thus, they have to engage in water abstraction in order to get more crop yields from their farms since they cannot qualify for any formal employment. 26% and 17% of the respondents indicated that they have attained college and university education, respectively. For occupation, 11% of the respondents indicated that they were employed by the county government, 10% were civil servants while 3% were teachers. Only 3% of the respondents have ventured in business. Of respondents who are employed, 85% earn between Kshs 5000 and 20000 per month. This is a rather low income which could be another reason why most of the respondents who were employed were also farming to supplement this low income (MCIDP, 2018).

4.4.3 Kimakia sub basin

In Kimakia sub basin, 47% of the respondents indicated that their main reason for water abstraction was to obtain water in order to improve yields and income from the farm. Water abstraction is also done in order to improve crop productivity through supplementary irrigation which accounted for 38% of the reasons given by respondents. About 8% of the respondents noted that they abstract water for domestic uses and 7% noted that they abstracted water from the river due to the unreliable nature of rainfall in the recent past. There is a significant seasonal variation in the volume of water abstracted from Kimakia River. The periods for the maximum water volume abstraction (ranging from 13,000 litres per day to 14,000 litres per day) are between June and September and also the period between December and February. The periods of the lowest water volume abstractions (<9,000 litres per day) are between March and May and between October and November. The low water abstraction in the period between March and May and between October and November could be attributed to the onset of long rains and short rains in those periods respectively. It was established that 38% of the respondents in Kimakia sub basin indicated that they use the abstracted water for irrigation while 37% use abstracted water for domestically. This can be attributed to the inadequate piped water supply in most of the households in the sub basin. The increase in water abstraction for irrigation is attributed to the fact that most of the people in the sub basin are farmers. It was noted that 22% of the respondents abstract water for commercial uses while 3% abstract water for dairy farming.

In this sub basin, 46% of the respondents indicated that they use 20 litre buckets or jerricans to abstract water from the river. This could be attributed to the fact that buckets and jerricans are cheap to acquire and easy to use. About 37% of respondents use diversion canals or furrows. These canals are mostly common in farms that are near the river since it easy to direct water into the farms from the river through gravity. Only 17% of the respondents use water pumps to abstract water from the river. The water pumps are mainly used by the people with large farms or institutions that need high water volumes of upto 4000 litres/day. These results are consistent with Mwadini (2018) who noted that farmers in Kiladeda sub basin relied on buckets and diversion canals/furrows to abstract irrigation water from the basin. Kossa *et al.* (2014) established that the main water abstraction technologies in Mkoji sub catchment were both traditional and modern. The traditional abstraction technologies were the most common among farmers since they were constructed using locally available materials such as gunny bags, wooden poles, stones and clay soils.

In Kimakia sub basin, the number of respondents with college and university education was 19% and 10% respectively while 52% of the respondents are secondary school drop outs. Thus, most of the respondents are not able to secure any form of formal employment. This is why most of them have turned to water abstraction in order to irrigate their farmers for better crop yields and income. The study established that 61% of the respondents engage in farming activities, 14% are employed by county government 14% while 6% work in the civil service. About 19% of the respondents have ventured in self employment activities such as business 8% and informal sector. 70% of those employed earn between Kshs 5000-20000 per month. This low income could be the reason why most of the employed respondents also engage in farming. Thus, there is an insignificant difference between water abstraction among the employed and unemployed. These findings are consistent with IUCN (2009) who established that the low income of the people drove them to other activities such as businesses to supplement their incomes. This is also in agreement with Adeoti (2009) who noted that there was a positive relationship between water abstraction and farmers income in Ghana. The results agree with Jansen and Schulz (2006) who noted that the income of the farmer was the main determinant of water consumption and irrigation water demand.

4.4.4 Chania sub basin

In Chania sub basin, 39% of the respondents indicated that their main reason for water abstraction was to obtain water in order to improve crop yields and income from the farm.

Water abstraction is also done to improve crop production through supplementary irrigation which accounted for 23% of the reasons given by the respondents. About 16% and 22% noted that they abstract water from the river due to reduction in rainfall which has made rainfed agriculture unsustainable in the recent past and for domestic uses, respectively. There is a significant seasonal variation in the volume of water abstracted from Chania River. The periods for the maximum water volume abstraction (ranging from 12,000 litres per day to 13,000 litres per day) are mainly in the dry months of June and September and also the period between December and February. The periods of the lowest water volume abstractions (<12,000 litres per day) are March-May and October-November. The low water abstraction in March- May and October-November could be attributed to the onset of long rains and short rains in those periods respectively. After May, water abstraction volume increases again and hits peak in August-September during the dry season. During this period, the water level in the river declines significantly due to over-abstraction.

In Chania sub basin, majority of the respondents abstract water from the river for domestic use and irrigation, 50% and 47%, respectively. Increased abstractions for domestic use could be attributed to the fact that most of the households either lack adequate supply of piped or are not connected to the same while the reason for increased water abstraction for irrigation could be linked to the fact that most of the respondents in the study area are farmers (See also AWSB, 2015). The respondents in this sub basin who use 20 litre buckets or jerricans to abstract water from the river were 36% while 34% use water pumps. Buckets and jerricans are common because they are cheap to acquire and easy to use. Water pumps are commonly used by the tea factories and large farms that require a lot of water of upto 40,000 litres/day. Diversion canals and pipes contribute 30% of water abstraction technologies.

In this sub basin, the number of respondents with college education was only 22%. The majority of the respondents 61% and 17% are secondary school and primary school drop outs respectively. The high number of respondents with low education qualifications could be the main reason why there are high water abstraction rates in the area since they mostly rely on farming. These findings are in agreement with Chebil *et al.* (2012), who noted that higher educational qualification enabled farmers manage and conserve water resources thus, abstracting less water than the uneducated. Getacher *et al.* (2014) established that educational level of the farmer is crucial in determining the water abstraction and management practices that the farmer will adopt. Similarly, Rockaway *et al.* (2011) noted that farmer's educational qualification contributes to sustainable water abstraction. 67% of the respondents in the study area earn between Kshs 5000-25000 per month. This low income could be the reason why most of the employed respondents also engage in farming. Thus, there is an insignificant difference between water abstraction among the employed and unemployed.

4.4.5 Comparison of the influence of education, occupation and technology on water uses and water abstraction in the basins

With regard to the influence of educational level, it was found that majority of the respondents had low levels of education as the results showed that 69% of the respondents have primary (15%) and secondary education (54%). This low level of education could be the main reason why people have engaged in activities that lead to increased water abstractions in the four sub basins. The low level of education means that most people cannot secure formal employment. Thus, they have to rely on farming as the sole source of livelihood. The inadequate education level also means that most of the respondents are not aware of the possible impacts of water abstraction and therefore, they abstract water without any consideration to the likely impacts of those abstractions. It was established that 24% of the respondents have attained college level education qualification while 8% have University level qualifications. Most of the respondents with high education levels are employed. Their high-income levels allow them to abstract a lot of water (up to 4000 litre/day) since they can afford expensive water abstraction technologies as well large tracts of land. This is consistent with Chebil *et al.* (2012) who noted that the educational qualification of the farmer has a significant influence on their water use efficiency. Farmers with higher education levels are more likely to make better water management and conservation decisions than uneducated farmers. Alufah (2010) and Getacher *et al.* (2014) established that the farmers educational level determines the ability of the farmer to adopt suitable water management practices to reduce irrigation water demand. This is also in agreement with Rockaway *et al.* (2011) who noted that educational level of the farmer contributes to sustainable water abstraction practices and better decision making to reduce irrigation water use.

The results showed that 50% of the respondents in the four sub basins are farmers with the majority (69%) having only primary and secondary education. This means, majority of the people cannot secure formal employment and have to depend on farming. The unreliability of rainfall has meant that rainfed agriculture is no longer sustainable and hence most of the people have resorted to irrigation agriculture to boost their crop production. The high percentage of respondents practicing irrigation agriculture in the area could also be the main reason why there is a high abstraction rate in the area. It was also established that 12% of the respondents operate businesses in the local markets, 9% are employed by the county government, 8% in informal sector and civil service while 6% are teaching (Table 4.2). These categories of people are able to invest in water abstraction technologies and hence pump more water from the river.

Table 4.2: Occupation of respondents in South West Upper Tana Basin

Sub-basin	**Occupation/Percentage (%)**					
	Farming	**Teaching**	**Business**	**Informal Sector**	**Civil Service**	**County Government**
Chania	57	11	14	4	7	7
Thika	63	3	8	5	10	11
Kimakia	61		8	11	6	14
Kiama	49	8	20	8	10	5

With regard to the influence of income levels on water abstraction, it was noted that 74% of the respondents earn between Kshs 5,000 and 20,000 per month. Only 4% of the respondents earn above Kshs 30, 000 per month (Table 4.3). This low-income level has driven most of the people in the study area to irrigation farming to supplement their incomes. The high-income earners are also involved in water abstraction in the study area but these form only 4% of the total population. These are the people who abstract high volumes (up to 40,000 litres/day) of water since they have enough income to put many acres under irrigation and also employ modern water abstraction technologies such as the use of electric or petrol water pumps (Plate 4.1). The main reasons of water abstraction were found to be; to improve yields from the farms, supplement piped water and irrigation due to the unreliable rainfall in the sub basin (Figure 4.22). The period of maximum water abstraction is between June and October and also between December and March. During these periods, water abstraction ranges from 10,000 litres per day to 22,000 litres per day. The maximum abstraction rate is usually in the months of August and September when water abstraction volume reaches 22,000 litres per day.

Plate 4.1: Water abstraction with a water pump in Kiama sub basin for irrigation

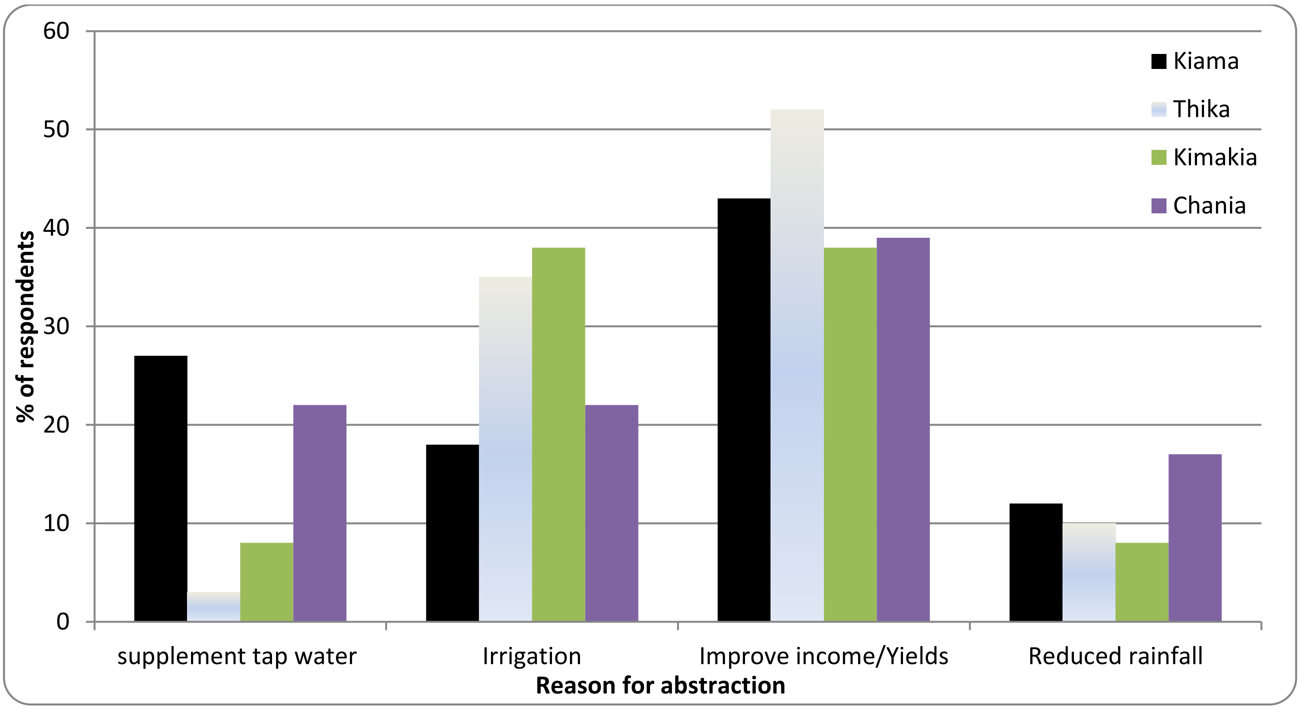

Figure 4.21: Comparison on reasons for water abstraction in Kiama, Thika, Kimakia and Thika Sub basins in 2018

Attempt was made to determine how water abstracted from the four rivers is used in the South West Upper Tana Basin. It was found out that water abstracted in the four sub basins is utilized in different ways. The volume of water abstracted daily differs depending on each use. The results of the study showed that the dominant use of water abstracted from the four rivers in the study area is for irrigation (range 34-50%; mean 40.25%), domestic use (range 37-47%; mean 40.5), and commercial/business (range 3-14%; mean 8.25%). It was noted that dairy farming and water vending is rather limited (Table 4.4). The results of the study showed that irrigation agriculture in the four sub basins uses between 1000 and 4000 litres of water per hectare. The total water abstraction for irrigation agriculture is 611,809.66 litres per month while the total water abstraction for commercial purpose is 125,401.98 litres per month. The total volume of water abstracted for domestic uses was estimated to be 20,520.32 litres per day. The per capita water consumption for the South West Upper Tana Basin is 150 litres/person/day (See also AWSB, 2015).

Table 4.3: Income levels for respondents in Chania, Kimakia, Thika and Kiama Sub basins

Sub basin	**Income level (Kshs)/Percentage (%)**					
	5001-10,000	**10,001-15,000**	**15,001-20,000**	**20,001-25,000**	**25,001-30,000**	**Above 30,001**
Chania	43	14	10	14	19	
Kiama	33	34	8		17	8
Thika	10	63	12	8	2	5
Kimakia	10	10	50	10	13	7

Table 4.4: Main uses of water in Kiama, Kimakia, Chania and Thika sub basins

Sub basin	**Water use / Percentage**				
	Irrigation	**Domestic**	**Business**	**Dairy**	**Water Vending**
Kiama	34	38	11	13	4
Thika	40	40	5	15	
Kimakia	37	37	14	3	9
Chania	50	47	3		
Mean	40.25	40.5	8.25	7.75	3.25

The main technologies used in water abstraction in the South West Upper Tana Basin are buckets, diversion canals, pumps and pipes. Water abstracted from the four rivers is mainly used for irrigation and domestic uses (81%). Changes in rainfall patterns and desire to obtain higher incomes from the farms have led farmers to increase in water abstraction from the rivers. Water abstraction for domestic uses has also increased due to the fact that many homes are not connected to piped water supply and even the ones connected receive inadequate supply. The study established that 8% of the respondents abstract water for their businesses, 8% for dairy farming while 3% of water is abstracted by water vendors. It was established that buckets form 40% of the water abstraction the main water abstraction technologies in the four sub basins. One of the reasons why buckets are common with the respondents is because they are cheap to acquire and also easy to use. In addition, most of the farmers have small plots (<1 ha) of land that can easily be irrigated using the bucket. 26% of the respondents use diversion canals or weirs constructed across rivers. Diversion canals are cheap to use but they require silt removal after the rainy season. Water pumps are also common with 25% of the respondents using them while only 8% use pipes to abstract water from the rivers. Those using water pumps are the ones with more income that can enable them to buy and maintain the pump (see also Wagnew, 2004; Mattias, 2010; Kossa *et. al*, 2014; Mwadini, 2018).

Table 4.5: Water abstraction technologies in Kiama, Kimakia, Chania and Thika Sub basins

Sub-basins	Buckets	Diversion canal	Water pumps	Pipes
Kiama	47	14	32	7
Thika	46	30	15	9
Kimakia	37	46	17	
Chania	35	15	35	15
Mean	41.25	26.25	24.75	7.75

4.5 The effectiveness of licensing and monitoring in controlling water abstraction

The effectiveness of regulatory measures in controlling water abstraction in the SWUT Basin was determined through analysis of responses on the existing licensing and monitoring arrangements. Licensing for water abstraction is normally done by Water Resources Authority (WRA). By 2019, a total of 10,000 farmers had been licensed by WRA to abstract water from the four rivers. However, this is just 10% of the total number of farmers abstracting water from the rivers. The level of illegal abstractions is high and more than 90% of the farmers abstracting water in the four sub basins do it illegally as they are not licensed by WRA (See also Ericksen *et al.*, 2011).

4.5.1 Kiama sub basin

In Kiama sub basin, it was established that, 98% of the water abstractions are done without licenses from WRA. Only 2% of the respondents are licensed by WRA to abstract water from the basin. These are mainly the large institutions and farms including tea factories.

Table 4.6: Streamflow and Water abstraction rates in Kiama Sub Basin

S. No	Water Uses	Daily Water Abstraction rate (Litres/day)	Monthly water abstraction rate (Litres/Month)	Abstraction as percentage of flow	Abstraction as percentage of dry season flow
1.	Agricultural (Irrigation)	123,713,000	371,139,000	35	41
2.	Industrial (Tea, coffee mills)	2,010,000	60,300,000	0.56	6.56
3.	Rural water supply	13,910,940	417,328,200	3.94	9.94
4.	Urban water supply	50,934,000	1,528,020,000	14.41	20.41
5.	Household/Direct abstraction	1,500,000	45,000,000	0.42	6.42
6.	Livestock Watering	1,095	32,850	0.0003	6.0003
	Total Abstraction Rate	192,069,035	5,762,071,050	54.33	90.33
	Mean flow	355,683,398			
	Mean Dry season flow	34,750,268			

Source: WRA; Mwendwa 2019

In addition, there is poor monitoring by National Environment Management Authority (NEMA) and Water Resources Authority (WRA). Some of the respondents do farming in the riparian land thus interfering with the riparian vegetation as well as flow of the river. The poor monitoring of water abstractions in Kiama sub basin has led to increased water abstraction rates which subsequently reduce the streamflow flow levels in dry season (Table 4.6). The dry season flow is only 9.7 % since 90.3% of the water is abstracted during this season.

4.5.2 Thika sub basin

In Thika sub basin, 96% of water abstractors are not licensed by WRA. These are the small diversions which may seem to cause very minimal effect to the flow of the river. However, the cumulative impacts of these diversions can be far reaching. In addition, there is no control of the specific volume that one is allowed to abstract each day. Only 4% of abstractors are licensed. The monitoring of the abstractions was found to be poor if any. NEMA and WRA officers rarely visit this area to monitor the effects of diversions. This could be the reason why the farming activities extend up to riparian land that should be left uncultivated.

Poor licensing and monitoring by WRA have also increased water abstractions especially in dry season where 89.31% of the streamflow is abstracted (Table 4.7). Irrigation agriculture is the main reason why people abstract water from the sub basin, with the percentage increasing to 26.63% during the dry season while water abstraction for urban water supply contributes to 26.07% of the total dry season water abstraction.

Table 4.7: Streamflow and Water abstraction rates in Thika Basin

S. No	Water Uses	Daily Water Abstraction rate (Litres/day)	Monthly water abstraction rate (Litres/Month)	Abstraction as percentage of flow	Abstraction as percentage of dry season flow
1.	Agricultural (Irrigation)	503,792,960	151,137,888,000	17.63	26.63
2.	Industrial (Tea, coffee mills)	9,757,290	292,718,700	0.34	9.34
3.	Rural water supply	5,453,200	163,596,000	0.19	9.19
4.	Urban water supply	487,700,000	146,310,000,000	17.07	26.07
5.	Household/Direct abstraction	2,302,243	69,067,290	0.08	9.08
6.	Livestock Watering	1,400	42,000	0.000049	9.000049
	Total Abstraction Rate	10,090,070,900	30,270,212,700	35.31	89.31
	Mean flow	28,828,774,000			
	Mean Dry season flow	3,171,165,140			

Source: WRA; Mwendwa 2019

4.5.3 Kimakia sub basin

In Kimakia sub basin, 96% of the water abstractors are not licensed by WRA. These are mainly small scale farmers who abstract water for farming, domestic use, commercial, dairy farming or by water vendors. In addition, there is no specific volume that farmers are allowed to abstract each day. However, only 4% of abstractions are licensed to abstract water in this sub basin (Table 4.8).

Table 4.8: Streamflow and Water abstraction rates in Kimakia Sub Basin

S. No	Water Uses	Daily Water Abstraction rate (Litres/day)	Monthly water abstraction rate (Litres/Month)	Abstraction as percentage of flow	Abstraction as percentage of dry season flow
1.	Agricultural (Irrigation)	230,971,000	692,913,000	30	37
2.	Industrial (Tea, coffee mills)	0	0	0	0
3.	Rural water supply	16,636,360	499,090,800	2.16	15.12
4.	Urban water supply	42,323,000	1,269,690,000	5.5	12.5
5.	Household/Direct abstraction	1,620,560	498,616,800	0.21	7.21
6.	Livestock Watering	1,145	1,145,000	0.00015	7.00015
	Total Abstraction Rate	253,461,365	7,603,840,950	37.87	78.83
	Mean flow	669,293,280			
	Mean Dry season flow	141,689,387			

Source: WRA; Mwendwa, 2019

The main abstractors who are licensed by WRA in this sub basin are the Nairobi Water and Sewerage Company (NWSC) at Gatura and Ngethu treatment plant. There is also another diversion by Gatanga Community Water at Kimakia forest for the supply of households in Gatanga Sub County. There is poor monitoring of these diversions by authorities such as NEMA and WRA. Poor licensing and monitoring of water abstractions have increased the rates of water abstraction in the sub basin which subsequently affects dry season flow. There are extremely low streamflows during dry season since 78.83% of the total streamflow is abstracted during the dry season (Table 4.8).

4.5.4 Chania sub basin

In Chania sub basin, 97% of the water abstractors are not licensed by WRA. 97% of the abstractions are done without licensing. These are mostly the small-scale abstractions which may to be inconsequential on the flow of the river but have far reaching impacts in the long run.

Table 4.9: Streamflow and Water abstraction rates in Chania Sub Basin

S. No	Water Uses	Daily Water Abstraction rate (Litres/day)	Monthly water abstraction rate (Litres/Month)	Abstraction as percentage of flow	Abstraction as percentage of dry season flow
1.	Agricultural (Irrigation)	303,857,000	9,115,710,000	33	41
2.	Industrial (Tea, coffee mills)	2,229,090	66,872,700	0.25	8.25
3.	Rural water supply	2,166,000	64,980,000	0.24	8.24
4.	Urban water supply	60,114,000	1,803,420,000	6.61	14.61
5.	Household/Direct abstraction	1,901,343	57,040,290	0.21	8.21
6.	Livestock Watering	1,245	37,350	0.00014	8.00014
	Total Abstraction Rate	370,268,678	9,304,640,340	40.31	88.31
	Mean flow	918,270,102			
	Mean Dry season flow	107,345,775			

Source: WRA; Mwendwa, 2019

Figure 4.9 above shows that about 88.31% of the streamflow is abstracted during the dry season. Of the water abstractions, 41% is used for irrigation agriculture licensing and monitoring of these diversions were found to be poor hence the increased water abstractions in the sub basin which subsequently leads to extremely low streamflows in the dry season. NEMA and WRA officers rarely visit this area to monitor the effects of river diversions. Only 3% of abstractors are licensed and they include the diversion at Ririndia for the KTDA power plant and the Water treatment plant at Ngethu.

4.5.5 Comparison on Licensing and monitoring in the four sub basins

The results of the study showed that 97% of water abstractors are not licensed by Water Resources Authority (WRA). Therefore, most people abstract water illegally. Abstractions that are unlicensed are mainly the small-scale diversions that seem to have little impacts on the rivers. The 3% of the abstractions that are licensed are mainly those done by KTDA at Ririndia, Gatanga Community Water, Athi Water and Services Board, Nairobi City Water and Sanitation Company and a few individuals who abstract water for irrigation and domestic uses.

Table 4.10: Streamflow and Water abstraction rates in SWUT Basin

S. No	Water Uses	Daily Water Abstraction rate (Litres/day)	Monthly water abstraction rate (Litres/Month)	Abstraction as percentage of flow	Abstraction as percentage of dry season flow
1.	Agricultural (Irrigation)	1,050,992,260	31,529,767,800	28.9	36.41
2.	Industrial (Tea, coffee mills)	13,996,380	419,891,400	0.29	6.04
3.	Rural water supply	38,166,500	1,084,995,000	1.63	10.62
4.	Urban water supply	641,071,000	19,232,130,000	10.9	18.4
5.	Household/Direct abstraction	7,324,146	219,724,380	0.23	7.73
6.	Livestock Watering	4,885	146,550	0.00016	7.5
	Total Abstraction Rate	1,751,555,170	52,546,655,100	41.95	86.7
	Mean flow	30,772,020,800	923,160,624,000		
	Mean Dry season flow	3,454,950,570	103,648,517,000		

Source: WRA; Mwendwa, 2019

In addition, monitoring of these diversions is also poor. Poor monitoring by both WRA and NEMA was attributed to lack of capacity among the institutions. NEMA and WRA officers in Murang'a County are under-capacitated in terms of personnel, finances and transport. The poor licensing and monitoring have led to increased water abstractions in the dry season. 86.7% of the streamflow is abstracted during the dry season leading to extremely low flows during this period (Table 4.10). The results also agree with Bekele (2013) who observed that weak enforcement and implementation of regulations of water abstraction was weak in Ethiopia.

4.6 The influence of agricultural practices on water abstraction

Attempt was made in this study to determine the extent to which agricultural practices influence water abstraction in the study area. As was noted in the earlier sections, majority of water abstractions are for irrigation agriculture. It is therefore important to unravel the agricultural practices that impact on water abstraction in the study area. The study established that farmers with higher acreage of land under irrigation obtain more crop yields than those with smaller plots. The income realized from the sale of crops is mainly used to pay school fees, sustain the family, investments and grow business. It was established that most farmers sell their crops during the dry season periods (December and March) and also in the period between (June and September) (See also AWSB, 2015).

Most of the respondents noted that without water abstraction from the rivers, they would not be able to obtain high crop yields from their farms due to unreliability of rainfall. It was noted that in the recent past rainfall in the study area has become more unreliable for sustaining rainfed agriculture. Larger farm sizes require more river water for irrigation, thus farmers with large farms abstract more water than those with smaller farms (see also Gichuki *et al.*,1998; Ericksen, 2011). There are a variety of crops in the study area. Most of these crops rely on irrigation because of the changing rain patterns in the area. It was established that, 90% of the farmers grow cabbages as the main crop grown under irrigation. Other types of crops that are irrigated are onions, kales, tomatoes, carrots and maize. In areas where coffee was found to be the dominant crop, there was no evidence of irrigation of the crop using river water.

4.6.1. Kiama sub basin

In Kiama sub basin, most of the respondents have small plots of land with their sizes ranging between 0.5 and 3 acres (See also Onduru and Muchena, 2011). These small plots could be attributed to the increased land sub division which has been occasioned by increased population in the area. The main crop grown in the sub basin is cabbage which covers a total area of 24 acres. Other crops grown in the area are tomatoes (6.78 acres), maize (5.65 acres), potatoes (3.39 acres), kales (3.39 acres) and beans (1.13 acres). These horticultural crops mainly rely on irrigation using water abstracted from the river. Tea (8 acres) is another major crop in the study area but there was no evidence of irrigation of the tea plantations (See also MCDIP, 2014; AWSB, 2015).

An attempt was made to determine why farmers have resorted to irrigation agriculture. Farmers noted that through irrigation, they are able to produce high crop yields and therefore the sales increase. The crop sales increase as water abstraction rate increases. There is concentration of low crop sales and low water abstraction. The highest crop sales >200,000 Kshs and water abstraction > 2000 litres per day are limited. The maximum water abstraction and crop sales were Kshs 500,000 and 3000 litres respectively while minimum crop sales and water abstraction were Kshs 2000 and 100 litres respectively. This shows that the higher the water abstractions the higher the crop production and sales in the sub basin. The relationship between water abstraction and crop sales yielded a simple linear regression coefficient r of 0.62 and a coefficient of determination R^2 of 0.57 (Figure 4.23). These results show that the volume of water abstracted could explain 57% of the variations in crop production and sales in Kiama sub basin. The rest of the variability in crop production and sales could be attributed to other factors such as the application of fertilizers, size of farm and the market where the crop is sold.

Moreover, the high crop sales are realized by farmers with higher acreage of land under irrigation. An increase in the area under irrigation provides the farmers more freedom to cultivate different types of crops and therefore obtain more yields and subsequently more sales. The results show that 40% of the respondents noted have benefited from improved crop yields due to water abstraction. The benefits are in terms of obtaining more money to pay school fees for their children. About 35% of the income realized from the crop sales are used to maintain the family, 15% used to grow business while 10% is used for other investments or savings.

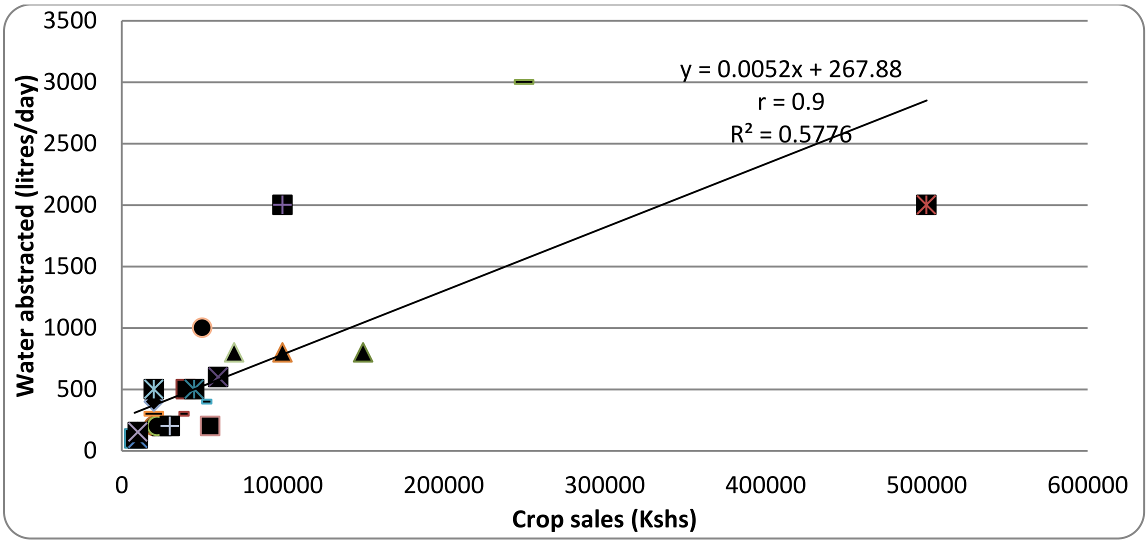

Figure 4.22: Relationship between crop sales and water abstraction in Kiama sub basin in 2018

Attempt was made to determine the extent to which trading patterns influence irrigation agriculture and water abstraction. It was found that 49% of the farmers sell their produce in the local markets, to middle men who buy from the farms or within the County. However, there are also other farmers who sell their produce in major urban areas such as Thika (15%) and Nairobi (6%) while others sell to other Counties such as Machakos, Makueni, Mombasa, Kitui and Nakuru. It was also established that 15% of the crop produce is supplied to schools. Therefore, both local and national trading patterns could be considered to be important drivers of water abstraction in the SWUT basin. Most of the farmers obtain the best sales during the dry season (67%) or the period between August and September. December holidays (25%) also presents a good opportunity to the farmers to obtain good value for their crops. Respondents who sell their produce to schools obtain the best sales when schools open. This study also established that 52% of the respondents in Kiama sub basin did not have an alternative livelihood apart from farming. Most of the people are operating below poverty line and hence they have no choice but to abstract river water for irrigation in order to boost crop production.

The main type of fertilizer applied by farmers in irrigation farming was found to be DAP. The mean application rate was 146 Kgs per hectare. The increased use of fertilizer in irrigated farms could be attributed to reduced soil fertility due to over cultivation of land. The application of nitrogen and phosphorous rich fertilizers is not controlled leading to high volume of fertiliser residues that end up in the river during rainy season. These normally accumulate in the river causing eutrophic conditions evidenced by change of colour of river water, from clear to green, due to high concentrations of green algae (chlorophyta) (WHO/EU, 2002). This is common in the months of September near the outlet of the river from Ndakaini dam.

4.6.2 Thika sub basin

The study established that, in the Thika sub basin majority of the farms are of the size one (1) acre or less. This was attributed to increased land sub division occasioned by rapid population growth. Therefore, population increase could be considered to be another important factor driving water abstraction. Cabbage is the main irrigated crop in the study area covering a total of 24.86 acres. Kales (11 acres), maize (10.17 acres), tomatoes (2.3 acres) and carrots (2.26) are also major crops in the study area. Farming of these crops is mainly sustained by water abstracted from the river. Tea is another main crop in the study area. However, tea mainly relies on rainfall and does not require irrigation like the other horticultural crops in this sub basin.

There is a significant relationship between water abstraction and crop sales in Thika sub basin. Crop sales increase with increase in water abstraction rate. There is concentration of low crop sales and low water abstraction. The highest crop sales >Kshs. 250,000 and water abstraction > 3000 litres per day are limited. The maximum water abstraction and crop sales were Kshs 400,000 and 4000 litres, respectively while minimum crop sales and water abstraction were Kshs 5000 and 100 litres respectively. This shows that the higher the abstractions the higher the crop sales in the sub basin. The relationship between water abstraction volumes and crop yielded a correlation coefficient r of 0.79 and a coefficient of determination R^2 of 0.68 (Figure 4.23).

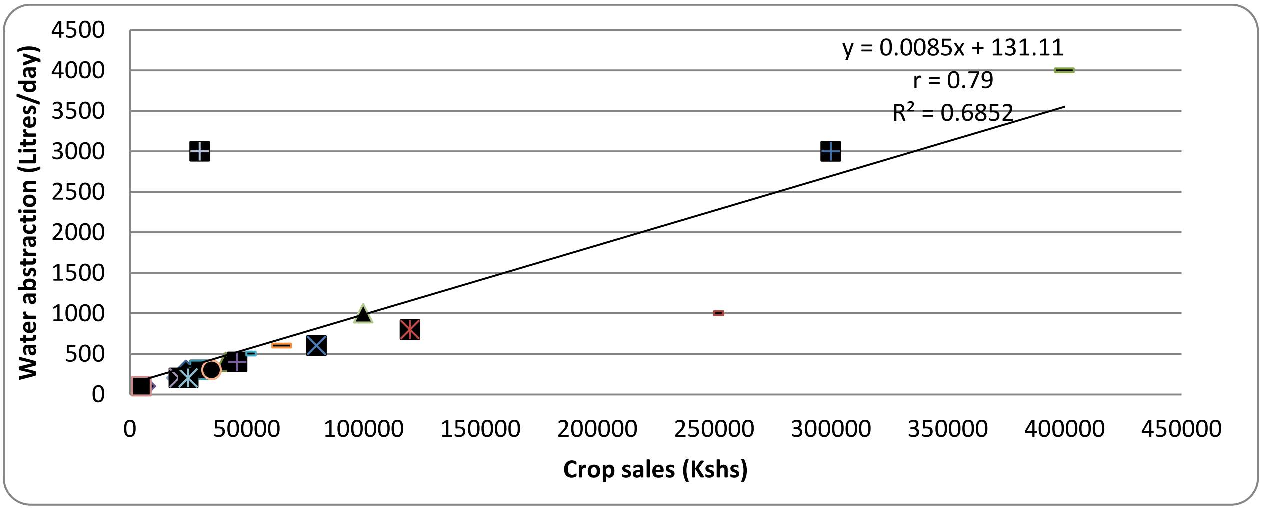

Figure 4.23: Relationship between crop sales and water abstraction in Thika sub basin in 2018

These results show that volume of water abstracted could explain 68% of the variations in crop production and sales. The rest of the variability in crop sales could be attributed to other factors such as the application of fertilizers, size of farm and the market where the crop is sold. In addition, the high crop sales are realized by farmers with higher acreage of land under irrigation which drives them to abstracting more water from the river. An increase in the area under irrigation provides the farmer with more freedom to cultivate different types of crops and therefore obtain more crop yields and subsequently more sales.

The results showed that 43% of the respondents had benefited from improved crop yields due to water abstraction. The benefits are in terms of obtaining more money to pay school fees for their children, cater for the needs of their families (37%), and grow their businesses (9%) and for investments or savings (11 %). The main types of fertilizers applied by farmers in irrigation agriculture in Thika sub basin is DAP at the mean of 158 Kgs, CAN at the mean of 87 Kgs, TSP at the mean of 12 Kgs and NPK at the mean of 13 Kgs. The increased use of fertilizers could be attributed to the loss of soil fertility due to overcultivation of land. The application of phosphorous and nitrogen rich fertilizers is not controlled leading to high volume of fertiliser residues that ends up in the river during rainy season. These normally accumulate in the river causing eutrophic conditions evidenced by change of colour of river water, from clear to green, due to high concentrations of green algae (chlorophyta) (Matsui and Takigami, 2001, WHO/EU, 2002).

Attempt was made to determine the extent to which trading patterns influence irrigation agriculture and water abstraction in the sub basin. It was found out that 32% of farmers sell their produce locally or within the county of Murang'a. However, some of the crops are sold in major urban centers such as Thika (20%) and Nairobi (26%). Most of the farmers obtain the best sales for their crops during the dry season or during the months of August and September (80%). This could be attributed to the fact that most of the other farmers who only rely on rainfall do not have good yields in that period. 16% of the farmers indicated that they obtain good prices for their crops during the December holidays. The study also established that 50% of the respondents in the study area did not have an alternative livelihood apart from farming. This could be the reason why there is an increase in water abstraction rates in the area. In addition, those with alternative livelihoods such as employment (32%) and business (18%) also abstract water for farming since those income sources are not enough to fully cater for their family needs.

4.6.3 Kimakia sub basin

In Kimakia sub basin, the mean farm size of the farmers was one (1) acre. The small plots of land could be attributed to the land sub division to accommodate the increasing population in the sub basin. The main crop in the sub basin area is cabbage which covers approximately 16.95 acres. Other main crops grown in this sub basin are maize (8 acres), beans (5 acres), carrots (1.13 Acres), potatoes (2 acres) and kales (2.3 acres). These horticultural crops are grown under irrigation using water abstracted from the river. The other major crop grown in this area is tea (10 Acres) which mainly relies on rainfall rather than irrigation.

An attempt was made to determine why farmers have resorted to irrigation agriculture. Most farmers noted that through irrigation, they are able to produce high crop yields and therefore the crop sales increase. There is a significant relationship between water abstraction and crop sales in Kimakia sub basin. Crop sales in the basin increase as water abstraction rate increases. There is concentration of low crop sales and low water abstraction. The highest crop sales > Kshs 300,000 and water abstraction > 3,000 litres per day are limited. The maximum water abstraction and crop sales were Kshs 400,000 and 4,000 litres respectively while minimum crop sales and water abstraction were Kshs 1,500 and 100 litres respectively. This shows that the higher the abstractions, the higher the crop sales in the sub basin. The relationship between water abstraction volume and crop sales yielded a correlation coefficient r of 0.95 and a coefficient of determination R^2 of 0.93 (Figure 4.24). These results show that volume of water abstracted can explain 93% of the variations in crop production and sales. The rest of the variability in crop sales could be attributed to other factors such as the application of fertilizers, size of farm and the market where the crop is sold. Moreover, the high crop sales are realized by farmers with higher acreage of land under irrigation. This could be attributed to the fact that, increase in the area under irrigation allows the farmer to have more freedom to cultivate different types of crops and therefore obtain more yields and subsequently more sales.

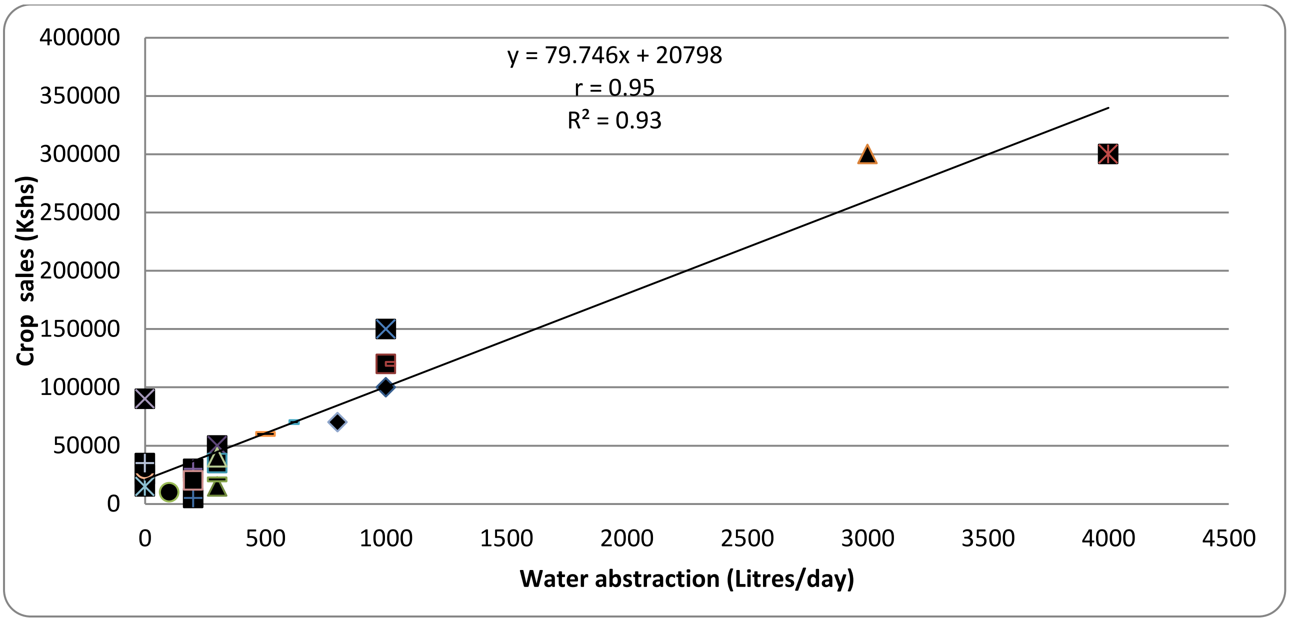

Figure 4.24: Relationship between crop sales and water abstraction in Kimakia sub basin

About 45% of the respondents noted that they had benefited from improved crop yields due to water abstraction. The benefits are in terms of obtaining more money that is used to pay school fees for their children, cater for the family needs (32%) while 13% and 10% of the income is used to start and grow business and investments for future use, respectively. The main type of fertilizer applied by farmers in irrigated farms was found to be DAP with a mean application rate of 128 Kgs per season. The other types of fertilizers used in the study area are CAN (89 Kgs), TSP (15 Kgs) and NPK (13 Kgs). The application of nitrogen and phosphorous rich fertilizers is not controlled leading to high volume of fertiliser residues that ends up in the river during rainy season. These normally accumulate in the river causing eutrophic conditions evidenced by change of colour of river water, from clear to green, due to high concentrations of green algae (chlorophyta) (WHO/EU, 2002).

Attempt was made to determine the extent to which trading patterns influence irrigation agriculture and water abstraction. It was established that 32% of the respondents sell their produce in the markets within the county. However, there is still a significant percentage (30 %) of respondents who sell their produce in major towns such as Nairobi and Thika. About 6% of the produce is sold in other counties, 3% to schools while 12% is exported. Thus, both local and national trade patterns can be considered to be important drivers to water abstraction in this sub basin. This study also established that the best time for crop sales in the sub basin is during the dry season or August to September (76%). This could be attributed to the fact that during this dry period most of the farmers who rely on rain fed agriculture do not have any of the produce to sell. 66% of the respondents do not have an alternative livelihood apart from farming. This leads them to abstracting more water to ensure they get maximum yields from their farms. The few who are employed (17%) also abstract water for farming since they do not earn enough to sustain their families.

4.6.4 Chania sub basin

In Chania sub basin, most of the farmers have small plots of land ranging from 0.5-2 acres. These small sizes of farms could be attributed to the fact that there is high demand for land due to increase in population which has led to land sub divisions. The main crop grown in this sub basin study is cabbages covering approximately 15.82 acres. Other crops grown in this sub basin are pineapples (13 Acres), tomatoes (6.78 Acres), maize (3.39 Acres), potatoes (2.26 Acres), carrots (2 Acres) and Kales (1.1 Acres). These horticultural crops mainly rely on water abstracted from this basin for irrigation. Tea is also a major crop in this area but it mainly relies on rainfall.

An attempt was made to determine why farmers have resorted to irrigation agriculture. Most farmers noted that through irrigation, they are able to produce more crop yields and subsequently more income from crop sales. The crop sales increase as water abstraction rate increases. There is concentration of low crop sales and low water abstraction, <Kshs 50,000 and <500 litres per day respectively. The highest crop sales >Kshs 400,000 Kshs and water abstraction > 2,000 litres per day are limited. The maximum water abstraction and crop sales were Kshs 500,000 and 4,000 litres respectively while minimum crop sales and water abstraction was Kshs 1,000 and 100 litres respectively. This shows that the higher the water abstraction volume, the higher the crop production and crop sales in the sub basin. The relationship between water abstraction volume and crop sales yielded a correlation coefficient r of 0.76 and a coefficient of determination R^2 of 0.68 (Figure 4.25). These results show that volume of water abstracted could explain 68% of the variations in crop production and sales. The rest of the variability in crop sales can be attributed to other reasons such as the application of fertilisers, size of farm and the market where the crop is sold. Moreover, the high crop sales are realized by farmers with higher acreage of land under irrigation. This could be attributed to the fact that, increase in the area under irrigation gives the farmer more freedom to cultivate different types of crops and therefore, obtain more yields and better sales.

Most of the farmers in this sub basin indicated that they had benefited from improved crop yields due to water abstraction. The study established that 42% of the income realized from crop sales is used to pay school fees for the respondents' children. Additionally, 33 % of the income is used to cater for the needs of the respondents' families while 15% is used to grow businesses in the study area. The remaining 10% is used for other investments or saved for future use.

This study established that the small farm sizes in this sub basin led to overcultivation and decreasing soil fertility. The farmers have to apply fertilisers to improve soil fertility. The main types of fertilizers applied by farmers in irrigated agriculture in this sub basin per season are DAP (358 Kgs), CAN (93 Kgs), TSP (20 Kgs) and NPK (16 Kgs). The application of nitrogen and phosphorous rich fertilizers is not controlled leading to high volume of fertiliser residues that ends up in the river during rainy season. These normally accumulate in the river causing eutrophic conditions as evidenced by change of colour of river water, from clear to green, due to high concentrations of green algae (chlorophyta) (Matsui and Takigami, 2001)

An attempt was made to establish the extent to which trading patterns influence agriculture and water abstraction in Chania sub basin. It was found out that 42% of the produce from the farms is sold locally or within Muranga County. The study established that 21% of the respondents sell their crops in Nairobi and Thika while 8% transport the produce to other counties. It was also established that 8% of the produce is sold to the schools in the area. Therefore, both local and national trading patterns have an influence on water abstraction in Chania sub basin. 64% of the farmers in this sub basin realize the best sales during the dry season. This is so because during this period, the only produce in the market is from irrigation since there is no rainfall during this period. This enables the farmers to sell their produce at a higher price than in other times of the year. Farmers also get better sales during December holidays and during the school opening period. The study also established that 71% of the respondents do not have any other source of income apart from farming. These respondents tend to abstract more water from the river to ensure that they get more yields from their farms.

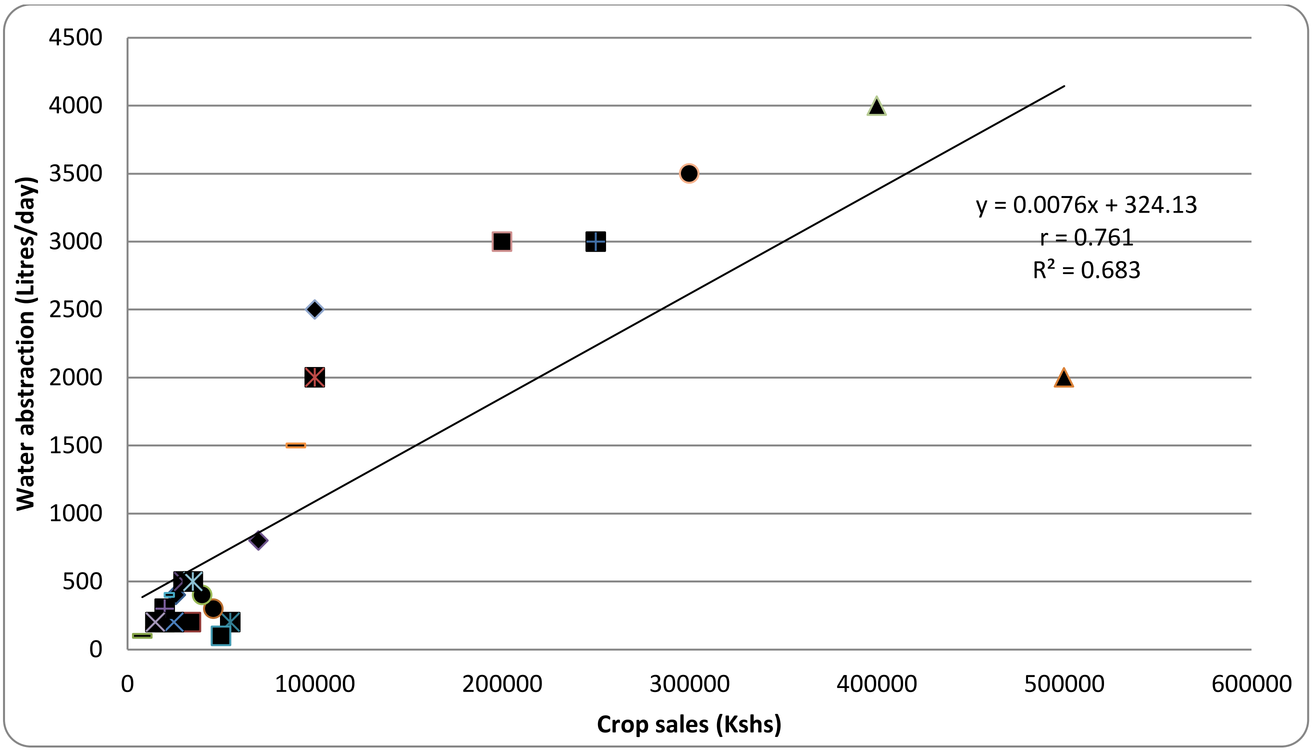

Figure 4.25: Relationship between crop sales and water abstraction in Chania sub basin in 2018

4.6.5 Comparison on agricultural influences on water abstraction in the four sub basins

The analysis of data on the extent to which agriculture influences water abstraction in the study area showed that this influence is variable. Most of the farms in the study area are between the size of 0.5 and 3 acres (Table 4.11). This is consistent with (IFAD/UNEP/GEF, 2004; Geertsema *et al.*, 2011 and Onduru and Muchena, 2011) who established that the average farm size in the study area varies between 0.2 and 1.6 ha). The results also agree with MCIDP (2014) that noted that the average farm size in Muranga County is 1.4 acres. The small sizes of farms can be attributed to land sub division occasioned by increase in population in the study area. This is consistent with MCIDP (2014) that established that the increasing population was pressurizing people in Murang'a to subdividing land into small uneconomical sizes. The small size of farms could also be attributed to the inability of the respondents to buy land because of low income levels. Therefore, population increase and high poverty levels can be considered to be important drivers of water abstraction in the South West Upper Tana Basin (SWUT).

Table 4.11: Size of irrigated farms in Kiama, Thika, Kimakia and Chania Sub basins (%)

	Farm Size (acre)					
Sub basin	**0.5 acre**	**1 acre**	**2 acres**	**3 acres**	**5 acres**	**10 acres**
Kiama	2	11	6	4	1	2
Thika	2	11	5	7	0	0
Kimakia	3	11	3	6	2	0
Chania	5	8	7	3	2	0
Mean	3	10.25	5.25	5	1.25	0.5

Source: Mwendwa 2018

The main crop grown under irrigation in the study area is cabbage (81.38 acres) (Table 4.12). Other crops in the study area are maize (27.21 acres), kales (17.79 acres), tomatoes (17.1 acres), beans (8.13 acres), pineapples (13 acres), potatoes (7.65 acres) and carrots (5.39 acres) (see also AWSB, 2014).

Table 4.12: Types of crops irrigated in Kiama, Thika, Kimakia and Chania sub basins (%)

Sub basin	**Cabbage**	**Kales**	**Maize**	**Beans**	**Carrots**	**Potatoes**	**Tomatoes**	**Pineapples**	**Tea**
Kiama	23.75	3.39	5.65	1.13		3.39	6.78		8
Thika	24.86	11	10.17		2.26		2.3		11
Kimakia	16.95	2.3	8	5	1.13	2	1.13		10
Chania	15.82	1.1	3.39	2	2	2.26	6.78	13	10.17
Total	81.38	17.79	27.21	8.13	5.39	7.65	17.057	13	39.17

Source: Mwendwa 2018

The unreliability of rainfall in the study area has led to increase in irrigation farming in the area. This is because rainfed agriculture is no longer sustainable thus the need for supplemented irrigation of crops. Supplemented irrigation allows crops to mature. Without this, crops will wither following cessation of rainfall. Initially, tea was the main source of income but today it seems farmers are diversifying their farming activities. Moreover, these crops take shorter period of time to mature and farmers get income immediately after sale as opposed to tea where the farmer has to wait for 12 months to get payment from KTDA. This agrees with (Geertsema *et al.*, 2011) who established that the main crops grown in the southern parts of Upper Tana to be beans, maize, cabbages, potatoes, bananas, tomatoes, tea and coffee. IFAD/UNEP/GEF (2004) noted that farmers in the southern Upper Tana region were turning coffee fields into horticultural crop zones.

Figure 4.26 shows the relationship between crop sales and water abstraction. The crop sales increase with increase in water abstraction for irrigation. High crop sales of about Kshs 400,000 were realized by farmers who abstracted above 3,000 litres of water per day. The maximum water abstraction in a day was Kshs 500,000, realized by farmers who abstracted above 4,000 litres while minimum crop sales (Kshs 2,000) were realised by farmers who abstracted 100 litres in a day. The relationship between water abstraction and crop sales yielded a correlation coefficient r of 0.78 and a coefficient of determination R^2 of 0.73 (Figure 4.26). These were significant at 95% confidence level (P=0.05). These results show that volume of water abstracted can explain 73% of the variations in crop production and sales in SWUT basin.

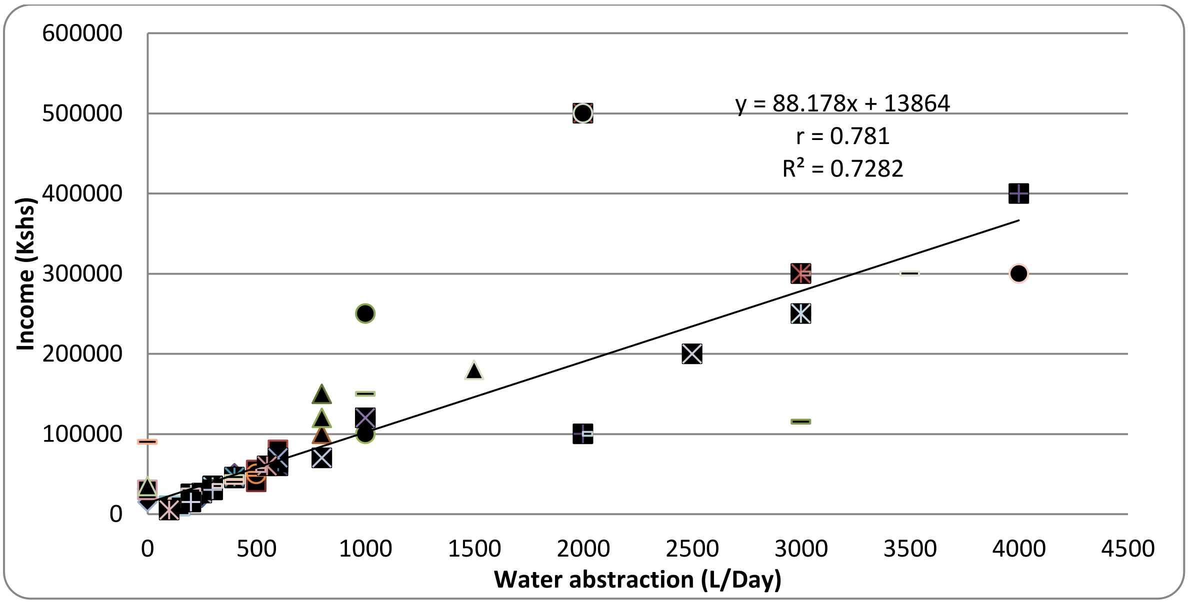

Figure 4.26: Relationship between crop sales and water abstraction in the SWUT Basin

The study revealed that, in the four sub basins, farmers with higher acreage under irrigation abstracted more water and hence realised higher crop sales. It was revealed that 43% of the respondents in SWUT basin have realised better crop yields due to water abstraction (Table 4.13).

Table 4.13: Benefits of income from crop sales in the SWUT Basin

Sub basin	Benefits of income from crops (%)			
	Maintaining family	Growing business	Pay fees	Investments
Kiama	35	15	40	10
Thika	37	9	43	11
Kimakia	32	13	45	10
Chania	33	15	42	10
Mean	34.25	13	42.5	10.25

Source: Mwendwa 2018

It was found that 39% of the farmers sell their produce in the local markets, to middle men who buy from the farms or within the county. However, there are also other farmers who sell their produce in major urban areas such as Thika (15%) and Nairobi (15%) while others sell to other counties such as Machakos, Makueni, Mombasa, Kitui and Nakuru (6%). It was also established that 14% of the crop produce is supplied to schools (Table 4.14). Therefore, both local and national trading patterns can be considered to be important drivers of water abstraction in the SWUT basin. Most of the farmers obtain the best sales during the dry season (72%) or the period between August and September. December holidays (22%) also presents a good opportunity to the farmers to obtain good value for their crops (Table 4.15).

Table 4.14: Crop marketing in SWUT Basin (%)

Sub basin	**Locally (Within the county)**	**Thika**	**Nairobi**	**Other Counties**	**Export**	**Supply schools**
Kiama	49	15	6	6	9	15
Thika	32	20	26	4	10	8
Kimakia	32	15	15	6	15	17
Chania	42	8	13	8	12	17
Mean	39	15	15	6	11	14

Table 4.15: Best time for sales in Kiama, Kimakia, Thika and Chania sub basins

Sub basin	**Time for sales (%)**		
	Dry season (Aug-Sep)	**December holidays**	**When schools open**
Kiama	67	25	8
Thika	80	16	4
Kimakia	76	24	
Chania	64	22	14
Average	72	22	6

This study also established that 60% of the respondents in SWUT Basin did not have an alternative livelihood apart from farming (Table 4.16). This could be the reason why most of the people have to abstract water for irrigation to improve crop production. It was also established that only 26% of the respondents have some form of employment in the study area. This could be a trigger to increased poverty levels that drives people to water abstraction for irrigation. Other studies such as MCIDP (2018) found out that 36% of the population in the study area live below poverty line since only 18% of the population has some form of employment.

Table 4.16: Alternative livelihoods in Chania, Thika, Kiama and Kimakia sub basins

Sub basin	Alternative Livelihood (%)		
	Employed	Business	No Altenative
Chania	24	5	71
Kimakia	17	17	66
Thika	32	18	50
Kiama	32	16	52
Mean	26	14	60

The main type of fertilizer applied by farmers in irrigation farming was found to be DAP. The mean application rate was 570 Kgs per season. Other types of fertilizers are CAN, TSP and NPK with 360 kgs, 57 kgs, and 51 kgs per season respectively (Table 4.17).

Table 4.17: Type and amount of fertilizer applied in farms in SWUT Basin

Sub basin	Type of fertilizer / Amount applied (kgs/season)			
	DAP	CAN	TSP	NPK
Kiama	146	91	10	9
Thika	158	87	12	13
Kimakia	128	89	15	13
Chania	138	93	20	16
Total	570	360	57	51

Source: Mwendwa (2018)

4.7 Analysis of the impacts of water abstraction and river diversion

The analysis of downstream and upstream impacts of water abstraction and river diversion in the SWUT basin was based on the analysis of the responses of questionnaire survey, focus group discussions, field observations and review of the results of other studies. Water abstraction and river diversion in the study area have both upstream and downstream impacts. Further, the impacts can be categorized into hydrological impacts, ecological impacts, and agricultural impacts, societal and economic impacts. Different sub basins exhibited differences and similarities in the extent of these impacts. These are detailed in the following sections.

4.7.1 Kiama sub basin

There have been increased crop yields (33%) in the farms upstream of River Kiama. This could be attributed to the fact that water abstraction allows the farmers to do farming even in the dry season. The water abstractions especially where canals or weirs are used have also led to increase in sediment deposition in farms. This is evidenced by the filling of diversion canals with silt in the rainy season.

Changes in turbidity (15%) have also been a major impact on the upstream as a result of diversion. During rainy season, the colour of water changes to brown due to high concentration of suspended sediments in water in the sub basin. Turbidity decreases as water abstraction increases during periods of low flows. The decrease in water turbidity as water abstraction rate increases could be attributed to the low flows that reduce the total suspended sediments (TSS) in the river water. The periods of high turbidity are between March and April with 1,000 NTU to 1,200 NTU and between October and November with 1,100 NTU to 1,260 NTU (Figure

4.27). The periods of low turbidity are between May and September with 600 NTU to 50 NTU and between December and February 540 NTU to 96 NTU.

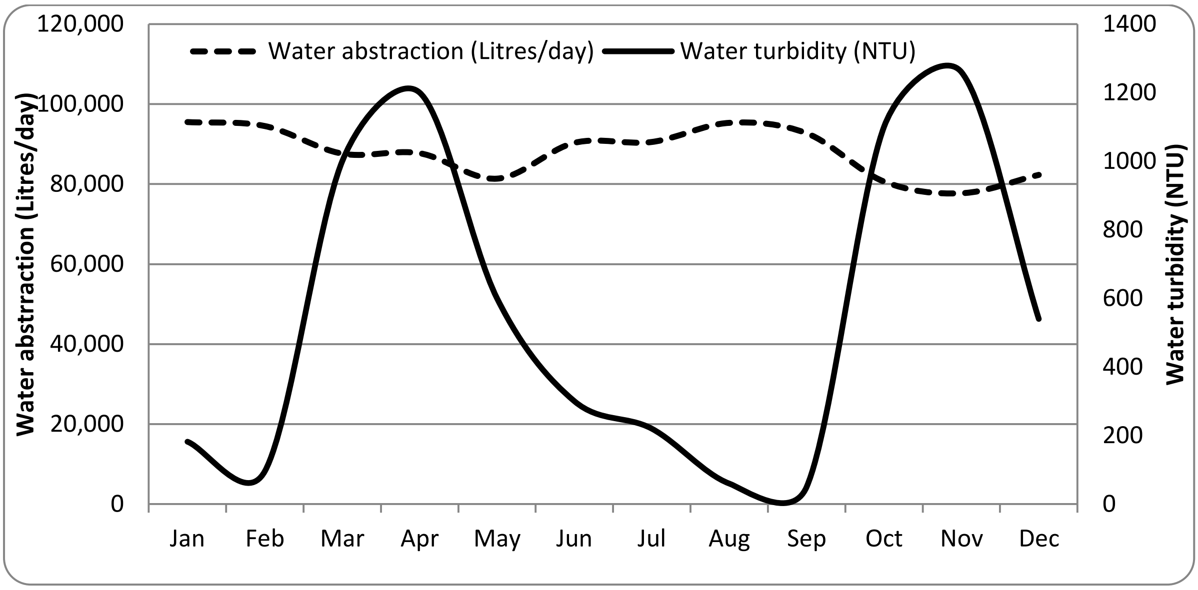

Figure 4.27: Seasonal variations of water abstraction and turbidity in Kiama Sub basin

It was established that water abstractions in the upstream of the river had led to decrease in the water levels in the river. The reduced water levels in the river have also reduced river flooding, both upstream and downstream in the area hence reducing the deposition of fertile alluvium in farms. Therefore, Farmers have to use more fertilizers to improve yields because of the decreasing fertility of soils in the sub basin.

There has been a 36% increase in the number of conflicts as a result of water abstraction. This has resulted in the formulation of informal societal and cultural guidelines for abstraction of water in the area. When conflicts arise, there are different mechanisms that are used to solve them. It was established that the main conflict resolution mechanism in the study area is through involvement of respected elders in the community. The two conflicting parties are listened to by the elders and then a resolution that is biding to both parties is given. The local administration consisting of chief and the assistant chief are also involved in solving some of the conflicts.

This study established that the main guideline that the society uses in water abstraction is protecting the river from pollution (40%). Respondents also maintain mutual respect when abstracting water by ensuring that they do not abstract large amounts that could affect downstream users. Those with water pumps normally pump water into their farms early in the morning and late evening. This osteribly ensures that they do not interfere with the flow of the river during the day. Farmers who abstract water using weirs also ensure that the weirs do not fully obstract the river to enhance environmental flows.

It was found out that respondents in the study area have cultural guidelines that are adhered to during water abstraction. The main cultural guideline in water abstraction from this river is the belief that water is for everyone (71%). Thus, everyone has a right to access water from the river. This means that the upstream users abstract the water while bearing in mind the potential needs of those downstream users. It is also against the existing cultural or societal norms to block the river completely while abstracting water. This means that even farmers upstream cannot divert all water into their farms or block the river from flowing downstream. However, these societal and cultural guidelines were found to be ineffective in controlling water abstraction in the SWUT basin. This is due to the limited capacity of the community to enforce them. Also, the penalties for farmers who do not abide by established guidelines are not severe enough. In most cases non-abiding farmers are just reprimanded by elders.

The main stakeholders involved in water abstraction/diversion in Kiama River are individuals (53%), NCWSC (36%) and County government (11%). Individuals contribute the highest percentage of water abstractions since most of the respondents in the study area are farmers. Thus, they have to abstract more water to irrigate their farms with an aim of producing more yields. The changing rainfall patterns have also led the people to abstracting more water since the rainfed agriculture is no longer sustainable. In addition, some households are not connected to piped water and even those that are connected to the same do not have constant supply of water. Thus, they have to abstract water directly from the rivers for domestic uses. The other major stakeholder in the diversion of water in this river is Nairobi City Water and Sanitation Company (NWSC). The company has diverted water at Koiba a short distance from Ndakaini dam. This diversion takes the water to Ngethu treatment plant where the water is treated and then supplied to Nairobi.

4.7.2 Thika sub basin

It was established that 36% of the respondents realised improved crop yields in their farms as a result of water abstraction. This is could be attributed to the fact that water abstraction from the river allows the farmers to irrigate their farms to achieve high crop yields. The increase in crop yields has also improved the income levels of farmers as well as their living standards.

Water turbidity has also increased significantly by 29%. It was observed that high water turbidity is between October and November with 720 NTU to 1,040 NTU and between March and April 840 NTU and 1,140 NTU (Figure 4.28). The results also indicate that water turbidity decreases in the periods between May and September with 936 NTU and 94 NTU and between December and February with 520 NTU and 70 NTU.

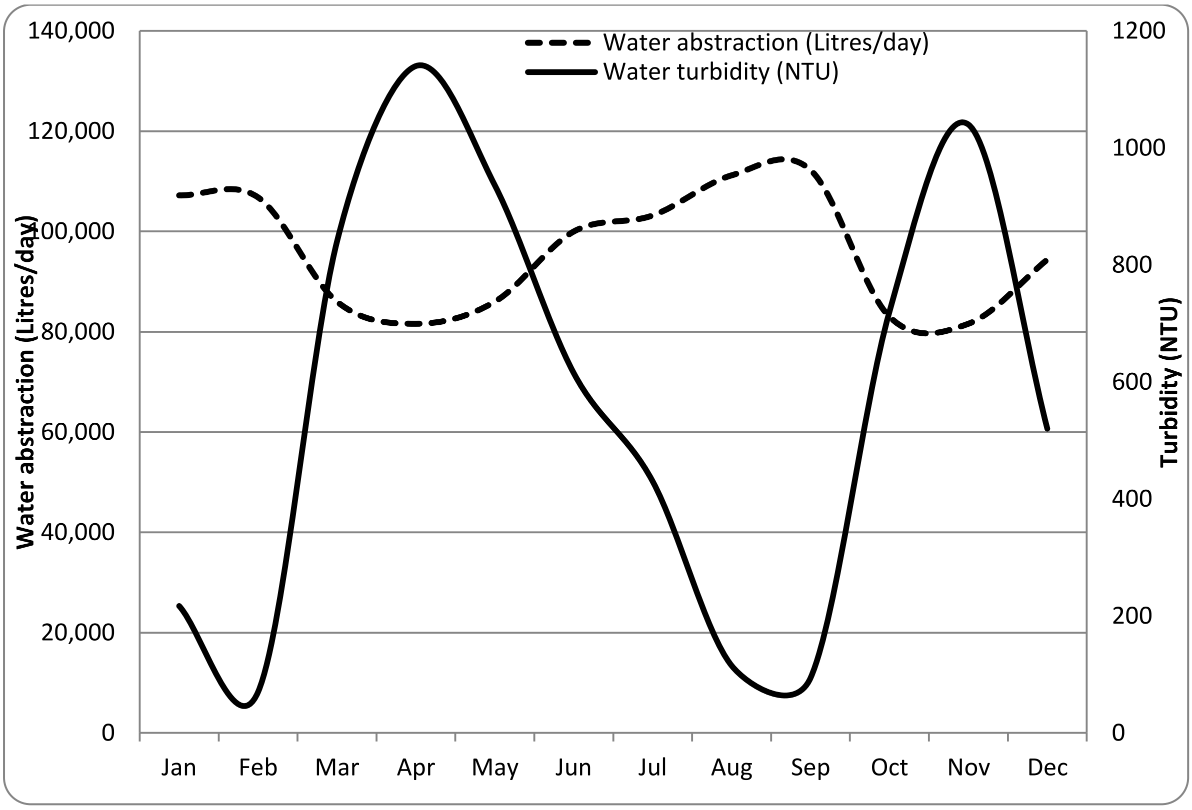

Figure 4.28: Seasonal variations of water abstraction and turbidity in Thika Sub basin

There has been 9% increase in the number of conflicts on water abstraction in the sub basin. Most of the conflicts are due to the reduced water levels in the river especially in dry season. This has resulted in the formulation of informal social and cultural guidelines for water abstraction in the area. When conflicts occur, they are solved through various mechanisms such as involving respected elders (60%) in the society, involving local administration (20%) and taking the matters to court (20%). The elders make resolutions that are always biding to conflicting parties. However, these societal conflict resolution mechanisms were found to be ineffective in controlling water abstraction in the sub basin. This is due to the limited capacity of the community to enforce them. Thus, some of the matters end up in court especially if one of the parties is not contended with the resolution from elders. The main cultural guideline in the sub basin is that the farmers maintain respect for each other (40%) when abstracting water from the river. This is done by abstracting an amount that will not minimize the chance of downstream users to get water. Also, pumping of water is mostly done early in the morning and late evenings to ensure that the flow of river is not interfered with during the day. For those who divert the water into their farms using canals, care is taken to ensure that they do not divert all the water from the river into their farms.

Most (71%) of the respondents hold the belief that water in the river is for everyone. Thus, everyone has a right to water in the river. This prevents the upstream users from abstracting large volumes that could deny the downstream users their right to access water. In addition, it is against the societal norms to fully block the river when abstracting water. Farmers in the upstream only divert a certain amount to allow the downstream users also to get water. However, there is also a belief that water is God given and thus, even when farmers abstract high volumes of water from the river they believe it will not affect others. This is detrimental because some farmers may take advantage and abstract huge volumes upstream abstract without taking into consideration the downstream users. Individuals (50%) are the main stakeholders in abstracting water from this river. The main reason for this high number is because most of the respondents are farmers. Thus, they have to abstract water for irrigation. Inadequate or lack of connection to piped water could also be a reason why many people are abstracting water from this basin. Water vendors have also come in to supply water because of the erratic supply of piped water in the area. NCWSC (27 %) has also contributed to water diversion in this river. The water is diverted into Ndakaini/Thika dam. The main aim for diverting water into this reservoir is to supply Nairobi County with water.

4.7.3 Kimakia sub basin

In this sub basin, 37% of respondents indicated that water abstractions in River Kimakia have led to increase in farm productivity. This is due to the fact that farmers can use the water abstracted from the river for supplementary irrigation in the sub basin. Water abstractions have also forced farmers to use more fertilizers (33%) in order to produce more yields from their farms. This is due to the fact that fertile alluvium that used to be deposited in farms in the downstream areas has greatly reduced as a result of abstractions.

This study found out that maximum turbidity level in this sub basin is between October and November with 1,021 NTU and 1,155 NTU and between March and April with 660 NTU and 1,200 NTU (figure 4.29).

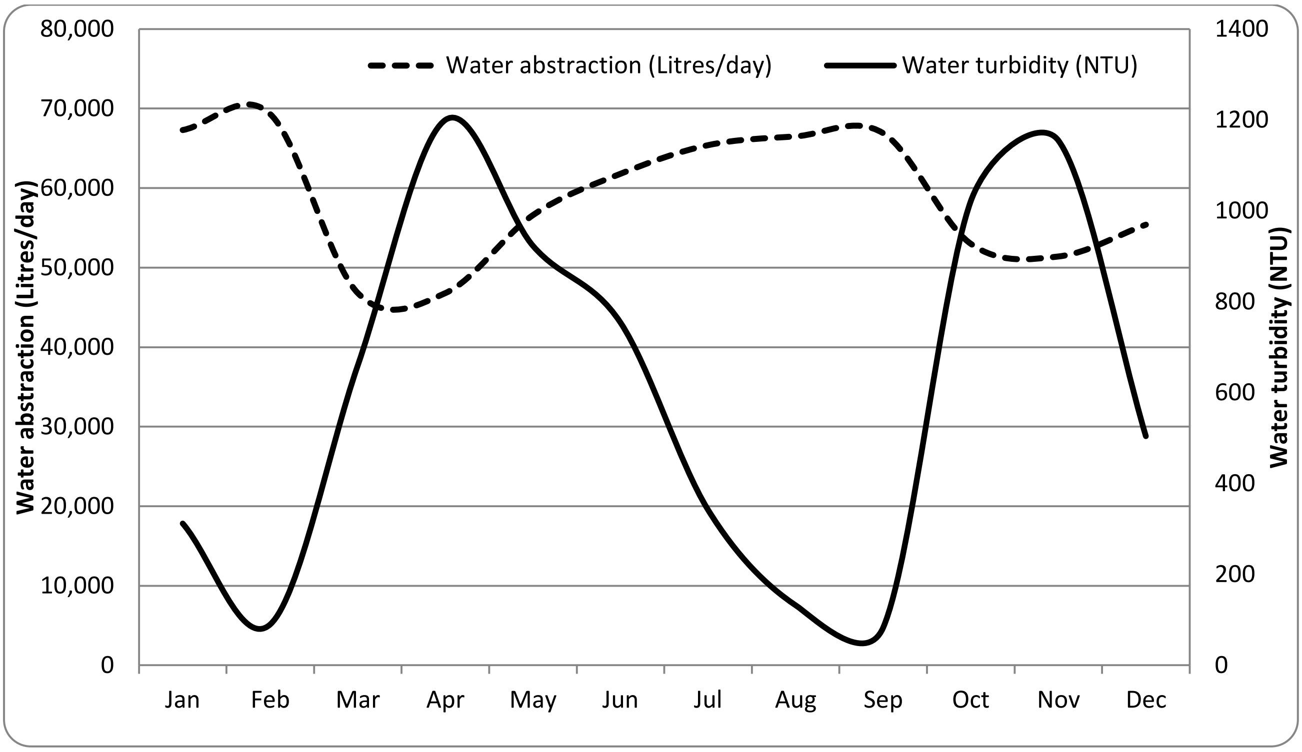

Figure 4.29: Seasonal variations of water abstraction and turbidity in Kimakia Sub basin

Conflicts resulting from water abstraction in this sub basin are very rare. Most of the conflicts are as a result of reduced water levels in the river especially during dry season. The conflicts have led to formulation of informal conflict resolution mechanisms in the sub basin. Most (75%) of the conflicts are solved by the local administration (Chief and Assistant Chief) while respected elders solve 25% of the conflicts in the sub basin. The main social consideration when abstracting water in the basin is mutual respect which accounted for 72% of the responses. This respect is maintained by only abstracting an amount that will not minimize the chances of downstream users getting water. For instance, those who use diversion canals only divert little amounts of water to ensure downstream users still get enough water. Farmers, who use water pumps, normally pump water early in the morning and late in the evening. The main reason for this is to ensure that the flow of water is not interfered with during the day.

Most of the respondents believe that water is for everyone. This guides against water over abstraction in the sub basin since farmers take into consideration the downstream users when abstracting water since everyone has the right to access water. However, some upstream users tend to abstract more water because they believe they have a right to it and that water is God given. This leaves the downstream users without enough water. These guidelines were also found to be inefficient because the penalties for farmers who over abstract water are not punitive enough to discourage over abstraction. In most cases, non abiding farmers are only reprimanded by elders. The main stakeholders in the diversion of water from this river are individuals accounting for 38%, NCWSC which accounted for 32% and Gatanga Community Water accounting for 30% of the responses. Individuals form the highest percentage because most of them are farmers. This leads them to abstracting more water from the river to improve their yields. Lack of connection to the piped water and erratic supply of the piped water to households has also driven more individuals to water abstraction in the river. Water vendors abstract water from the river to sell to the households and businesses that get inadequate piped water. NCWSC has diverted water from the river near the bridge at Gatura and directed this water to Rwegetha treatment plant. This river water is also diverted at Ngethu to improve the supply of water to Nairobi. Gatanga Community Water, a company that supplies water to households in Gatanga Sub County is also a major contributor to water diversion in Kimakia River. The water is diverted at Kimakia forest using a weir then supplied by pipes to households in Gatanga Sub County.

4.7.4 Chania sub basin

In this sub basin, 40% of the farmers noted that water abstractions have contributed to the improved crop yields from their farms. This could be attributed to the fact that water abstractions enable the farmers to irrigate their farms thus they do not only rely on rainfall for farming.

Figure 4.30 shows that high turbidity levels were observed between October and November with 1,065 NTU to1,392 NTU and between March and April 780 NTU to 1,380 NTU. The results also indicate that low turbidity levels are in the periods between June and September with 641 NTU to 70 NTU and between December and February with 668 NTU to 94 NTU. However, the rate of the increase has declined over the years since it lasts for only three months when high amounts of rainfall are experienced and then water becomes clear. Farmers who use diversion canals to abstract water have to desilt their canals after 2 to 3 weeks during the rainy season. This means that during this period there is an increase in sediment loads in the rivers. In addition, deposition of this silt in farms improves the fertility of soils in the farms. Water abstraction reduces water level in the river subsequently reducing the sediment capacity leading to rapid sedimentation during low flows. Sedimentation in low flows when velocity is low leads to increased water clarity (reduced turbidity).

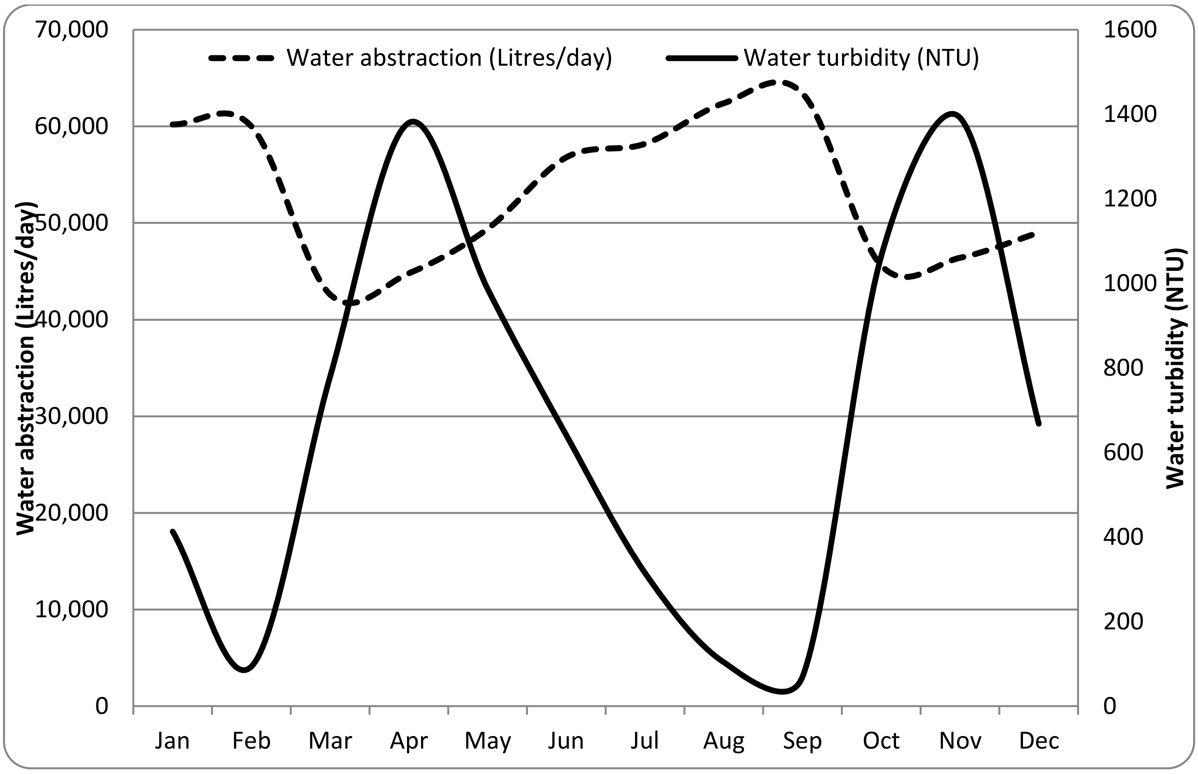

Figure 4.30: Seasonal variations of water abstraction and turbidity in Chania sub basin

About 45% of respondents in the study area noted that they have increased the amounts of fertilizer usage in their farms. This is attributed to the fact that increased abstractions upstream have led to decrease in water levels in the river which decreased fertile alluvium deposits in the farms have reduced in the farms. This could be attributed to decrease in sediment loads in the river since most of them are trapped by the diversions upstream. Thus, the farmer has to apply more fertilizer in the farm in order to improve crop yields in the farm.

There has been a 25% increase in the number of conflicts resulting from water abstractions. These conflicts are mainly between the upstream and downstream users. Reduction in water levels in the river can be cited as the major source of these conflicts especially during the dry season. Increase in the number of conflicts has resulted in formulation of informal societal and cultural guidelines for abstraction of water in the sub basin. 47% of the conflicts are solved by respected elders in the society while 40% of the conflicts are solved through the involvement of local administration such as the chief and assistant chief.

Most of the respondents (74%) believe that everyone in the basin has a right to access water. This belief that water is for everyone has led to over-abstraction of water by some of the upstream users. This leaves downstream users with little water for abstraction. In addition, 12% of the respondents believe that water is a free resource given by God and it cannot get finished. This means that they abstract water without considering the downstream users. However, it is against the norms to fully block the flow of the river. The main guideline that the society has adopted for water abstractions is mutual respect which accounted for 72%. The respondents ensure that the amount abstracted will not reduce water in the river to a level that the downstream users will not get enough. In addition, water is normally pumped early in the morning and late in the evening to ensure that the flow of the river is not interfered with during the day. Moreover, the society does not allow people to bathe, wash clothes or wash vehicles in the river. This protects the river from pollution. In Chania sub basin, the main stakeholders in water diversion are individuals accounting for 45%, NWSC which accounted for 29%, County government accounting for 5% and KTDA which accounted for 21% of the responses. Individuals contribute highly to abstractions because most of them are farmers, some are not connected to piped water or piped water supply is unreliable. NWSC has also diverted water from this river at Ngethu. This diversion is aimed at improving water supply to Nairobi County.

4.7.5 Comparison on downstream and upstream impacts of water abstraction

There are both upstream and downstream impacts of water abstraction in SWUT basin. These impacts include (i) increased crop yield due to irrigation, (ii) reduced turbidity, (iii) reduced water volume in the river, (iv) reduced alluvium deposition in farms, (v) reduced water clarity, (vi) water use conflicts, (vii) increased stakeholder involvement in the use of river water, (vii) formulation of societal guidelines for water abstraction, (viii) increased awareness on water issues, (ix) eutrophication due to nutrients from irrigated farms, and (x) degradation of riparian/aquatic vegetation.

It was noted that 39% of the respondents in the study area have realised increased crop yields in their farms following water abstraction (Table 4.18). This could be attributed to the fact that water abstraction allows the farmers to do farming even in the dry season because they do not necessarily rely on rainfall. The water abstractions especially where canals or weirs are used have also led to increase in sediment deposition in farms. This is evidenced by the filling of diversion canals with silt in the rainy season.

Table 4.18: Impacts of water abstraction on the upstream of R. Chania, R. Thika, R. Kiama and R. Kimakia

Sub basin	Upstream impacts (%)				
	Increase in turbidity	**Change in River Morphology**	**Low water volume**	**Change in water colour**	**Increased Crop Yields**
Chania	26	8	14	12	40
Kimakia	30	6	13	14	37
Thika	29	5	14	16	36
Kiama	32	7	13	15	33

Source; Mwendwa, 2018

Changes in turbidity (29%) have also been a major impact following water abstraction and river diversion in SWUT basin. Figure 4.31 shows seasonal variations in water turbidity in South West Upper Tana Basin. Turbidity increases in the period between February and April and between September and November. The highest water turbidity levels are in Chania River. Low turbidity levels are in the months of May and September and between November and February. Water abstraction in the basin increases during the same periods. The increase in water turbidity as water abstraction rate increases could be attributed to the low flows which decrease total suspended sediments.

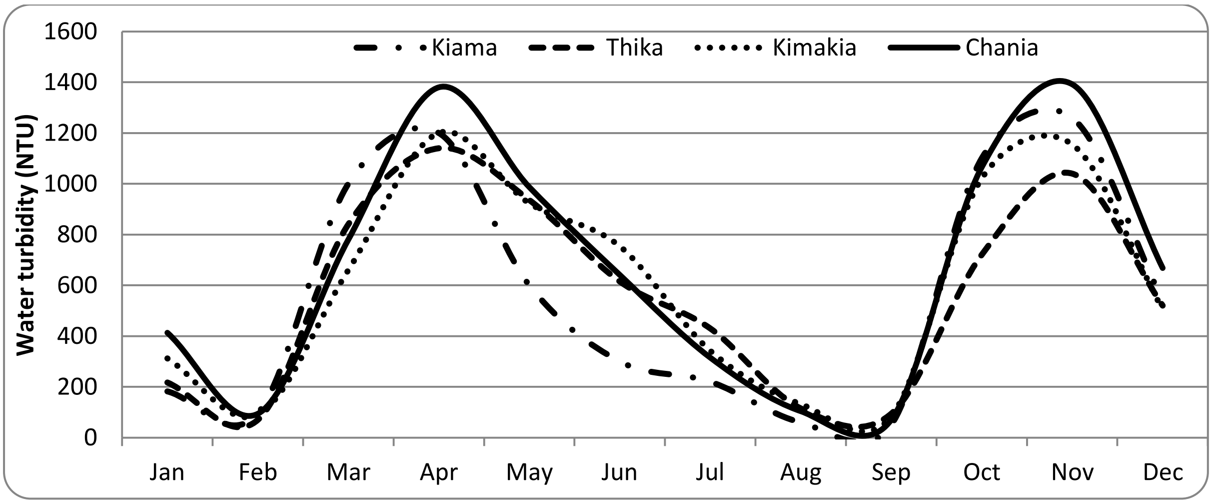

Figure 4.31: Seasonal variations of water turbidity in South West Upper Tana Basin

Water abstractions have also resulted to low water levels in the basin. The reduced water levels in the river have also reduced river flooding, both upstream and downstream in the area hence reducing the deposition of fertile alluvium in farms. Therefore, farmers have to use more fertilizers (36%) to improve yields because of the decreasing fertility of soils in the basin (table 4.19). This is consistent with Jacobs *et al.,* 2007; Bunyasi *et al.,* 2007., Kithiia, 2008; Njogu and Kitheka, 2017; Kitheka *et al*., 2019).

The four rivers in the basin have major diversions that could have contributed to low water levels downstream. This includes diversion of R. Thika into Ndakaini/Thika dam, diversion of Kiama at Koiba, diversion of Kimakia in Gatakaini, Gatura and Ngethu, and diversion of Chania at Ngethu. In some of the rivers, water partly changes to green colour (4%) in September and early October (Table 4.19). Changes in river morphology were also noted as a major impact of water diversion in SWUT basin. The river channels have become narrow as a result of reduced water volume especially in the dry periods as a result of water abstraction and river diversion. Reduced water levels in the rivers means there is less bank storage as well as recharge of ground water. This may increase the hydraulic gradient such that the flow of bank storage and ground water into river is accelerated. This will deplete groundwater aquifers which subsequently affect the base flow which may be reduced or depleted rather rapidly.

There has been a 22% increase in the number of conflicts as a result of water abstraction in SWUT basin (Table 4.19). Reduced water volume and increased demand for water among many users has led to conflicts in the use of the resource (see also ERM, 2007; Bekele, 2013 and Mokaya, 2015). This has resulted in the formulation of informal societal and cultural guidelines for abstraction of water in the area. When conflicts arise, there are different mechanisms that are used to solve them. The main conflict resolution mechanism is through involvement of respected elders in the community. The society relies on several guidelines when abstracting water from the rivers. The main guideline is to ensure that the rivers are protected from pollution. Respondents also maintain mutual respect when abstracting water by ensuring that they do not abstract large amounts that could affect downstream users. Those with water pumps normally pump water into their farms early in the morning and late evening. This osteribly ensures that they do not interfere with the flow of the river during the day. The respondents also ensure that the river is not fully obstructed when they use weirs to abstract water. This is consistent with IWMI (2007) who noted an increase in conflicts due to the increase in water demand in many parts of the world. Similarly, Aeschbacher *et al*., (2005);

Notter *et al*., (2007); Ngigi *et al*., (2007) established that the rising number of conflicts in Ewaso Ng'iro basin were a result of the low flow experienced in the river especially during dry spells.

It was established that the main cultural guideline in abstraction of water from this river is the belief that water is for everyone (51%). Thus, everyone has a right to access water from the river. This means that the upstream users abstract the water while bearing in mind the potential needs of those downstream users. It is also against the existing cultural or societal norms to block the river completely while abstracting water. This means that even farmers upstream cannot divert all water into their farms or block the river from flowing downstream. However, these societal and cultural guidelines were found to be ineffective in controlling water abstraction in the SWUT basin. This is due to the limited capacity of the community to enforce them. Also, the penalties for farmers who do not abide by established guidelines are not severe enough.

Table 4.19: Downstream impacts of water abstraction in Chania, Thika, Kimakia and Kiama sub basins

Sub basin	Downstream impact (%)				
	Reduced water volume	Reduced alluvium	Reduced Turbidity	Increased use of fertilizer	Increased Nitrate concentration
Chania	30	20	5	45	0
Kimakia	34	22	11	33	0
Thika	27	15	12	27	19
Kiama	29	21	12	38	0
Total	29	7	14	14	37

Source; Mwendwa, 2018

Most (71%) of the respondents believe that water is for everyone. This makes these respondents believe that water is God given and cannot get finished (7%). This belief allows every person to be able to access water from the four rivers. However, most of the respondents use these believes to over-abstract water since they give them all the rights to do so. This lowers the water levels especially in the downstream of the rivers which reduces the availability of water for irrigation farming. Culture does not allow people to fully block the river when abstracting water. This is important for the downstream users because there is no time when the upstream users can block all the water from getting downstream.

The main stakeholders involved in water abstractions are individuals who do so to get water for irrigation and domestic use. Nairobi Water and Sewerage Company (NWSC), the company that supplies water to Nairobi County is also involved in abstraction of water in this area. Other stakeholders in the abstraction of water in this area are county government, KTDA and institutions such as schools. Individuals form the highest percentage (47%) of those abstracting water in the four sub basins. Most of the individual abstract water for domestic and irrigation purposes. Moreover, the increased abstractions could also be as result of weather changes where rainfall has become unreliable. The long dry season leads more farmers into water abstractions to ensure they get more yields from the farms. Water abstractions by individuals have also increased because most of the homes either do not have connection to piped water or the piped water is unreliable. NCWSC (31%) is the other main stakeholder in the abstraction of water in the study area. This water company has diverted water from Thika River to Ndakaini dam, Kiama River at Koiba, Kimakia River at Gatura and Chania River at Ngethu. All these diversions are done by the company to ensure that there is enough supply of water to Nairobi County. Gatanga Community Water contributes 8% of the diversions in the study area. This company has diverted water from Kimakia River at Gatakaini in Kimakia forest. The main reason for the diversion of water from this river is to supply Gatanga Sub County with piped water. Other stakeholders in the abstraction of water from these four sub basins are KTDA (5%), Athi Water Services Board (5%) and County government (4%). Tana Athi Water Service Board is involved in the diversion of water from Thika River for the NCT.

There has been a significant change in riparian vegetation as a result of increased abstraction especially on the lower course of the rivers. In Kiama and Thika sub basins, there is introduction of water weeds and new plant species in the rivers. This is evident in the lower courses of these rivers after water is released from Ndakaini dam. It was noted that these water weeds were not present on the upper parts of rivers, meaning that the diversion of water into the dam has led to the introduction of the water weeds in the river. The study also established that some plants that grow along the river beds had dried up. The plants mostly die in the dry season when water abstraction which lowers the water levels in these rivers is high. Some plants have also became extinct in these river beds. Either, crops that require more water such as arrow roots have been on the decline along the river beds. Mukhwana (2016) in the study of water abstractions in upstream of R. Ewaso Ng'iro established that there was a significant change in the vegetation cover between the years 2000-2015 because of increased water abstractions. Moderate vegetation cover decreased by 58% while dense vegetation cover decreased by 51%. This decline in vegetation cover types was linked to the reduced stream flows in Ewaso Ng'iro River. In the flood plains, the health of vegetation was found to be strongly correlated to the flooding regime (Mukhwana, 2016). Changes in the flow of the river led to decline in the dense vegetation types in the floodplain as well as loss of biodiversity (Mukhwana *et al*., 2016.

The study established a significant seasonal variation of eutrophication and siltation in South West Upper Tana Basin. Eutrophication is mainly as a result of presence of high levels of nutrients in the river water. These nutrients include nitrates, nitrites and phosphorous (Schilling and Wolter, 2001; Manohar *et al.,* 2017). The nitrate concentrations in this basin vary from 4 mg/l to 14 mg/l during dry season and 0.4 mg/l to 2 mg/l in rainy season. Nitrate concentration levels in this basin increase between July and August and between January and February. Decrease in nitrate concentration levels is in October and November and between March and May. Nitrate concentration levels do not coincide with rainy season but occur in relatively dry periods when water levels are generally low and water abstraction rates are high (Figure 4.32). This can be attributed to concentration of nutrients in dry period when fertilizers (DAP, CAN, TSP and NPK) are washed to the rivers since there is no return flow and entry of bank storage into the river bed. These findings are consistent with those of other studies that established that nitrogen and phosphorous are the major nutrients that cause eutrophication in Ndarugu and Ruiru river basins, Kiambu, Kenya (See also Kithiia, 1992, 2006; Okoth and Otieno, 2000 and Mavuti, 2003).

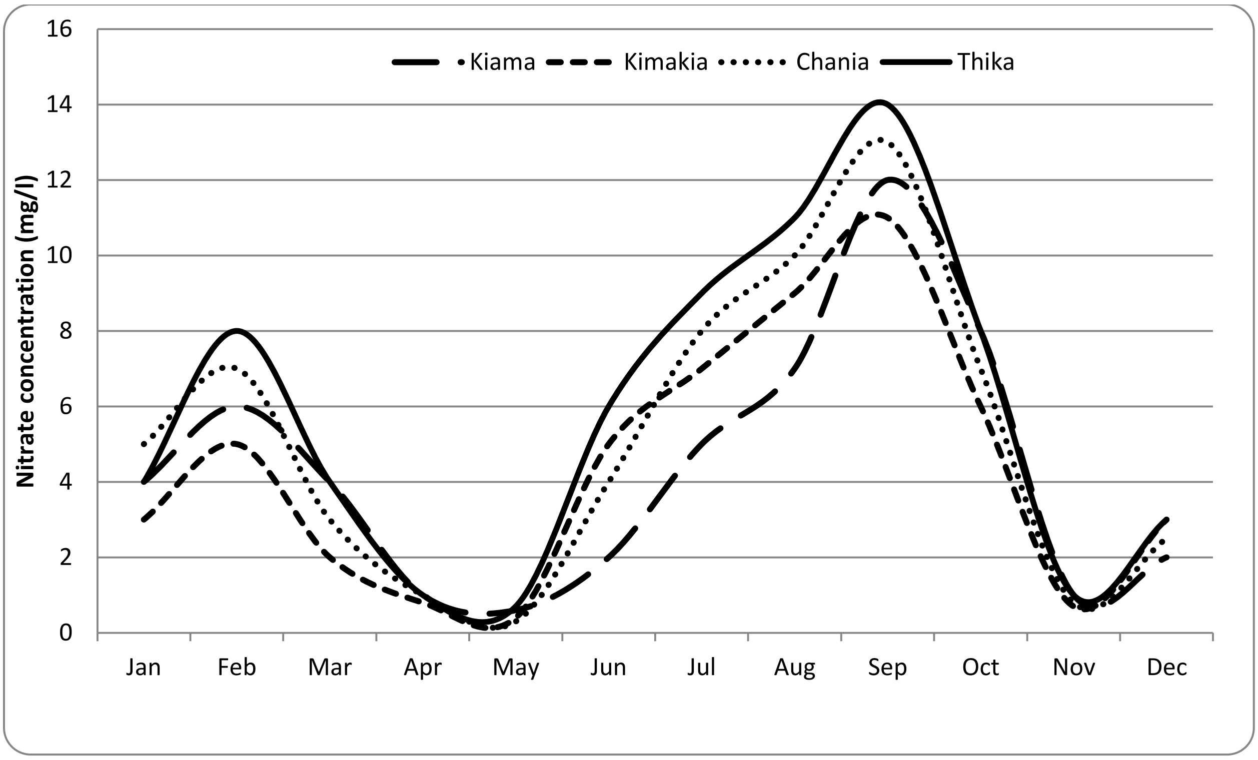

Figure 4.32: Seasonal variations of nitrate concentrations in South West Upper Tana Basin

Most of the diversions take between 1-3 months to fill up with silt (63%). The reason why the diversion canals take this long to fill up with silt could be attributed to the fact that increased water abstraction reduces sediments in the rivers. Only 20% of the diversion canals fill up with silt within the first week after rains. About 3% of the diversions fill up within 2 weeks while 1% takes 3 weeks to fill up. These low percentages are an indicator that the increase in water diversions in the four sub basins has led to decrease in sediment loads in the rivers. Some of the diversion canals even take more than 3 months (13%) to fill up with silt. This saves farmers cost of desiltation but also makes their farms less productive since silt adds fertility in the farms when the river floods.

Table 4.20 : Siltation of water in South West Upper Tana Basin

Sub-Basin	Time taken for diversions to fill up (Percentage)						
	1 week	**2 weeks**	**3 weeks**	**1 month**	**2 months**	**3 months**	**More than 3 months**
Chania	30	5		45	5	10	5
Kimakia	17	5	6	22	17	11	22
Thika	14		5	18	27	18	18
Kiama	40	8	28	8	8	8	

4.8 Water abstraction and diversion projects in the study area

The main water abstraction/diversion projects being undertaken in the study area include the Northern Collector Tunnel, diversion of Kiama and Kimakia River by Gatanga Community Water and diversion of Kimakia River at Gatura (AWSB, 2014). The first phase of the Northern Collector Tunnel will divert rivers Gikigie, Irati and Maragua to a tunnel which will then empty the water into Ndakaini/Thika dam. This water will then be taken by a tunnel from the dam to a water treatment plant then supplied to Nairobi County (AWSB, 2015) (Table 4.21). The diversion of water from Kimakia River at Kimakia forest and Gatura is aimed at improving water supply to Gatanga Sub County. The design capacity of each of the water projects is dependent on the size of population served. Thika dam which serves 3 m people has a larger design capacity than Gatanga Community Water which serves 70,000 people (Plates 4.2 and 4.3)

Table 4.21: The main water projects in the study area

Sub -Basin	Water Project	Year of completion	Design Capacity (m^3/day)	Population served
Kiama and Kimakia	Gatanga Community Water	2016	3,000	70,000
Thika	Thika/Ndakaini dam	1994	70,000,000	3,000,000
	Ithanga Water	2018	6,000	
	Northern Collector Tunnel	2022	140,000	3,000,000
	Gituamba Community Water Project		147	
	Nyaga Water Project		274	
	Ndakaini Wanduhi Irrigation water Project		1000	
	Gikakima Water Project		308	
	Nairobi City Water and Sewerage Company		100224	
	National Horticultural Research Station		1551	
	Athi Water Services Board		450,000	
Chania	Independent Mataara and Komothai Water Production Plants		32,000	128,000

(Source: AWSB, 2016; WRA, 2018)

Plate 4.2: Weir constructed across Kimakia River Ririndia

Plate 4.3: Water abstraction point in Chania River at Gatakaini

4.9 Analysis of the effects/impacts of landuse change on streamflows

The analysis of impacts of land use on streamflow was for the purpose of determining whether land use is an important driver of reduced flows in the rivers. This was done through the analysis of land use/landcover change using remote sensing and ArcGIS. The land use cover for the periods between 2000 and 2017 was analysed. Kiama, Kimakia, Thika and Chania sub basins have undergone tremendous changes in land use/land cover. There is a change from the previously predominant agricultural land uses to other land uses such as real estate. For instance, the area under coffee decreased by 38.4% while the built-up area increased by 34.5% between 2000 and 2016 (Table 4.22).

Table 4.22: Land use/cover changes in SWUT Basin

Land use/cover	Land use in 2016 (Ha)	land use in 2000 (Ha)	Change (Ha)	% Change	Remark
Water	265.32	265.4	0.08	0.03	No Change
Forest and shrub land	2016.9	1555.38	461.52	22.88	Increase
Agriculture	7402.68	7050.6	352.08	4.76	Increase
Pineapple	4116.29	4118.31	1258.02	0.98	No change
Coffee	5211.81	7213.23	2001.42	38.40	Decrease
Tea	5630.04	5352.66	277.38	4.93	Increase
Built up	6255.72	4093.47	2162.25	34.56	Increase

Source; Kitheka *et al.,* 2019

Figure 4.33 shows the land uses in SWUT in 1984 while figure 4.34 shows land use/land cover in 2018. The Figures show changes in the area under agriculture which has increased. The area under forest has decreased as evidenced in the Figures with agricultural activities occupying some of those areas that were initially under forest in 1984. Areas under coffee have also decreased while tea farming has increased. It has been established that increasing area under tea and forest by 60% can lead to 100% river discharge in upper Tana Basin (Kagira, 2007). Hua *et. al.* (2008) established that land use/land cover changes can modify frequency and magnitude of floods in the basin. Similar findings were reported by Mutie *et al.* (2006) and Stolgren (2008) who established that the modification of natural vegetation cover leads to changes in the rainfall-runoff characteristics which subsequently lead to low flow regimes.

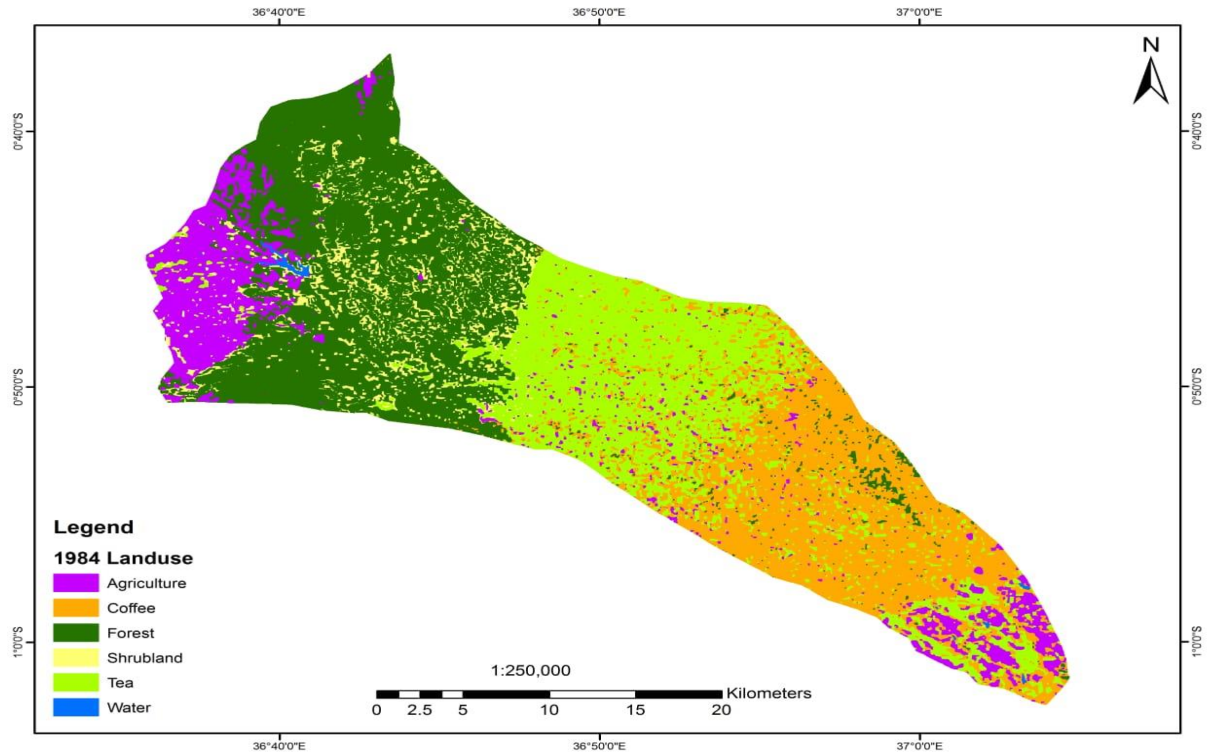

Figure 4.33: land use/ land cover in SWUT Basin in 1984 (Source ; Mwendwa, 2019)

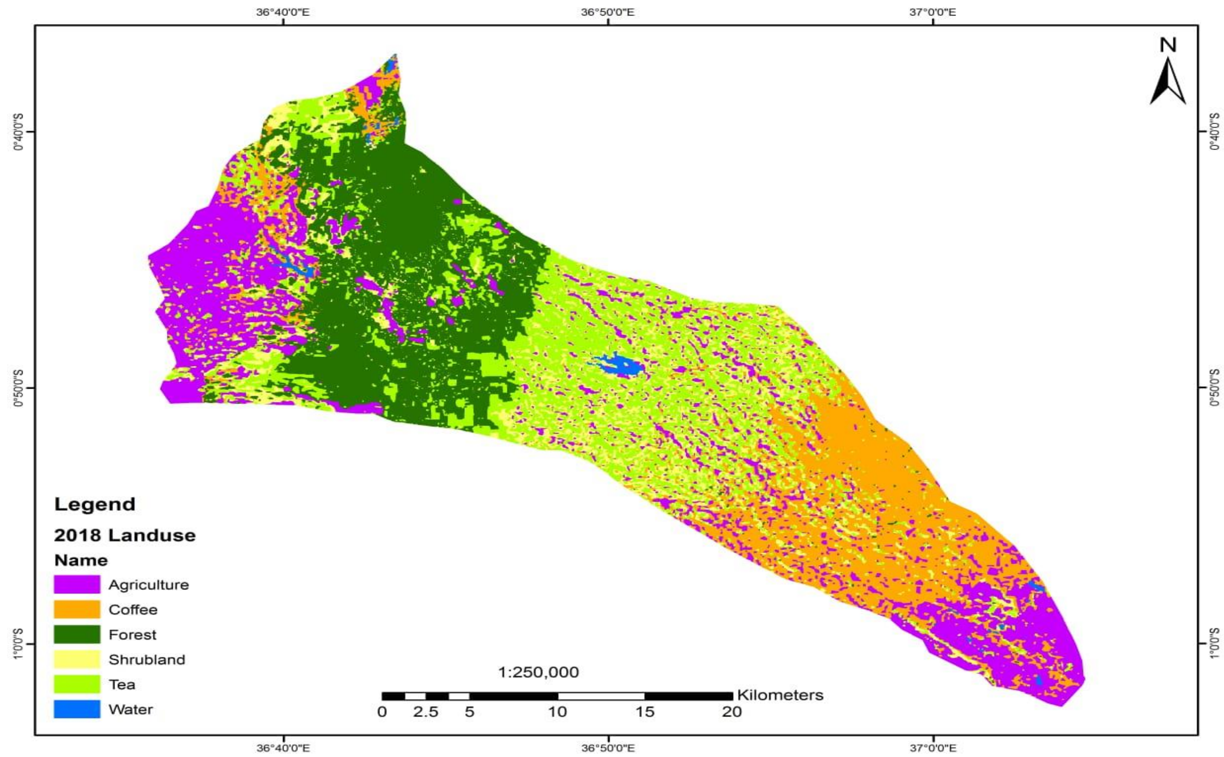

Figure 4. 34: Land use/land cover in SWUT Basin in 2018 (source ; Mwendwa, 2019)

4.10 Analysis of Climate Change impacts on streamflows

Climate change is an important driver of fluctuating water levels in rivers found in South West Upper Tana Basin. There have been changes in rainfall patterns in South West Upper Tana Basin in the last 15 years. These changes have increased the unpredictability of rainfall in South West Upper Tana Basin (TNC, 2015). There is increased variability of rainfall and river discharge in the study area (Kitheka *et al.,* 2019). This study established that there is a significant relationship between rainfall and stream flow in Kiama, Kimakia, Thika and Chania rivers. This is consistent with the findings of Kingston and Taylor (2010) and IPCC (2014) that the projected climate changes are expected to have significant consequences in the alterations of streamflow and the availability of water resources. The increased variabilities in rainfall have led to the variabilities in river discharge in the study area. The periods between 2001 and 2004 and between 2010 and 2015, exhibited an increase in rainfall and river discharge. However, it has been noted that there has been a decrease in peak discharge in the basin. This is consistent with results of Matondo *et al.* (2004); Hagg *et al.* (2007); Kingston *et al.* (2011). These findings also agree with the results of Mukhwana (2016) who established that in Ewaso Ng'iro basin, the increasing water abstraction was the main cause of declining river flows to levels that are ecologically unsustainable at times. It was also noted that, drought cycles in the region could also have had a significant role in the declining flows. However, some studies have shown that despite the increasing low discharge in the river, the mean discharge shows no negative trend (Aeschbacher *et al.,* 2005). The main reason for this was due to the high flood peak flows due to the increased generation of run off as a result of land use changes in the upstream. The results for studies undertaken in Likii, Burguret and Timau sub basins show that water abstractions were the main cause of decreasing stream flows (Liniger *et al.*, 2005).

4.11 Analysis of Population growth impacts on streamflows

Population growth in South West Upper Tana Basin has increased tremendously over the last 50 years. In the period between 1969 and 2017, the population grew from 64,619 people to 163, 597 people. The population growth rate has however reduced from 3.2% in 1969 to the current 2.7%. Increase in population has led to increase in the needs for water for irrigation to produce more yields for feeding the population and for domestic uses, decreasing streamflows. Water abstraction rate in SWUT Basin is 101,050 liters/day. Ngigi *et al.* (2007) established that the population increase combined with the intensification of agriculture placed enormous demand on water resources. Increase in population growth has threatened the availability of water resources (Musau *et al.*,2015). This is consistent with Kossa *et al.* (2014) who established through a questionnaire survey data that 30% of the downstream respondents attribute low streamflows to the increased water abstraction upstream.

Population change from rural to urban has also placed urban areas as potentially water scarce regions. People have also turned to horticultural farming which requires a lot of water for irrigation to cater for the growing demand of those products by the urban population. Kiama, Kimakia, Thika and Chania Rivers have been diverted by the Nairobi Water and Sewerage Company for water supply to Nairobi. The need to improve water supply in Nairobi County has also led to the ongoing construction of Northern Collector Tunnel. With the projected increase in population in the study area, it is expected that water abstractions will be on the increase. These findings are consistent with Mokaya (2015) who established that rapid population growth was significantly increasing the gap between water demand and supply. However, Howard *et al.* (2003) noted that population growth is a major driver but it is not sufficient to accurately make projections on water demand.

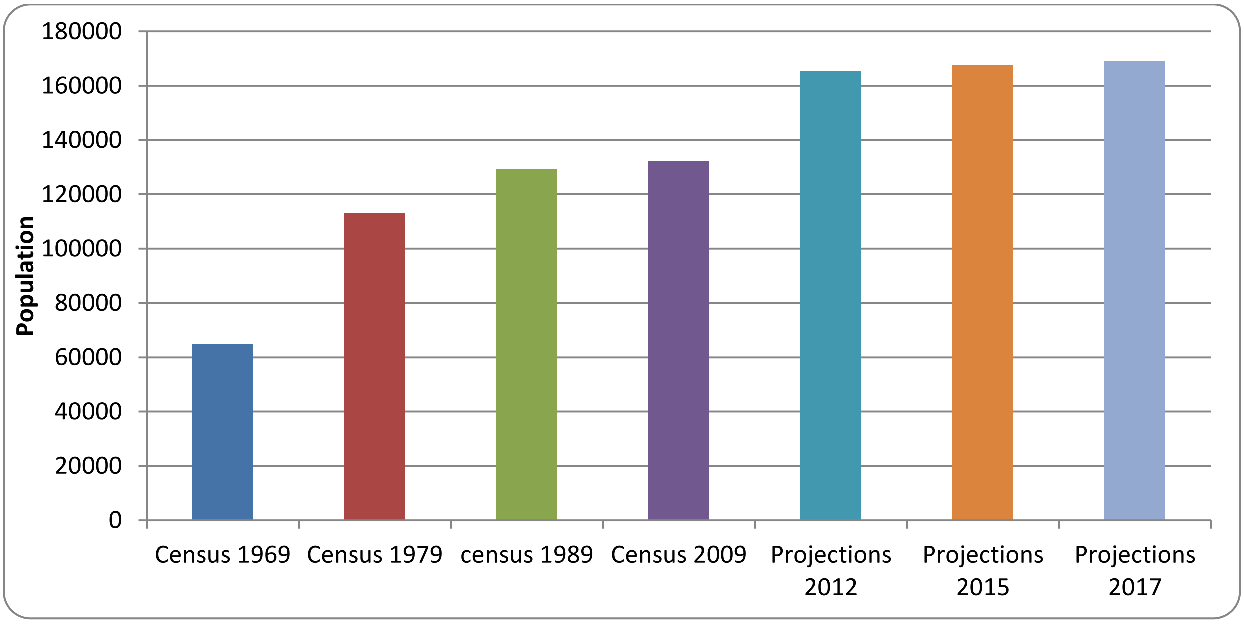

Figure 4.35: Population changes in SWUT Basin

4.12 Analysis of the impacts of Socio-Economic Development on streamflow

The socio-economic development witnessed in the study area since 1963 has contributed immensely to increased demand for water to meet the various uses. There has been an increase in the number of rural and urban areas, institutions, agriculturally based industries among others. All these exert tremendous demands on water resources in the study area. The information on socio-economic information was obtained from secondary sources, mainly government reports and County Integrated Development Plans (CIDPs). Farming (60%) is the main source of livelihood in South West Upper Tana Basin. This data is consistent with that obtained from Muranga County Integrated Development Plan (MCIDP) showing that 57% of the residents are farmers (MCIDP 2014). This is attributed to the low literacy levels in the area that leaves people unable to secure formal employment. The literacy levels in the study area are lower (70.1%) than the national average (71.4%). In addition, the realization that horticultural crop is more profitable than coffee farming has led to a shift from the previously dominant rain fed agriculture to irrigation agriculture. Farmers also desire to get more income from crop sales and hence abstract more water for irrigation, reducing streamflow in the four rivers. The poverty levels in the four sub basins could also be the cause for increased water abstractions. According to MICDP (2014), 36.3 % of the residents in Muranga County live below poverty line. The poverty level can drive people to abstracting water to enable them feed their families.

Industries in the study area are mainly agriculturally based. Coffee and Tea processing are the main industries in the study area. Most of these industries produce semi-finished products which are exported to other countries for processing. There are 21 coffee mills, three (3) tea factories, and two (2) fruit processing plants in the study area (MCIDP, 2018). The employed population in the study area account for only 26% of the total population in the area. Most of the employed persons are employed on casual basis (18%) meaning that they do not have job security.

4.13 Hypothesis Testing

To test the six (6) hypotheses for this study, simple linear regression and logistic regression analysis was done. Through the model, the strength of relationships between different variables was established (McFedries, 2018).

4.13.1 Relationship between streamflow variability and water abstractions/diversions

The hypothesis that there is no significant relationship between streamflow variability and water diversions/abstractions in the South West Upper Tana Basin was tested by entering streamflow values into the regression model as dependent variable while water abstraction was the independent variable. The simple linear regression analysis for the four sub basins in SWUT

Basin was done and the results indicate that in each of the sub basins, there was a significant relationship between water abstraction and streamflow (Table 4.23).

Table 4. 23 Model summary for predicting streamflow based on water abstraction

Model	**R**	**R Square**	**Adjusted R square**	**Std. Error of the estimate**
1	0.51(a)	0.46	0.38	1.13

The results indicate that water abstraction can only explain 46% of streamflow in SWUT basin as shown by R^2 (Table 4.23). This implies that the remaining 54% of the variation in streamflow could be accounted for by other factors included in this study. To further understand the contribution of water abstraction to the changes in streamflow, the estimated coefficients from the model were computed (Table 4.24).

Table 4. 24 Coefficients of determination

Model	Unstandardised Coefficients		Standardised Coefficients	t	Sig.
	B	St. Error	Beta		
1 Constant	1.37	0.29		4.16	0.00
Water abstraction	0.29	0.11	-0.34	2.51	0.01

The results indicate that there was negative influence of water abstraction on streamflow. The coefficients in table 4.24 indicate that a unit increase in water abstraction led to 0.34 units decrease in streamflow. The study concluded that there is a significant relationship between water abstraction and streamflow since the Sig. value of 0.01< 0.05.

Thus, the null hypothesis that there is no significant relationship between streamflow variability and water diversions/abstractions in the South West Upper Tana Basin is rejected.

4.13.2 Relationship between streamflow variability and rainfall variability

In testing the hypothesis that there is no significant relationship between streamflow variability and rainfall variability in the South West Upper Tana Basin, streamflow values were entered into the regression model as dependent variable while rainfall variability was the independent variable. The results are presented in Table 4.25 below;

Table 4. 25 Model summary for predicting streamflow based on rainfall variability

Model	R	R Square	Adjusted R square	Std. Error of the estimate
1	0.70(a)	0.61	0.49	0.38

The results in the above table indicate that rainfall variability accounts for 61% of the streamflow variability in SWUT Basin. Further, the contribution of rainfall variability to streamflow variability was explained by the estimated coefficients from the model (Table 4.26).

Table 4. 26 Coefficients of determination

Model	Unstandardised Coefficients		Standardised Coefficients	t	Sig.
	B	St. Error	Beta		
1 Constant	0.64	7.55		1.70	0.00
Rainfall variability	3.92	1.07	0.55	5.08	0.02

From the regression coefficients, it is evident that a unit increament in rainfall variability will lead to 0.55 unit increase in streamflow. The relationship was deemed significant since Sig. 0.02 < 0.05.

Thus, the null hypothesis that there is no significant relationship between streamflow variability and rainfall variability in the South West Upper Tana Basin is rejected. These results agree with (Meron and Wilems, 2012) who established a positive Pearson's correlation coefficient between rainfall and streamflow of 0.8. Similarly, a study by Bekele (2013) established a strong positive Pearson's correlation coefficient r of 0.719 and coefficient of determination R^2 0.635 between rainfall and streamflow.

4.13.3 Influence of household structure on water abstraction

To test the hypothesis that there is no significant influence of household structure on water abstraction in the South West Upper Tana Basin, logistic regression was run. The technique was used to determine the influence of independent variables; household size, age of household head, marital status of household head and settlement period on the dependent variable water abstraction in the SWUT Basin. The regression results are presented in table 4.27.

Table 4. 27 : Influence of household structure on water abstraction

Explanatory varible	Estimated coefficient	Odds ratio	P value
Household size	-0.01	1.26	0.95
Age of household head	0.05	1.36	0.50
Marital status of household head	0.01	0.29	0.78
Settlement period	0.23	2.17	0.60
(Constant)	0.00	1.88	0.97

The results indicate that the household size (coefficient = -0.01; odds ratio = 1.26; P = 0.95) negatively influences water abstraction. Further, a unit increase in household size reduced water abstraction by a factor of 1.26. The P value of 0.95 was greater than the alpha value of 0.05, hence, the influence of household size was deemed to be insignificant. However, the influence of the age of household head (Coefficient = 0.05; odds ratio = 1.36; p = 0.50) on water abstraction was positive. A unit increase in age of household head increased the probability of water abstraction by a factor of 0.05. The influence of age of household head on water abstraction was non-significant since the P value of 0.50 was greater than the 0.05 alpha value.

The marital status of the household head (Coefficient = 0.01; odds ratio = 1.36; p = 0.78) positively influenced water abstraction. This implies that married household heads were 1.36 times more likely to abstract more water than unmarried household heads. The influence of marital status of household head on water abstraction was insignificant since the P value of 0.78 was greater than the alpha value of 0.05. Moreover, the settlement period of the water abstractor had a coefficient of 0.23 and odds ratio of 2.17. This implies that there is a positive relation between settlement period of the household head and water abstraction. Further, those people who have settled in the study area for a longer period are 2.17 times more likely to abstract more water compared to those who settled there recently. In addition, the influence of settlement period on water abstraction was insignificant since the P value 0.60 was greater than 0.05.

Hence, household structure has no significant influence on water abstraction. Thus, the null hypothesis that there is no significant influence of household structure on water abstraction in the South West Upper Tana Basin is accepted.

4.13.4 Relationship between education, income of the household head, employment status and water technologies and water abstraction

Logistic regression was run to determine if there was a significant relationship between education, occupation and water technologies and water abstraction in the South West Upper Tana Basin. The results are shown in the table 4.28.

The results in table 4.28 below show that there is a positive relationship between water abstraction and education level, income of household head, employment status and technology used. The influence of education level on water abstraction was found to be positive. The results for income level of household head (coefficient = 0.09; odds ratio = 1.24) indicate that a unit increase in income of household head increased the probability of abstracting water by a factor of 1.24. This implies that households with more income are more likely to abstract more water than those with lower incomes.

The employment status of household head had a positive influence on water abstraction (Coefficient = 0.21; odds ratio = 4.63) implying that respondents who are employed are 4.63 times more likely to abstract more water than the unemployed. Moreover, the results showed that application of technology increased the probability of water abstraction rates by 3.97 times (coefficient = 1.12; odds ratio = 3.97). This indicated that farmers who apply technology abstract more water than those relying on traditional methods of abstracting water. However, the relationship of the predictor variables to water abstraction was deemed insignificant since the P values of 0.74,0.23, 0.91 and 0.52 for education level, income of household head, employment status and technology used, respectively, were greater than 0.05.

Thus, the null hypothesis that there is no significant relationship between education, income, employment status and water technologies and water abstraction in the South West Upper Tana Basin was accepted.

Table 4. 28 : Influence of education, income, employment status and water technologies on water abstraction

Explanatory variable	Estimated coefficient	Odds ratio	P value
Education level	0.16	0.40	0.74
Income of household head	0.09	1.24	0.23
Employment status	0.21	4.63	0.91
Technology	1.12	3.97	0.52
(Constant)	0.13	0.05	0.56

4.13.5 Influence of agricultural practices on water abstraction

The null hypothesis that there is no significant relationship between agricultural practices and water abstraction in the South West Upper Tana Basin was tested through running logistic regression. The results are presented in table 4.29.

Table 4. 29 : Influence of agricultural practices on water abstraction

Explanatory variable	Estimated coefficient	Odds ratio	P value
Crop sales	0.78	22.35	.01*
Farm size	0.85	11.19	.04*
Fertiliser use	0.65	3.08	.02*
(Constant)	0.03	.02	.04*

Note: *indicates significant at 5% level of significance

The results indicate that crop sales (coefficient = 0.78; odds ratio = 22.35) positively influenced water abstraction in SWUT Basin. Thus, a unit increase in the crop sales increased the probability of abstracting water by 22.35 units. This influence was significant since the P value of 0.01 was < 0.05. Moreover, farm size (coefficient = 0.85; odds ratio = 11.19) was found to have positive influence on water abstraction. The results imply that farm size in the study area influenced the probability of abstracting water by a factor of 11.19. The influence was significant since the P value of 0.04 was less than 0.05. Additionally, the amount of fertilizer used (coefficient = 0.65; odds ratio = 3.08) also had a positive influence on water abstraction.

A unit increase in fertiliser use in a farm increased the probability of abstracting water 3.08 times. The influence was significant since the P value of 0.02 was less than 0.05. Hence the null hypothesis that there is no significant relationship between agricultural practices and water abstraction in the South West Upper Tana Basin was rejected.

4.13.6 The downstream and upstream impacts of water abstraction/diversion

The testing of hypothesis that the abstraction of river water has no significant downstream and upstream impacts in the South West Upper Tana Basin was done through logistic regression analysis (Table 4.30). The results indicated that there is a positive relationship between water abstraction and reduced river water level with a coefficient of 0.51 and odds ratio of 0.20. This implies that water abstraction increased the probability of reduced water levels by a factor of 0.20. The relationship was deemed significant since P value of 0.01 was less than 0.05. Similarly, the relationship between water abstraction and decreased turbidity (coefficient = 0.54; odds ratio = 2.28; P = 0.03) was positive. The results imply that water abstraction increased the probability of decreased turbidity by a factor of 2.28. The relation was significant since $P < 0.05$.

The results also indicated that improved crop yields (coefficient = 0.78; odds ratio = 22.35; P = 0.01) was positively influenced by water abstraction. Water abstraction would thus increase the probability of improved crop yields 22.35 times. The relationship was deemed to be significant since the P value < 0.05. Additionally, the relationship between water abstraction and nitrate concentration (coefficient = 0.29; odds ratio = 5.79; P = 0.31) was positive. The relationship was however insignificant since the P value of 0.31 was greater than 0.05. With regard to water related conflicts in the basin, the results generated a coefficient of 0.23, odds ratio of 1.97 and P value of 0.09 implying a positive relationship. However, the relationship was not significant ($P > 0.05$).

Degraded vegetation also got a positive coefficient of 0.05 and an odds ratio of 2.09. This means that water abstraction in the basin has increased the probability of vegetation degradation by 2.09 times. The P value of 0.06 was however greater than 0.05 implying the relationship is not significant. The coefficient of changes in river morphology was 0.48, translating to odds ratio of 7.55. This implies a positive relationship between water abstraction and changes in river channel morphology. The P value of 0.01 < 0.05 indicating a significant relationship between water abstraction and change in river morphology. Finally, the relationship between water abstraction and reduced silation in the river channel was positive with a coefficient of 0.56, odds ratio of 1.15 and P value of 0.00. The relationship was significant (P < 0.05). Hence, the null hypothesis that the abstraction of river water has no significant downstream and upstream impacts in the South West Upper Tana Basin was rejected.

Table 4. 30 : Coefficients of determining impacts of water abstraction

Explanatory variable	Estimated coefficient	Odds ratio	P value
Reduced water level	0.51	0.20	0.01*
Decreased turbidity	0.54	2.28	0.03*
Improved yields	0.78	22.35	0.01*
Nitrate concentration	0.29	5.79	0.31
Conflicts	0.23	1.97	0.09
Degraded vegetation	0.05	2.09	0.06
Changes in river morphology	0.48	7.55	0.01*
Reduced siltation	0.56	1.15	0.00*
(Constant)	0.01	0.60	0.00*

Note: *indicates significant at 5% level of significance

CHAPTER FIVE

5.0 DISCUSSIONS OF THE RESULTS

5.1 Introduction

This chapter presents the discussions of the results for the study. The discussions were aimed at providing details on the relationship between various factors that were found to play a critical role in influencing water abstraction in the study area. Attempt was made to examine the relationship between impacts and responses. The discussions presented in this chapter also present comparisons with the findings of other studies conducted elsewhere.

5.2 Relationship between rainfall and stream flow

This study established that there is a significant relationship between rainfall and streamflow (Table 4.25). Therefore, variability of rainfall positively influences the changes in streamflow in SWUT Basin. There is evidence of increasing variability in rainfall and streamflow in the study area. Other studies have shown that the mean discharge does not show a negative trend even when there is an increase in low discharge in the river (Kitheka *et.al*, 2019). This can be attributed to the land use changes in the upstream that led to changes in the flood peak flows (Aeschbacher *et al.*, 2005). Streamflow in this area has been affected by the changing rainfall patterns. Years that have experienced more rainfall have also had higher river discharge. These are periods between 2002 and 2003, and between 2010 and 2015. The results from the simple linear regression model indicated that R Square of the relationship between rainfall and river discharge was 0.61. This shows that, while rainfall can explain 61% of the variability of streamflow in the sub basin, it is not the sole factor affecting river discharge in this sub basin. Other factors such as land use /land cover change and basin characteristics could also lead to streamflow variabilities (Kitheka *et al.*, 2019).

A study by Dawdy and Bergmann (1969) established that differences in the distribution of rainfall had subsequently affected the streamflow in river basins. In their study, Sharma *et al*. (2015) established that rainfall variability was a major factor explaining the quality of streamflow. This is in agreement with Bekele (2013) who established a strong positive Pearson's correlation coefficient r of 0.719 and coefficient of determination R^2 0.635 between rainfall and streamflow. Similarly, Merom and Willems (2012) established that there was a positive Pearson's correlation coefficient r of 0.8 between rainfall variability and streamflow variability. These findings are consistent with Mokaya (2015) who established that there was a significant relationship between rainfall and streamflow with a Pearson's correlation coefficient r of 0.58. These results also agree with Gabrecht *et al*. (2004) who established that changes in rainfall trends had a significant influence on streamflow. Similar findings were reported by Dettinger and Diaz (2000), Kabede *et al.* (2006) and ERM (2007). However, a study by Martins and Martins (2016) noted that rainfall was not the main factor influencing streamflow in Ivai River, Brazil. In this study, landcover changes were identified as having significant relationship with streamflow in the river basin. Similar findings were reported by Yardav (2002), Viessman (2003) and Njuguna (2006). The results of the study showed that during the dry periods in Kiama, Kimakia, Thika and Chania sub basins, the streamflows decline to very low levels. Water abstractions are normally high in dry season due to the increased need for irrigation water. These abstractions affect the low flows during this period leading to extremely low levels of water (mean <0.5 m). The results are consistent with others that have shown that during the dry-season, water abstractions reduce base flows during this period (Liniger *et al.,* 2005; TNC, 2015). The results also agree with Ahmed *et al.* (2011) who established that rainfall and streamflow variability have direct impact on agricultural production (See also Jesse *et al*. 2005).

5.3 Relationship between water abstraction and streamflow

The results of the study showed that there is a significant negative relationship between streamflow and water abstraction (table 4.23). Increase in water abstractions in the four sub basins has led to variations in river discharge in dry seasons (see also Mukhwana, 2016). The simple linear regression model results showed that water abstraction can only explain 46% of streamflow in SWUT basin as shown by R^2 (Table 4.23). This implies that there are other factors that account for 54% of streamflow variations in the basin. The impacts of streamflow and water abstraction are more evident during low flow conditions when the demand for water is very high. The abstraction of water for irrigation agriculture leads to considerable decline in baseflows in the rivers. This agrees with Mromba (2012) who established a strong relationship between water abstraction and stream discharge. However, the impacts of water abstraction on flood flows (high flows) during rainy seasons were less evident. This could be attributed to the fact that during rainy season, farmers reduce abstraction of water from the rivers. It seems that water abstraction from the rivers is used to boost crop production following the cessation of rainy season. The results are consistent with those of Kossa *et al.* (2014) and Mwadini (2018).

Without irrigation, most of the farmers would not be able to harvest because the chances of crop failure after the cessation of rainfall are extremely high (Mutiga *et al*., 2010; Shah *et al*., 2013). These findings are also in agreement with Olang and Kundu (2011), Sampson (2012) and Mokaya (2014) who established that water abstractions for industrial, agricultural and municipal uses were responsible for the diminishing streamflow during the dry season in Nyakomisaro River. This study established that there was a significant relationship between streamflow and water abstraction for municipal supply with a correlation coefficient of 0.91. Similarly, Cai and Rosegrant (2004) noted that water abstraction and diversion in China's Yellow River resulted in the drying up of upto 600 km of the river in 1997. This agrees with Pyka *et al.* (2016) who noted that the diversion of River Ruhr, Germany would negatively impact on streamflows in summer. Similar findings were reported by Juckem and Robertson (2013) who determined that water abstraction and river diversion decreased water levels in the river but when these diversions were removed, water levels increased gradually in the following years.

5.4 Relationship between household characteristics and water abstraction

There is a significant influence of household characteristics in regards to water abstraction. The results of the study showed that 90% of the farmers have lived in this area of study since they were born. The 10% mainly consist of people who have migrated to these sub basins to look for jobs in the tea farms. Others migrate here to gain access to water from the rivers for irrigation agriculture. The results of the study also showed that 71% of the people living in the study area were married while 21% were single and 1% divorced. The single-family respondents mainly comprised of women which explains why more women (56%) were involved in water abstraction than men since they have to abstract water for irrigation to ensure they get income to maintain their families and pay school fees for their children. This agrees with Cheruiyot (2016) who established that the settlement period of a person affects water demand in an area. The other reason for involvement of women in water abstraction more than men is the literacy levels. In Murang'a County, 73.9% and 66.7 % of men and women respectively are literate (MCDIP, 2014). This means that men are more likely to gain formal employment than women. Emigration of male to the nearby urban areas such as Thika and Nairobi in search of economic opportunities has also limited their numbers in water abstraction. Though the influence of marital status of household head on water abstraction was positive, the results show that the influence was insignificant since the P value of 0.78 was greater than the alpha value of 0.05.

The mean family size in the area was found to be 4 members with 81% of the households having 3-5 members. The relationship between water abstraction and household size was a negative one (coefficient = -0.05; odds ratio = 1.26; P = 0.95). The relationship was deemed insignificant since the P value of 0.95 was greater than the alpha value of 0.05. Thus, there are small households that abstract more water than larger households. This could be attributed to the fact that the small households employ casual labourers or procure water abstraction technologies such as water pumps that abstract more water (see also Mwadini, 2018). Water abstraction is therefore not determined by household size but by other factors such as rainfall variability, farm size and age. However, a study by Mokaya (2014) established that household size could have a significant influence on water abstraction. This also agrees with Keshavarzi *et al.* (2006) and Froukh (2001) who noted that household size is the most important factor affecting water abstraction.

The study also established that most of the people involved in water abstraction were aged between 30 and 50 years old. These are people with low levels of education and with relatively young families. Thus, they abstract more water for irrigation agriculture in order to obtain high income to fulfill the needs of their families. It was established that people aged >50 years abstract very low volumes of water since most people in that age are retirees who may not have a lot of energy and financial ability to do large scale farming that requires a lot of water (see also Ramirez *et al.,* 2008; Adeoti, 2009; Owilla, 2010). The fact that the retirees have pension and therefore do not need to struggle with the demanding agricultural activities could also be a reason why they abstract low volumes of water. This study established that the influence of age on water abstraction was positive (Coefficient = 0.05; odds ratio = 1.36; p = 0.50). However, the influence was not significant since the P value of 0.50 was greater than the 0.05 alpha value. This agrees with the findings of Speelman (2009) who found out that age was an important factor influencing water abstraction in South Africa.

In the study area, 56% of the people abstracting water were women as compared to 44% who were men. This high proportion of women abstracting water from the basin can be attributed to the fact that in the basin, there are more families that are headed by women. Emigration of male to the nearby urban areas such as Thika and Nairobi in search of economic opportunities has also limited their numbers in water abstraction (MCIDP, 2014). This is consistent with other studies such as Kimani and Kombo (2010); Sultana (2012); Belay and Bayene (2013). The results also agree with Nhamachena and Hassan (2007) who established that the decline in men’s involvement in farm activities in Central Kenya was due to emigration to Nairobi and other local town centres. This study established that there is no significant relationship between household structure and water abstraction. Therefore, it can be argued that household size, age of household head, marital status, and settlement period in the study area do not significantly influence the patterns of water abstraction in the study area. As it will be demonstrated in the other sections, other factors related to agricultural uses of water, seems to be more dominant (Adeoti, 2009; Kossa *et al.,* 2014).

5.5 Influence of education, occupation, income and technologies on water abstraction

This study examined the extent to which education, occupation, income and application of technologies affect water abstraction in the study area. It was established that there is a positive relationship between educational level (coefficient 0.16; odds ratio 0.40) and rate of water abstraction. Majority of the people abstracting water from the rivers have only secondary education. This low level of education cannot qualify the respondents for formal employment. Thus, they have to rely on farming as the sole source of livelihood. It was also noted that majority of the people abstracting water are relatively poor with low levels of income ranging between Kshs 5,000 and Kshs 20,000 per month. Only 4% of the respondents earn > Kshs 30,000 per month. This low income drives most of the people in the study area to farming to help them raise enough income to maintain their family and pay fees. This agrees with Rutaisire *et al.* (2010) who established that the occupation of household head significantly affects the water abstraction and the agricultural activities the family engages in. The high-income earners are also involved in water abstraction in the study area.

The results indicate that the coefficient of income level was 0.09 which translated to odds ratio of 1.24. This implied that high income earners are 1.24 times more likely to abstract more water than low income earners. The high-income earners abstract high amounts of water since they have enough income to put many acres under irrigation and also employ modern water abstraction technologies. This is also consistent with Chebil *et al.* (2012) who found out that education and income were potential determinants of water demand in Tunisia (See also Mwangi, 2017). However, Speelman (2009) established that educational level did not have a significant influence on water abstraction among small scale farmers in South Africa.

Similarly, Owilla (2010) established a negative relationship between water use and farmers age in Mwea irrigation scheme. The study noted that young farmers were more likely to use more water for irrigation than old farmers since the later are more restricted in irrigation water use. Adeoti (2009) noted that there was a negative relationship between irrigation technology used and age of the farmer in Ghana while Ahmed *et al.* (2012) and Ahmed *et al.* (2013) found out that there was a negative relationship between age and water abstraction technology used.

It was also established that the use of water abstraction technology positively influences water abstraction. The main means of abstracting water in the study area is the use of buckets or jerricans. The use of buckets is common because they are cheap to acquire and also easy to use. In addition, most of the farmers have small plots of land that can easily be irrigated using the bucket. Weirs are also used to divert water to farms accounting for 26%. However, the popularity of the diversion weirs and canals is not high because they require constant silt removal after every rainy season. The use of water pumps was found to be common with 25% of the respondents while only 8% use pipes. Those using water pumps are the ones with more income that enables them to buy and maintain the pump (see also Kossa *et al.* 2014). A study study in Mkoji sub basin established that, the abstraction technologies that were applied in abstracting water from the river were both traditional and improved (Kossa *et. al,* 2014). Similarly, Mwadini (2018) established that the main water abstraction technologies in Kiladeda sub basin were buckets and diversion canals.

5.6 Influence of agricultural practices on water abstraction

The results of the study show that irrigation agriculture is the dominant cause of water abstraction. There is a significant positive relationship between water abstraction and income from crop sales. The results show that a unit increase in the crop sales triggered 0.78 units increase in water abstraction. This influence was significant since the significant value of 0.01 was less than the alpha value of 0.05. There is also a significant relationship between farm size and water abstraction. Higher acreage of land under irrigation enables the farmers to get more yields since they are able to abstract more water for irrigation. A unit increase in farm size was found to influence 0.85 units increase in water abstraction. The influence was significant since the significant value of 0.04 was less than the alpha value of 0.05. The farmers with larger farms have more income which enables them to use abstraction technologies such as water pumps which abstract huge volumes of water from rivers. Without water abstraction most farmers would not be able to obtain the high crop yields (Gichuki *et al.*, 1998; Ericksen, 2011).

This agrees with Speelman (2009) who established that farm size and crop type have a significant influence on water abstraction for irrigation use. These findings also agree with Hussain *et al.* (2011) who established that agricultural water use is important in ensuring food security in many countries. The study also noted that irrigation agriculture is important in sustaining the incomes of farmers since it enables them to diversify crop production. Michailidis *et al.* (2010) established that in many developing countries, irrigation agriculture contributes the highest water abstraction volumes. This agrees with Shah *et al.* (2013) who noted that agriculture is the main livelihood of most people in Sub Saharan Africa and contributes 30% of Gross Domestic Product of the countries in the region. This is also consistent with Ntale and Litondo (2013) who found out that agriculture contributes 25% of Kenya's Gross Domestic Product. However, Bekele (2013) established that changes in streamflow led to reduced average production of crops in Gademso river basin. In addition, Moore (2009) found out that large farms are more likely to use less water per hectare since they employ water efficient techniques in irrigation as opposed to smaller farms.

Therefore, irrigation agriculture guarantees higher crop yields and hence, higher income from the sale of crops. This explains why farmers strive to increase water abstraction in order to maximize on crop production and subsequent high incomes. It was established that farmers who abstract >2000 litres every day are able to receive more than Kshs 200,000 in crop sales every season. Most of the crops are sold during the dry season, an indication that only farmers who abstract/divert water for irrigation are able to produce crops in this season. Those practicing rainfed agriculture are therefore greatly disadvantaged. The results of this study agree with those of Amosson *et al.* (2005); Evans and Sadler, (2008); Mromba (2012). Similarly, Bekele (2013) established that the demand for irrigation water significantly increases during drier months while Ahmed *et al.* (2011) noted that regions that are predominantly dependent on rainfed agriculture, are highly affected by changes in onset, distribution and duration of rainfall.

5.7 The influence of Water abstraction projects on streamflow

The main water abstraction projects in the study area are Thika/Ndakaini dam, Indipendent Mataara Water Production plant and Gatanga Community Water. The design capacity of these projects is to supply 70,035,000 m^3/day (AWSB, 2016). This represents 43% of the water volume in the rivers. Expansion of these projects could lead to extreme low flows during the dry season. This agrees with Kossa *et al.* (2014) who established that 80% of the downstream users in Mkoji sub catchment believed that water abstractions upstream were the main cause of reduced flows in the sub basin. Similarly, Mutiga (2010) established that there was a reduction in domnstream flows of Ewaso Ng'iro River due to increase in water abstraction upstream. These findings also agree with Jacobs *et al.* (2007) who established that the increase in water uses for agricultural production was the main cause of erratic downstream flows.

5.8 Application of DPSIR assessment framework

This study established several drivers, pressures, state, impacts and responses to water abstractions in the study area. Figure 5.1, shows a summary of the DPSIR framework for South West Upper Tana Basin focused on examining the root causes and impacts of increased water abstraction in the basin. These are expounded in the following sections.

5.8.1 Drivers of water abstraction in the study area

The results of the study showed that the main drivers of increased water abstractions in the South West Upper Tana Basin are agriculture, climate change and population pressure. The drivers are discussed in detail in the following sections.

5.8.1.1 Urbanisation

There has been considerable urbanization in the study area. In the last 50 years, there has been market expansion of rural trading centres and urban centres in the study area (MCIDP, 2018). Urbanization has led to the conversion of once rich agricultural lands into settlement areas. Areas currently under crop farming (coffee) have decreased by 38.4% in the last 15 years while built up area increased by 34.6% (Kitheka *et al.,* 2019). The built-up area is mainly in real estate developments which drives water abstraction since more water is needed by the urban population. Further, the growth of Nairobi City has increased the water demand. The increasing demand for water due to urbanization will put great stress on the existing water sources in the study area (Bates *et al.*,2008). Currently, the city has a deficit of 125,000m^3/day (AWSB, 2012). To solve this, The Northern Collector Tunnel project is under construction and it is expected to be completed by 2022.

5.8.1.2 Culture and Traditions

Majority of people in Kiama, Kimakia, Thika and Chania sub basins (71%) believe that water is free for everyone. They believe that water is God given and cannot get depleted (7%). This belief allows every person to be able to access any amount of water from the four rivers. This tragedy of commons results in wasteful use of water since no one takes responsibility of the resource. Thus, people misuse these traditions to over-abstract water since they give them all the rights to do so, lowering the water levels especially in the downstream of the rivers which affects the users there. Culture does not allow people to fully block the water way (22%). This is important for the downstream users because there is no time when the upstream users can block all the water from getting downstream. Erosion of culture and traditions that were important to the forest conservation which are water catchment areas has also contributed to destruction of the water catchment areas. People no longer respect the traditions like viewing certain forests as sacred since they no longer respect their traditional beliefs.

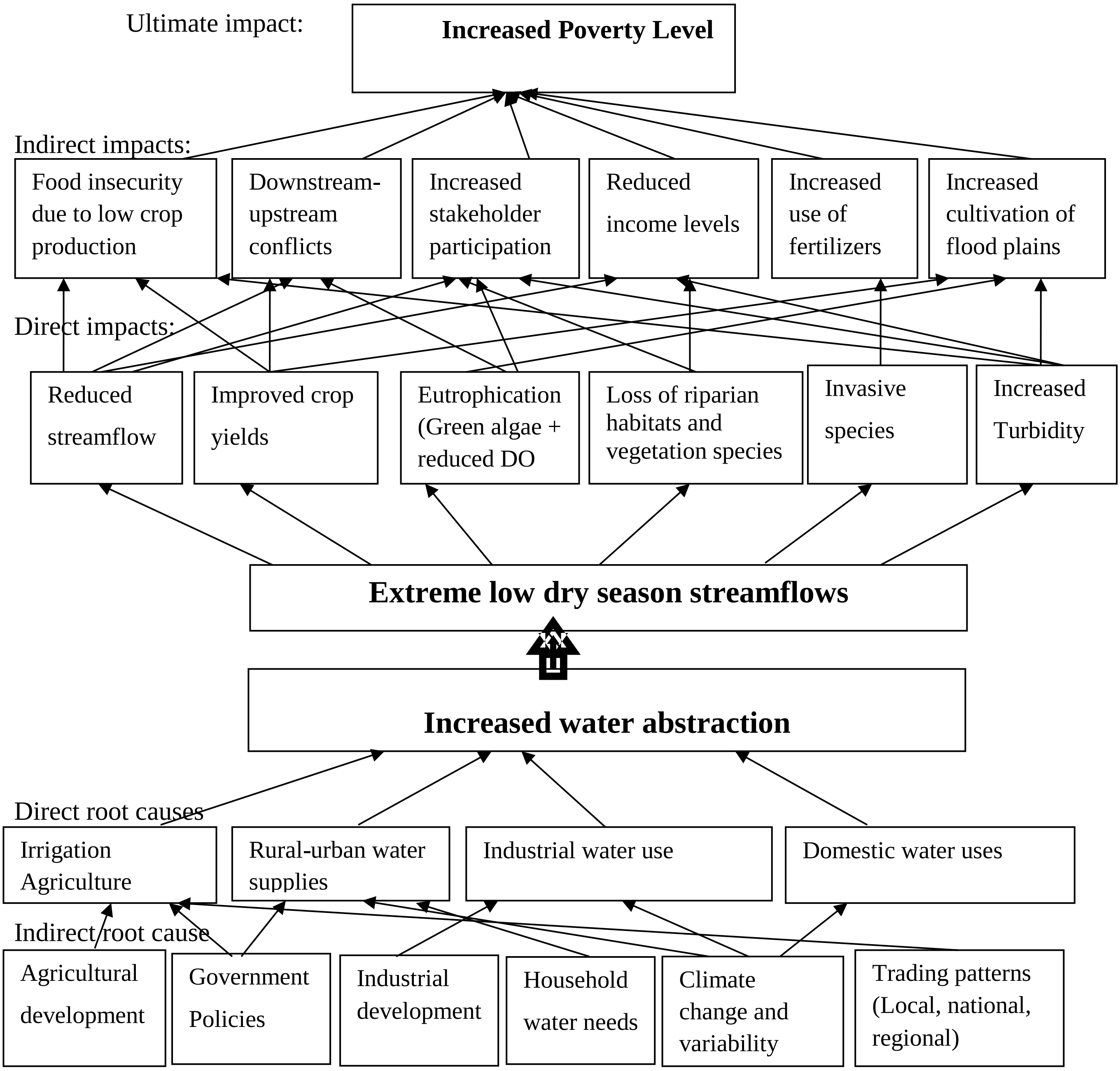

Figure 5.1: Drivers, Pressures, State, Impacts and Responses of water abstraction in SWUT

5.8.1.3 Agricultural development

Agriculture is the main driver of water abstraction in this area (IWMI, 2007). 60% of the people in the study area are farmers (see also (MCIDP, 2014). They rely on agriculture to feed their families and also educate their children. However, the literacy levels in the study area are lower (70.1%) than the national average (71.4%) (MCIDP, 2014). This low literacy rate is also a driver to water abstraction in the study area since most of the people cannot gain formal employment. Thus, they have to rely on farming to get income. In addition, horticultural crops have become very popular among farmers. This has driven farmers to abstracting more water for irrigation from the rivers. Either, there is the desire for the farmers to get more income from crop sales. As discussed in the previous sections, increase in water abstractions leads to increase in crop sales (see also Wagnew, 2004 and Ngigi *et al.,* 2007). In addition, the results of this study show that there is a significant relationship between crop sales and acreage under irrigation farming. This is due to the fact that increased acreage allows the farmer to diversify but also increase water abstraction to improve crop yields which subsequently increase income from sales (Owilla, 2010; Schaible and Aillery, 2013). In similar studies, it has been established that water abstraction for agriculture is the main driver of water abstraction in rivers (IUCN 2009, DAAD 2009). These findings are similar to UN-Water (2013) report that established that increasing water demand for irrigation was causing a strain on water resources in Africa.

5.8.1.4 Population growth and expansion

There has been a major increase and expansion of population in the study area. This has been occasioned by high fertility rate and a limited external migration of people (MCIDP, 2018). Since 1969, population has increased 100 folds from 64,619 persons in 1969 to 132, 069 in 2009 (KNBS, 2010). The increase in population led to increased demand for water for domestic uses and for irrigation agriculture to cater for the growing food demand. This rapid population increase combined with intensification in agricultural production has placed huge demands on water resources (Ngigi *et al.*,2007). The population change from rural to urban has also driven people to horticultural farming because of the growing demand for the horticultural products in urban areas. Horticultural farming mainly relies on irrigation due to the unreliable rainfall in the study area. The increase in urban population has also increased the need for piped water in the area and other adjacent towns such as Thika and Nairobi. A lot of water is abstracted from the four rivers by the Nairobi City Water and Sewerage Company (NCWSC) to supply water for the city of Nairobi. With the projected increase in population in the study area, it is expected that water abstractions increase tremendously in the next 50 years. This will exert considerable pressure on the rivers in the study area. This is similar to Qadir *et al.* (2010) who established that increase in population caused uneven distribution of water resources in the world.

A significant proportion of the population in the study area lack connection to piped water supply. Others have the connection but the supply is unreliable. This has led to an increase in water abstraction from the rivers to improve the supply of water into the household. Either the need to maintain household also drives people to abstract water since most of them rely on farming only as their source of income. Poverty levels could also be cited as a driver to water abstractions in the study area. According to MICDP (2014), 36.3 % of the residents in Muranga County live below poverty line. Poverty has therefore driven people to abstracting water to enable them feed their families (Conway *et al.*,2009; Brooks and Brandes, 2011; Speed *et al.*,2013).

5.8.1.5 Government policies and strategies

Government policies geared towards promoting rural development and agriculture are some of the drivers of water abstraction in the study area. National government and Murang'a County government has been encouraging farmers to diversify crop production by investing more on horticultural farming (MCDIP, 2014). This drives water abstraction because horticultural crops have to be produced through intensive irrigation. Kenya's Vision 2030 also promotes agricultural development in rural area. The Kenya government has also improved access and affordability of fertilizer. Through the provision of this affordable fertilizer, more land has been put into irrigation which means more water abstraction/diversion. Establishment of SACCOs, another provision in this blueprint, has enabled farmers to have more financial ability to improve their farming activities. They are able to access credit facilities from the institutions which help them grow their farming activities through ways such as procuring better water abstraction technologies, increasing water abstraction. Other important policies include focus on rural development, sessional paper No. 10 of 1965 on African socialism that promoted development in high potential areas of the country, irrigation policy (2017) that promotes expansion of small scale irrigation projects in rural areas, agricultural policies, water policies that permit abstraction of water for irrigation agriculture among others.

The National Environment policy (2013) provides an integrated approach to guide planning and management of natural resources in Kenya. The National food policy, sessional paper no.4 of 1981 was the first policy aimed at making Kenya food sufficient. This was followed by the

National food policy, sessional paper no. 2 which promoted market driven approach to improve food security in Kenya. The Kenya Rural Development Strategy (KRDS) 2002-2017 which outlines the strategy for rural development laid emphasis on food security. The Economic Recovery Strategy (ERS) 2003-2007 emphasized on generating wealth and having a lasting solution on poverty and hunger. The strategy for Revitilising Agriculture (SRA 2004-2014) was formulated with a primary objective of promoting investment and encouraging involvement of private sector in agriculture. The Agriculture Sector Development Strategy (ASDS) was developed by the Ministry of Agriculture to align agricultural sector initiatives with Vision 2030. These policies laid emphasis on improved agricultural production to improve food security in the country. This could explain why there are increased water abstractions for irrigation agriculture.

5.8.2 Pressures associated with increased water abstraction

The increased water abstractions in the SWUT basin have led to extreme dry season streamflows. This has resulted to significant impacts that exert specific pressures that are discussed in the following sections. Pressures have direct effect on physical parameters that is the hydrology of the river channels, which in turn alter the state of the environment (Sniffer, 2012). The pressures have led to the modification of the river's natural flow regime in various ways (see also Petts, 1984; Acreman *et al.*, 2008). In the SWUT basin, several pressures exerted on the rivers were identified including use of water for irrigation agriculture, use of water for rural–urban water supplies, use of water for domestic purposes, Inter-basin water transfer, damming upstream and construction of weirs upstream.

5.8.2.1 Use of water for irrigation agriculture and domestic use

Agriculture is the main income generating activity in the study area. It was established that 34%, 40%, 37% and 50% of the farmers in Kiama, Thika, Kimakia and Chania rivers, respectively abstract/divert water for irrigation. Water for domestic uses has also increased pressure for water abstraction because 38%, 40%, 37% and 47% of the respondents in Kiama, Thika, Kimakia and Chania sub basins abstract water for domestic uses. The prolonged dry conditions could be the reason why many farmers have turned to irrigation farming. Average water usage in Kiama, Kimakia, Thika and Chania sub basins is 300 litres/day. This is slightly higher than the average value of 200 litres/day in developed nations and the internationally adopted value of 50 litres/person/day for basic human water needs (Gleick, 1996). Study by Mengistu (2008) established that irrigated agriculture was excerting great pressure on the local hydrology and management of water resources. This agrees with Wim (2010) who established that the irrigation practices in Central Rift Ethiopia were exerting pressure on the hydrological systems in the watershed. Similarly, Smith and McDonald (2000), Booker *et al.* (2012) identified irrigation agriculture as the main water use exerting the highest pressure on water abstraction. Michailidis *et al.* (2010) also established that irrigation water use was the highest driver of water abstraction in developing countries.

5.8.2.2 Use of water for rural –urban water supplies

There are a significant number of water supply projects for rural and urban water supplies in this area. The main one is Thika/Ndakaini dam which diverted water from River Thika and has a design capacity of 70,000 m^3/day. Water in the reservoir is supplied to Nairobi County. The Northern Collector tunnel, which is yet to be completed, is expected to deliver 140,000 m^3/day to Nairobi (AWSB 2016). Other water supply projects in the study area are Gatanga Community water which abstracts water from Kimakia and Kiama rivers. This has a design capacity of 3,000 m^3/day and supplies water to people in Gatanga Sub County (AWSB, 2014).

5.8.2.3 Inter-basin water transfer

The inter-basin water transfers in this area can be found in River Kiama and R. Kimakia whose water are diverted to Ng'ethu treatment plant for supply of water to Nairobi County. Also, after R. Thika is diverted to Ndakaini dam there is an outlet into Kiama River which is then transferred to Ng'ethu treatment plant through a tunnel (AWSB 2016).

5.8.2.4 Damming upstream and construction of weirs

The study established that rivers have been dammed to improve water supply. For instance, Thika River is dammed at Ndakaini to provide water for Nairobi County. Weirs have also been constructed in Kimakia River at Gatakaini to allow the intake of water (3000 m^3/day) for Gatanga Community, R. Kiama at Koiba and Kimakia at Gatura to allow intake of water to Ng'ethu water treatment plant, and in Kiama River near Mbugiti to ease the pumping of water to nearby schools.

5.8.3 State of rivers due to increased water abstraction

The pressures discussed in the preceeding sections results into specific state changes in the river water and associated aquatic ecosystems. The state changes are reduced water levels and volume, reduced water quality, modification of aquatic ecosystems and reduced fertility of flood plains. These are detailed in the following sections.

5.8.3.1 Reduced water quality

There is a relationship between water abstraction and water quality which was evident by the change in water colour (green colour). The change in water colour could be attributed to the nitrate concentrations in the basin. These concentrations vary from 4 mg/l to 14 mg/l during dry season and 0.4 mg/l to 2 mg/l in rainy season. Concentration levels in this basin increase between July and August and between January and February while decrease in nitrate concentration levels is in October and November and between March and May. Similarly, Song *et al.* (2018) established that water diversion in Yangtze River led to deteoriation of water quality in the river. This agrees with Mattias (2014) who established that water abstraction for agricultural use leads to increase of nitrate and phosphorous compounds in water. However, Arroita (2017) established that water abstraction does not affect water quality but only reduces the biomass and nutrient uptake rate. Water abstractions/diversions weirs have also resulted to decreased siltation in the rivers. This is evident from the diversions that 63% of them take approximately 1-3 months to fill up with silt. Most of the diversions weirs take between 1-3 months to fill up with silt (63%). Even in the first week after the onset of rains, only 20% of the diversion canals fill up with silt.

The periods of high turbidity levels are between October and November with 1,065 NTU to 1,392 NTU and between March and April 780 NTU to 1,380 NTU. Low turbidity levels are experienced between June and September with 641 NTU to 70 NTU and between December and February with volume ranging from 668 NTU to 94 NTU (see also Moldan and Ceny, 1994). This is the same period when there is increased water abstraction in the four basins. Increased irrigation also results to loss of soil fertility and increased salinisation. This drives farmers to using more fertilizers that are rich in nitrogen and phosphorous. The fertilizers cause eutrophication when they are washed into the rivers. Similar studies in the area noted an increase in turbidity. For instance, Kimani *et al.* (2016), established that the turbidity level ranges from 64.83 ± 2.30 NTU to 291.33 ± 2.62 NTU during the dry and wet seasons, respectively. This was attributed to anthropogenic activities such as change of land use in the area. These findings also agree with Lane *et al.* (1999) who noted a decrease in total suspended sediment concentrations in Missippi River in spring and summer following the diversion of the river. Similarly, Juckem and Robertson (2013) established that nitrate and phosphorous levels increase in low flow periods because of the high retention rates in upstream wetlands (See also Moldan and Ceny 1994; Manohar *et al*., 2014; Wambugu, 2018).

5.8.3.2 Modification of aquatic ecosystems

Flow regime changes can disturb or eliminate the ecosystem emergent properties such as biodiversity, nutrient breakdown and cycling, carbon sequestration, and stability and resilience of the ecosystem (SNIFFER, 2012). Some of these changes are seen in the trophic webs and dynamics (Woodward and Hildrew, 2002) and they may adjust to respond to the flow impacts and other disturbances (Orth, 1995; Death, 2010). Abstractions have led to changes in the riparian vegetation. In some rivers, plants such as reeds have completely disappeared. Water demanding crops such as arrow roots have also diminished in most of the areas. There are also new plant species that have been introduced into the river after diversion. For instance, on the downstream of River Kiama, immediately after outflow from Ndakaini dam, there are water weeds. The weeds are also found downstream of River Thika after the outflow from Ndakaini dam. This is an indicator that the diversion of water into the dam led to the introduction of the weeds. In Chania River, the plants have outgrown almost covering the river. This is because of the reduced flow which leaves most of the river bed dry for most part of the year. In addition, some plant species have dried up because of the prolonged dry season in the area. These findings are consistent with results of Mukhwana (2016) who noted that water abstraction leads to loss of aquatic biodiversity, disruption of the ecosystem services and invasion of flood plain by alien species (see as reported by Bunn and Arthington, 2002).

5.8.3.3 Reduced fertility of river flood plains

45% of respondents in the study area reported to have increased the amounts of fertilizer usage in their farms. This is attributed to the fact that increased abstractions upstream have led to decrease in water levels in the river which decreased alluvium deposits in the farms. This could be attributed to a decrease in sediment loads in the river since most of them are trapped by the diversions upstream. This means that the farmer has to apply more fertilizer in the farm in order to improve the crop yields. This is consistent with Milton and Dean (2010) who established that reduction in water levels and cultivation along river flood plains can lead to reduction in soil fertility.

5.8.4 Impacts associated with increased water abstraction

The major impact associated with increased water abstraction in the SWUT basin is low dry season streamflow. The specific impacts associated with the low streamflows are detailed in the following sections.

5.8.4.1 Hydrological impacts

This study established that water abstraction and river diversions in the study area had resulted to hydrological impacts such as reduced water volume, changes in stream morphology, reduced silt deposition, reduced ground water charge, increased siltation and reduced water quality. It was found out that water volumes in the rivers in the study area had declined especially in the dry season as a result of water abstraction. Water abstractions are usually high during the dry season since farmers require more water for irrigation farming. Hence, the reduction of water levels in the rivers during those periods. These findings agree with Mokaya (2015) who established that increased water demands during dry season led to decline in streamflow of Nyakomisaro River. The findings are also consistent with those by Mromba (2012) who established that there is a significant relationship between water abstraction and stream discharge. However, during the rainy season, the water abstractions are low, thus there is increase in water levels in the rivers.

The reduction in flows also affects the groundwater recharge since streamflows recharge groundwater (Kithiia 2008; Njogu *et al.,* 2018; Kitheka *et al.,* 2019). The study established a positive relationship between nitrate concentration and water abstraction. However, the results show that the relationship was a weak one since the P value of 0.31 was greater than 0.05. These findings are consistent with Manohar *et al.* (2014); Wambugu (2018). The findings also agree with Ehrman and Lamberti (1992), Larranaga *et al.* (2003) who established a significant relationship between water abstraction and hydromorphology leading to narrow, shallow and slow flow velocity (see also Pitlick and Cress, 2000; Ven, 2011 and Defersha *et al*, 2012).

The study also established that there has been increase in eutrophication levels as a result of increased use of fertilizers. The main type of fertilizer used in the study area is DAP (570 kgs/season). Other types of fertilizers in the study area are CAN (360 kgs/season), TSP (57 kgs/season) and NPK (51 kgs/season) (See also Jacobs *et al.,* 2007; Bunyasi *et al*., 2007). The sub division of land into smaller pieces and increased irrigation in the area has led to decreased soil fertility, hence the need to use fertilizer. Use of fertilizer in the farm allows the farmer to get more crop yields (See also Wagnew, 2004 and Ngigi *et. al* 2007). However, all these types of fertilizers are either rich in nitrogen or phosphorous. The uncontrolled application of these types of fertilizers leads to increased volumes of fertilizer residues in rivers during the rainy season. These fertilizer residues accumulate in the river causing eutrophic conditions, evidenced by change in water colour to green (Manohar *et al.*, 2014).

5.8.4.2 Changes in water turbidity

Turbidity in Kiama, Thika, Kimakia and Chania Rivers increases during the rainy season. However, the rate of increase has declined over the years. From the responses, 26%, 30%, 29% and 32% for Kiama, Thika, Kimakia and Chania Rivers, respectively, it was evident that turbidity increased after water diversions. This is also the case with water colour which only changes to brown for the three months when high amounts of rainfall are experienced and then becomes clear (see also Moldan and Ceny, 1994). Farmers who use diversion canals to abstract water have to desilt their canals after 2 to 3 weeks during the rainy season. This means that during this period there are increased sediments in the rivers. The relationship between decreased water turbidity and water abstraction was significant since the P value of 0.03 was less than the 0.05 Alpha value.

5.8.4.3 Ecological impacts

This study established that there were significant ecological impacts as a result of water abstractions and river diversions in the study area. These ecological impacts include degradation of riparian vegetation, proliferation of weed in the channel, invasive species and loss of biodiversity. Proliferation of water weeds was found to be a major impact on rivers Kiama and Thika. This was mainly on the downstream of Ndakaini dam, an indicator that the weeds could have originated from the dam. The relationship between degraded vegetation and water abstraction got a positive coefficient of 0.05 and an odds ratio of 2.091. Water abstraction in the study area has also resulted to the loss of biodiversity since some of the riparian vegetation that used to provide food to some bird species has since dried up. This agrees with Ven (2011) who established that water abstraction leads to increase in turbidity which decreases sunlight penetration and subsequently restrict photosynthesis leading to death of plants. These findings are also consistent with Reinfelds *et al.*, 2006 who found out that reduced streamflows as a result of water abstraction can alter the assemblage of microinvertebrates and reduce river biodiversity. Additionally, the changes in stream morphology have been found to alter the aquatic habitat and subsequently affect the aquatic biodiversity. These alterations result to changes in the density, composition and abundance of benthic micro invertebrates (Procipio, 2010).

The low flows in the dry season as a result of high-water abstraction rates during that period increase water temperatures subsequently affecting aquatic plants and animals (Mukhwana, 2016). This could be the reason why there is a reduction in riparian vegetation in the study area. Invasive plant species were also found in the rivers in the study area. Invasion of plant species could be attributed to the alterations in streamflow regimes caused by water abstraction (see also Bunn and Arthington, 2002; Milton and Dean, 2010).

5.8.4.4 Agricultural impacts

This study established that there was a significant impact on the agricultural practices in the study area as a result of water abstraction. It was found out that the main agricultural impacts were increase in crop yields, crop diversification and introduction of new agricultural practices. The study established a significant relationship between water abstraction and agricultural practices in the study area. It was established that increase in water abstraction leads to increase in crop yields and subsequently increase in crop sales. It was also established that increase in acreage under irrigation agriculture leads to increase in crop sales since it improves the crop yields in the farm and also allows the farmer to diversify the crop production. These findings conform to Qadir *et al.* (2010) who established that water abstraction for irrigation agriculture significantly improved crop production, enhancing food security in a country. However, Abu-Madi (2009) established that there is a negative correlation between farm size and water abstraction.

Crop diversification in the study area was also a major agricultural impact identified by this study. It was found out that farmers no longer rely on one crop like to they used to do several years ago when tea and coffee were the only crops farmers relied on. Farmers have diversified with horticultural crops being grown in most of the river basins in the study area. This was attributed to the fact that with water abstraction, farmers do not necessarily need to rely on rainfed agriculture since they can do farming even in the dry season. This agrees with Hussain *et al.* (2011) who found out that irrigation agriculture provides farmers with a greater opportunity for crop diversification (See also Ngigi *et al.* 2007). The reduced water levels in the river have also reduced river flooding, both upstream and downstream in the area hence reducing the deposition of fertile alluvium in farms. Therefore, Farmers have to use more fertilizers (36%) to improve yields because of the decreasing fertility of soils in the basin. This is consistent with Jacobs *et al.* (2007); Bunyasi *et al.* (2007).

5.8.4.5 Socio-economic impacts

This study established that water abstraction and river diversions in South West Upper Tana (SWUT) Basin had brought forth several socio-economic impacts such as conflicts, innovative societal guidelines, innovations in water management, employment opportunities, increased income levels and poverty reduction. It was established that water resource use conflicts had increased by 22% in the SWUT Basin. These conflicts were mainly due to the reduced water levels especially in the dry season. However, the study established that the relationship between water related conflicts and water abstraction was insignificant. This was shown by the P value of 0.09 which was greater than the Alpha value of 0.05. This contradicts the findings of Mutiga (2010) who established that excessive water abstraction in the upstream of Ewaso Ng'iro Basin was the main cause of water use conflicts downstream of the basin.

Innovative societal guidelines have been formulated to deal with these conflicts. The study established that 60% of the conflicts arising from water abstraction are solved by respected elders in the society. However, it was found that these informal ways of solving conflicts were not effective since farmers are only warned about increased abstractions meaning they are more likely to over abstract water at the expense of the other downstream users. This study also established that majority of the people in the study area only have secondary school education, thus they cannot gain any formal employment. Adeoti (2009) established that socio-economic factors such as household size, gender and education had a significant influence on water abstraction. Water abstraction has enabled people in the study area to obtain income from farming since 60% of the people living in the study area were found to be farmers. Innovative ideas in water resource management were also found to have emerged among the water users in the study area. Farmers using water pumps mostly pump water early in the morning and late in the evening to ensure that they do not interfere with river flow during the day (see also Mutiga, 2010; Ndiiri, 2011; Kossa *et. al.*, 2014). Similarly, Mwadini (2018) established that agricultural water use could ensure food security and reduce the impacts of drought. This agrees with FAO (2008) who noted that water abstraction for agricultural use was important since agriculture significantly contributes to employment and economies of countries in Sub Saharan Africa.

5.8.5 Analysis of responses to water abstraction

This study attempted to examine the responses to water abstraction in the South West Upper Tana Basin. Responses are the human management actions taken to resolve the impacts (Sniffer 2012). These are designed to respond to the undesired impacts. The responses that were found to be evident in the South West Upper Tana Basin include; i)Water use restrictions (licencing and monitoring by WRA-Water Act), ii) water projects environmental impact assessments (NEMA-EMCA and relevant regulations under EMCA), iii) damming/reservoirs (Thika/Ndakaini), iv) construction of weirs, v) inter-basin water transfer (Northern Collector tunnel project), vi) alternative land uses (Shift from agriculture (coffee) to real estate) and vii) enactment and implementation of policies and legislations are the main responses from the government. These responses are presented in detail in the following sections.

5.8.5.1 Water use restrictions

In the South West Upper Tana Basin, several water use restrictions have been put in place by Water Resources Authority (WRA). The National Environment Management Authority (NEMA) through Environment Management and Coordination Act (EMCA) 1999 places restrictions on the use of wetlands and riparian land. These include water abstraction licensing and legislations like the Water Act 2016. The Water Act 2016, created a framework for participation of local communities in decision making (Republic of Kenya, 2016). The Act provides for creation of local water resource management committees to manage water resources in their localities. The 2016 Act provided for the formation of Basin Water Resource Committees (BWRCs). The committee members are drawn from stakeholders from the basin. The main aim of the committees is to ensure that wide stakeholder participation is achieved in the management of the basin. The committee also establishes Water Resource Users Associations (WRUAs). WRUA is a community-based association for collective management of water resources and resolution of conflicts arising from the use of water resources (Ghazouani *et al.*,2012; Zhang, 2013). This framework can help the community to abstract water in a sustainable manner since it places them at the centre of decision making. In this area we have the Gatanga Community Water, which is a community-based association that helps in supplying and billing water in upper Gatanga.

However, the WRA regional water rights officer indicated that most of the WRUAs have failed since the heads or the chairmen of those associations are usually the main water abstractors. This limits the ability of the chairmen to reprimand or inform the WRA officers about the illegal abstractions in the river basins.WRA licenses people abstracting water with the license specifying the amount they are allowed to abstract from the river. However, most of the water abstractions/diversions are not licensed. The regional water rights officer also indicated that there have not been prosecutions of illegal water abstractors since the authority does not have the capacity to carry out frequent monitoring of the river basins. To control water abstractions in the study area, the County Assembly of Murang'a is enacting a Water Bill which is currently in the second reading. If enacted, the Act will provide for the formation of a County Water Service Board that will have the mandate to control and monitor water abstractions in the county.

5.8.5.2 Water projects environmental impact assessments

A comprehensive environmental and socio-cultural impact assessment must be done before any project in the environment takes place. If the project is to take place, the assessment report should indicate a reasonable degree of certainty that the project will minimally degrade the environmental quality within the area of origin as well as those of delivery (EMCA, 1999). If there exist some devastating impacts to the environment, a justified compensation to offset the same should be provided (EMCA, 1999). These assessments are undertaken by NEMA. However, in the study area, the assessments have not been done. This explains why there is a lot of cultivation in the river beds which has led to their degradation. Assessments on the environmental impacts of increased use of fertilizers in the farms should also be done. The only notable environmental impact assessments done on water resources were during the construction of Ndakaini dam and during the construction and rehabilitation of the Gatanga Water Supply (AWSB, 2016). The small-scale water abstractions have been undertaken illegally without any environmental impact assessment.

5.8.5.3 Policies on water resources

The policies on water resources in SWUT basin include EMCA 1999, Wetland regulations 2009, Waste management regulations, the EMCA (Conservation of Biological Diversity Resources, Access to Genetic Resources and Benefit sharing) Regulations 2006. The EMCA 1999 provided for the development of appropriate institutions and legal framework to manage environment (ROK, 1999). Under EMCA, institutions such as National Environment and Management Authority (NEMA) and District Environment Commitees have been established. NEMA supervises and co-ordinates all matters relating to environment while District Environment Committees enable participation of local communities. Section 58 of EMCA requires any project that will have an impact on environment to have an Environment Impact Assesment licence (ROK, 1999). The Wetlands Regulations 2009 empower the District Environment Committee to monitor, co-ordinate and advise on all wetland resource management and conservation matters within the district (ROK, 2009). Water Quality Regulations provides for the protection of domestic water sources and agricultural water use. These regulations involve monitoring of domestic water sources, provides standards for effluent discharge to the environment and a monitoring guide for discharge into the environment.

The EMCA Regulations 2006 stipulate that any person or institution intending to carry out an activitiy with adverse impact on the environment should have a license from NEMA. The regulations also state that any person intending to access genetic resources in Kenya should have an Access permit for genetic resources (ROK, 2006). The Muranga County government has also formulated policies to deal with the impacts of water abstraction. For instance, MCIDP 2014, emphasis on reducing environmental degradation in the catchment areas through tree planting to improve forest cover in those areas. This has been done in the study area with significant large areas having planted trees especially on the boundaries of tea and cofeee plantations (TNC, 2015). To cope up with the increasing demand, the county government of Murang'a has been encouraging efficient irrigation mechanisms, emphasizing on conservation, encouraging efficient use of water and accelerated awareness campaigns. The government has also outlined a plan to expand the capacity of water supply schemes to attain a minimum of 40% coverage of households with piped water. To cope with the shifting rainfall patterns, the county has outlined a plan to diversify the crops grown in the area and promote sound agricultural practices. To improve on food security, the County government has been encouraging small scale horticulture irrigation projects, food preservation, storage and marketing. This could be the reason why more people are currently engaging in horticulture irrigation. The county government has also been issuing farmers with fertilizer and seedlings during the rainy season to improve crop yields. This has increased the land under cultivation and subsequently led to increased water abstractions (MCIDP, 2018).

5.8.5.4 Legislations on water resource use

The main legislations that were found to be effective in the study area are the Forest Act 2016, Irrigation Act 2017 and Water Act 2016. The Irrigation Act 2017 enables the Cabinet Secretary for Water to come up with appropriate measures to ensure effective harvesting and storage of water for irrigation. It also promotes use of efficient irrigation systems across the country, issues licenses for establishment of irrigation schemes and monitors the conditions attached to licenses for irrigation schemes. This law helps to regulate the water abstractions since irrigation activities are monitored and people required to get licenses when establishing irrigation schemes. The Forest Act 2016, provides for establishment of Kenya Forest Service which manages water catchment areas. This is in relation to water and soil conservation, carbon sequestration and other environmental services (ROK, 2016). This has ensured that the water catchment area which is Aberdares is well managed and conserved. Proper management of the forests in Aberdares has enabled the rivers in this area to have enough water which is abstracted for the various uses.

5.8.5.5 Inter-basin water transfer

The construction of the Northern Collector Tunnel in the study area is aimed at improving water supply to Nairobi and adjacent urban areas. Water from River Mathioya, River Hembe, River Maragua, River Gikigie and River Irati will be diverted through the tunnel to Thika/Ndakaini dam which supplies water to Nairobi. This water project is subject to a conflict between Nairobi County government and Murang'a County government. There are also other diversion projects in River. Kiama, R. Thika, R. Kimakia and R. Chania for the supply of water to Nairobi and also in the county. These projects have increased water abstractions in these rivers (AWSB, 2016).

5.8.5.6 Increased awareness creation

The water management awareness campaigns in the study area have been carried out by Murang'a County government and several NGOs operating in the Upper Tana Basin. The public awareness campaigns are listed as one of the water resource management tools in the County integrated Development Plan (MCIDP, 2017). NGOs such as The Nature Conservancy and Green Water Credits have been creating awareness among people in the study area on the importance of water resources conservation and several ways of managing the catchment areas. The Nature Conservancy has supported the water and soil conservation measures through funding while Green Water Credits encourage farmers to plant more trees in the catchment (TNC, 2015).

5.8.5.7 Societal guidelines on water use

There are several guidelines that the community in the study area has adopted to ensure prudent use of water resources. For instance, when abstracting water, farmers are guided by the principle of mutual respect. Thus, farmers in the upstream always ensure that they use water while minding about the downstream users. Farmers are also discouraged against blocking the river when constructing weirs. In most cases, pumping is done early in the morning and late evening to ensure minimal disturbance of river flow during the day. However, the success of these guidelines remains very low since they are not legally binding. This agrees with Huggins (2000) who noted that customary water management practices were not effective in dealing with water abstraction.

5.8.5.8 Conflict resolution mechanisms

This study established that there are minimal conflicts resulting from water abstraction. Thus, the respondents have adopted different conflict resolution mechanisms. For instance, 60% of the conflicts arising from water abstractions are solved by respected elders in the society. The resolutions are normally binding to both parties in conflict. The local administration including the chief and the assistant chief, have also been involved in solving conflicts. However, these conflict resolution arrangements were found to be inefficient since they are not highly punitive. Hence, people who have undergone through the process of conflict resolution are more likely to continue with over abstraction of water and escalate the conflict. This is consistent with Huggins (2000) who noted that customary systems of water management were not adequate in dealing with water
overuse.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter presents the key findings, the main conclusions and the recommendations of the study. These were formulated on the basis of the results and discussions presented in chapter 4 and 5.

6.2 Key Findings of the Study

The main findings of this study are;

i) Water abstractions/diversions have a significant impact on streamflow in South West Upper Tana Basin. However, the abstractions mostly affect the flow during dry season. There is no evidence of significant impacts during extreme high flows.

ii) The drivers of water abstractions in the study area are climate change, government policies and strategies and agricultural development. The pressures underlying these drivers are need of water for irrigation agriculture, domestic use, inter-basin transfers and damming of rivers.

iii) There is a significant relationship between streamflow and rainfall variability in the study area. Hence, increased variability of rainfall in the basin leads to corresponding increase in variability of streamflow.

iv) Agricultural practices and in particular that include farm size, income from crops and use of fertilizers have significant influence on water abstractions/diversion in South West Upper Tana Basin. Since increase in water abstraction leads to increase in crop sales, there is an increased focus on irrigation agriculture. This is partly driven by the fact that rainfall in the basin has become unreliable and rainfed agriculture is unsustainable.

v) Farm size substantially influences crop yields and the income from crop sales. The farm size influences the amount of water abstracted from the river. Farmers with higher farm acreage obtain higher crop yields and subsequent increase in crop sales.

vi) Household characteristics have an insignificant influence on water abstraction/diversion in South West Upper Tana Basin. Gender, household size, occupation, settlement period and marital status did not have a significant statistical relationship with water abstraction. Some of small households abstract more water than larger households because of their ability to employ better water abstraction technologies such as water pumps.

vii) Most of the water abstractions in the SWUT basin are driven by those in the active ages of 30-50 years but the abstraction rate decreased among those aged >50 years. The people in this age bracket have young families whom they have to feed thus they abstract water to improve crop production, in light of increasing unreliability of rainfall.

viii) There is a weak relationship between age and water abstraction in South West Upper Tana Basin. The statistical analysis showed that age of farmers does not have a significant influence on water abstraction. Some smaller households abstract more water than larger households since they have the ability to procure technologies and hire labourers to abstract more water.

ix) Most of the people in the study area only have secondary school level education which limits their ability to secure formal employment. Hence, they rely on irrigation agriculture to get income to maintain their families.

x) Improved income levels have increased the ability of the farmers to abstract more water from rivers through acquisition of advanced water pumping technologies. These pump more water within a short period of time.

xi) The main water abstraction technology used in South West Upper Tana Basin is 20 litre buckets and Jerricans. This is due to their affordability and ease of use as compared to other water abstraction technologies.

xii) Women form a slightly higher proportion of those abstracting water in the study area. This is due to emigration of men to the nearby towns in SWUT basin. This is also due to the fact that approximately 30% of the family heads in the basin are women.

xiv) Water abstractions in the dry season affect riparian vegetation. Some of the species dry up during the dry season due to the reduced streamflow. Invasive species in form of water weeds also emerge during dry season because of the low velocity of the river.

xv) The main impacts of water abstraction in the study area are reduced water levels, changes in turbidity, improved crop yields, siltation, changes in channel morphology and conflicts. Water levels are extremely low during the dry season since farmers abstract more water during this period to enhance crop production. The conflicts resulting from water abstraction emanate from over abstraction upstream which leaves downstream users without enough water for irrigation. Water turbidity decreases during the dry season because of the reduced Total Suspended Sediment loads due to the low velocity of the river.

xvi) The main responses taken to mitigate the impacts of water abstractions/diversions in South West Upper Tana Basin are water use restrictions, policies and legislations and societal guidelines. These responses are, however, not effective since they haven't been fully enforced. The societal guidelines are not legally binding but only based on verbal warning.

xvii) Licensing and monitoring are still poor in this basin since most of the people abstracting water are not licensed. 90% of water abstractors in this basin are not licensed, meaning they do not have a limit on the amount of water they should abstract from the rivers. Monitoring of these sub basins is also poor with low frequency of visits by WRA officials.

6.3 Main Conclusions of the Study

The main conclusions of the study are as follows;

i) The study concluded that the increasing rainfall variability in South West Upper Tana Basin has significantly influenced streamflow variations.

ii) Water abstractions/diversions only affect streamflow in dry season when abstractions are at peak.

iii) The main drivers of water abstraction in the study area are; climate change, agricultural development and government priorities and strategies.

iv) Agricultural practices such as farm size, income from crop sales and use of fertilizers have a significant influence on water abstraction in the study area.

v) Household characteristics have no significant influence on water abstraction in South West Upper Tana Basin.

vi) The main age for water abstraction in the South West Upper Tana Basin is between the age of 30-50 years.

vii) Education, occupation and water abstraction technologies do not have a significant influence on water abstraction in South West Upper Tana Basin.

viii) There is poor monitoring of water abstractions in the South West Upper Tana Basin.

ix) The impacts of water abstraction/diversion in the study area are improved crop yields, low water levels, changes in water quality, changes in water turbidity, changes in channel morphology and conflicts.

x) The responses to water abstraction and river diversion in South West Upper Tana Basin are policies and legislations, water use restrictions and societal guidelines.

6.4 Recommendations of the Study

The following are the main recommendations of this study.

6.4.1 Recommendations to National Government

i) The Ministry of Agriculture, Livestock, Fisheries and Irrigation should formulate policies that will ensure efficiency in agricultural water uses and water abstraction technologies. The existing policies should also be reviewed to ensure that they do not encourage water abstraction especially in low flow season.

ii) The Ministry of Water and irrigation should mobilize resources to ensure that Water Resources Authority (WRA) is adequately funded to carry out regular monitoring of rivers to curb illegal water abstractions. The ministry, through the department of water services, should carry out capacity building to county governments to ensure they are well equipped in dealing with illegal water abstractions in the respective counties. The department of Irrigation and Drainage should in consultation with County government of Murang'a endavour to support in building capacity of Water Users Associations in this basin.

iii) The Ministry of Interior and Coordination should provide some back up to WRA officers through the chiefs and assistant chiefs to help deal with illegal abstractions.

iv) The Ministry of Environment and Forestry should intensify reforestation programs to improve forest cover since this can potentially improve water yield in the rivers.

6.4.2 Recommendations to County Government

i) The county assembly of Muranga should hasten the enactment of the County Water Act that will allow for the formation of County Water Service Board to help deal with illegal water abstractions.

ii) The Murang'a County Integrated Development Plan provides for the development of tree planting and water resource conservation measures. Therefore, the county government should ensure these policies are implemented.

6.4.3 Recommendations to institutions

i) Water Resources Authority (WRA) officers should increase the frequency of visits to monitor water abstractions and river diversions in South West Upper Tana Basin.

ii) Water Resources Authority (WRA) should carry out awareness campaigns to sensitise farmers on the process of acquiring water abstraction licenses. They should also ensure that the process of acquiring water abstraction license is simple for the farmers.

iii) Water Resources Authority (WRA) should ensure that the Water Resource Users Associations (WRUAs) are functional to enable monitoring of water abstractions.

iv) The National Environment Management Authority (NEMA) should ensure that Environmental Impact Assessments (EIA) are done before any abstraction and river diversion project is implemented. The authority should also ensure that regular environmental audits are carried out to ascertain the impacts of water abstraction and river diversions in the study area.

6.4.4 Recommendations to NGOs and CBOs

i) The NGOs and CBOs in the study area should carry out public education and awareness campaigns to enable farmers to understand efficient water abstraction technologies.

ii) NGOs and CBOs should encourage stakeholder participation to ensure that the decisions made on water resource uses in South West Upper Tana Basin are representative views of all stakeholders.

iii) NGOs should encourage farmers to practice soil and water conservation measures through adopting the mechanisms that pays farmers for management and conservation activities.

6.4.5 Recommendations to key stakeholders

i) Water Resource Users Associations (WRUAs) should be properly constituted to ensure the leadership can properly manage water abstractions in the Basin.

ii) Athi Water Service Board should ensure that all the households in the study area are connected to piped water to minimize abstractions for domestic use.

6.4.6 Recommendations to farmers

i) Farmers should ensure that they use water efficient technologies such as drip irrigation to minimize the amounts of water abstracted for irrigation.

ii) Farmers should also consider harvesting rain water to minimize the need for water abstraction in dry season.

6.4.7 Recommendations for further research

i) More research needs to be done on the impacts of water abstraction and river diversion on sediment loads in the study area.

ii) There is also a need for further research to establish the influence of water abstraction and river diversion on groundwater resources.

iii) Further research to establish the management practices of irrigation water and their effects on water abstraction in the study area.

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APPENDICES

Appendix I: Household questionnaire

SOUTH EASTERN KENYA UNIVERSITY

SCHOOL OF ENVIRONMENT, WATER AND NATURAL RESOURCES MANAGEMENT

DEPARTMENT OF HYDROLOGY AND WATER RESOURCES MANAGEMENT

HOUSEHOLD QUESTIONNAIRE

This questionnaire is for the purpose of this research only, titled **Determination of the Drivers and Impacts of water Diversion and Abstraction in Selected Rivers in the Upper Tana Basin, Kenya.** Please provide your answers in the spaces left after each question. Do not write your name anywhere in this questionnaire. The information provided will be completely confidential.

SECTION A

<u>The socio-economic factors influencing river water diversion from the rivers in upper Tana in the period between years 2008 to 2018</u>

<u>Family issues</u>

1. County……. Location/Village
2. When were you born?……………………..……………………......................................
3. Sex: Male ………………….……………………….. Female……………………………….…….
4. Marital Status: Married…………. Not Married……….……. Divorced……………….
5. If married, what is the number of your children…………………………………….……….
6. Provide details on the ages of each of the child:
   ………………………………………………………………………………..………..
   ……………………………………………………………………………….………..
   ………………………………………………………………………………………….
   ………………………………………………………………………………………….
   ………………………………………………………………………………………….
7. How many are you in your family (Household size)
   ………………………………………………………………………………………….
   ………………………………………………………..……………………………….
8. How long have you lived in this area?
   ………………………………………………………….…………………………..
9. Which is your highest level of education

…………………………………………………………………………………………
…………………………………………………………………………………………

10. What do you do for a living?
    a)
    b)
    c)
11. Have you ever been employed?...Where?.........................
12. If yes for the above, why did you leave employment?
    …………………………………………………………………………………………
    ……………………………………………………………………………………….,.
13. What was your monthly income during the period of employment? …………………………………………………………………………………………

Information on water abstraction

14. Which is the main river near your area?
    ……………………………………………………………………………………
15. Do you abstract water from this river?..
16. If yes, what are the main uses of water that you abstract from the river?
    i)……………………………………………………………………………………...
    ii) …………………………………………………………………………………….
    iii) ……………………………………………………………………………………
    iv)…………………………………………………………………………………….
    v)…………………………………………………………………………………….
    vi)……………………………………………………………………………………
17. How many litres of water do you abstract from the river each day?
    …………………………………………………………………………………………
    ………………………………………………………………………………………..
18. Why did you decide to abstract water from the river?
    a) ……………………………………………………………………………………..
    b) ………………………………………………………………………………………
    c)……………………………………………………………………………………..
    d)………………………………………………………………………………………
    e) ………………………………………………………………………………………
19. How do you abstract water from the river? (Example: use of water pumps, buckets, diversion canal, siphons, etc)
    ………………………………………………………………………………………
    ……………………………………………………………………………………..
20. Do you have a water abstraction license from WRA?..
21. If yes in Q. 21, what is the volume of water that you are authorized to abstract?
    …………………………………………………………………………………………
22. Do Officers from NEMA and WRA visit you?..
    …………………………………………………………………………………………
23. Estimate the volume of water that you abstract from the river each month in a year
    Jan……………..Feb…………….Mar…………….Apr……………..May…….…….
    June……………July…………….Aug……………Sept……………Oct…….………
    Nov………………Dec…………………….
24. Estimate the volume (or water level in metres) of water in the river in each month in a year
    Jan……………..Feb…………….Mar…………….Apr…………………May…….……
    .June ……………July…………….Aug……………Sept……………Oct…….………

Nov………………Dec…………………….

25. Have you noticed any changes in the flow of the river in the recent past?...........
If yes, state the changes observed……………………………………………………..……
……………………………………………………………………………………..…
……………………………………………………………………….………………

26. How have these changes affected people in your area?.
....……………………………………………………
………………………………………………………………………………………
……………………………………………………………………………………..

27. Have you noted any changes in rainfall patterns in your area?..........If, yes, state the nature of changes observed in rainfall
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

28. What is the size of your farm?...

29. What crops do you grow in your farm? (estimate the acreage under each crop)
……………………………...
.............……………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………..

30. For the crops mentioned in Q. 30, estimate the yield per season or year?............................
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

31. Without irrigation, would you have been able to obtain the same yields mentioned in Q. 31 above?...

32. If no, in Q. 32, state the reasons………………………………………………………….
………………………………………………………………………………………
…….……………………………………………………………………………….
…………………………………………………………………………………….
………………………………………………………………………………………
………………………..

33. For crops listed in Q. 30, how much do you get when you sell the crops?
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

34. Where do you sell your crops?
………………………………………………………………………………………
…….……………………………………………………………………………….
…..……….…………………………………………………………………………
…………………...

35. When do you get the best prices for the crops that you grow in your farm using water abstracted from the river?...
……………………………………………………………………………………

36. To what extent has the diversion of water in this river affected your income
....
………………………………………………………………………………………
………………………………………………………………………………………

…………………………………………………………………………………………
……………………………………………………………………………

37. How do you use income that is derived from your farm?..
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
………………………………………………………………………………………...

38. Apart from farming, what are your other sources of income?..
…………………………………………………………………………………………
…………………………………………………………………………………………
………………

39. How do you ensure that when you abstract water, you do not impact negatively on other down stream users of the river water?
....
…………………………………………………………………………………………
……...……………………………………………………………………………………

40. Do conflicts occur on the use of the river water?...............If yes, when do they occur most?...
......

41. How are the conflicts in the use of the river water resolved?
....
…………………………………………………………………………………………

42. What are the societal guidelines for the diversion of river water?
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
………..…………………………………………………………………………….…

43. Are there cultural considerations when diverting river water?.............If, yes, state them
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

44. Who are the main people involved in diverting water from the river (state the number in each category);
    a) Individuals……………….
    b) Non-governmental organizations……………
    c) County government………………
    d) Private firms…………………….
    e) Any other, specify……………………………………………………………

SECTION B

Changes in sediment load following diversion of water from Kimakia, Kiama and Thika rivers in upper Tana basin

1. How is the colour of the water in each month of the year?
   Jan……………..Feb…………….Mar…………….Apr……………..May……..……..
   ….June……………July…………….Aug……………Sept……………Oct…….……
   …..…Nov………………Dec…………………….

2. In which months is the water most turbid?
Jan……………..Feb…………….Mar…………….Apr……………..May…….……..
….June……………July…………….Aug……………Sept……………Oct…….……
…..…Nov………………Dec…………………….

3. In which months does the water become clear?
Jan……………..Feb…………….Mar…………….Apr……………..May…….……..
….June……………July…………….Aug……………Sept……………Oct…….……
…..…Nov………………Dec…………………….

4. In which months does the water become greenish in colour?
Jan……………..Feb…………….Mar…………….Apr……………..May…….……..
….June……………July…………….Aug……………Sept……………Oct…….……
…..…Nov………………Dec…………………….

5. What is the estimated time that these diversions take for them to be filled up with sediments during rainy season?
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………………………
……………………………………………………………………..…………

6. Have these diversions led to an increase of sediments (and turbidity) in the river?
   a) YES b) NO
   Explain……………………………………………………………………………
   ……………………………………………………………………………………
   ……………………………………………………………………………………
   ……………………………………………………………………………………
   ………………………………………………………………………………….

7. Have these diversions led to decrease in sediments in these rivers?
   a) YES b) NO
   Explain……………………………………………………………………………
   ……………………………………………………………………………………
   ……………………………………………………………………………………
   ……………………………………………………………………………………

8. How often do you deepen or remove deposited silt in your diversion channel?..
State the months when this is usually done……………………………………………..
……………………………………………………………………………………
…………………………………………………………………………………..…

9. If you use a water pump, how is it affected by water turbidity and sediments in the river water?
....
....
....
……………………………………………………………………………………

11. Have you noted an increase or decrease of water turbidity in the recent past?................. If, yes, state the nature of increase or decrease
……………………………………………………………………………………………
12. How does changes in the water turbidity and sediment deposition affect your activities?...
………………………………………………………………………………………………
………………………………………………………………………………………………
………………………………………..…………………………………………………………
…………………………………………………………………………………………………
13. How do farmers upstream affect your activities?
....
....
....
14. Have you noticed deposition of sediments in your farm?......................If, yes, state how the same affects your activities..........…………………………………………………………
………………………………………………………………………………………………
………………………………………………………………………………………………
……………………………………………………………………………………………..
15. Do you apply fertilizers in your farm? If yes, state the type and amount applied……………..……………………………………………………………………………
………………………………………………………………………………………………
………………………………...
....

SECTION C

The impacts of reduced sediment load in the lower course of the river following diversion of river water

1. Explain more about the amount of alluvium after diversion as compared to when the river was not diverted
   ………………………………………………………………………………………………
   ………………………………………………………………………………………………
   ………………………………………………………………………………………………
   ………………………………………………………………………………..
2. How does this change in alluvium impact on your farming practices?
   ………………………………………………………………………………………………
   ………………………………………………………………………………………………
   ……………………………………………………………………………
3. Has the river water diversion improved or decreased your agricultural yields?
   ....
   ....
   ....
   ....
   ....
   ....
4. Compare the colour of water on the upper course of the river before diversion and lower course after diversion
   ………………………………………………………………………………………………
   ………………………………………………………………………………………………
   ………………………………………………………………………………………………

……………………………………………………………………………………………
…………………………………………………………..………..

5.What changes on the riparian vegetation in the lower course of the river have you seen after diversion
……………………………………………………………………………………..………
……..……………………………………………………………………………………
…………………………………………………………………………………………
………………………………………………………………………………………….

Appendix II: Interview Schedule

SOUTH EASTERN KENYA UNIVERSITY
SCHOOL OF ENVIRONMENT, WATER AND NATURAL RESOURCES MANAGEMENT
DEPARTMENT OF HYDROLOGY AND WATER RESOURCES MANAGEMENT

INTERVIEW SCHEDULE

This interview schedule is for the purpose of this research only, titled **Determination of the Drivers and Impacts of water Diversion and Abstraction in Selected Rivers in the Upper Tana Basin, Kenya**. The information provided will **only** be used for the purposes of this study. The information provided will be completely confidential.

SECTION A

<u>The socio-economic factors influencing river water diversion from the rivers in upper Tana in the period between years 2008 to 2018</u>

1. Job Description (work place and mandate)
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ……………………………………………………………………………………….
2. How long have you held this position……………………………………………….
   ……………………………………………………………………………………….
3. For how long have you been working in this area ……………………………………
   ……………………………………………………………………………………….
4. Which is our highest level of education………………………………………………
5. Which rivers are under our jurisdiction………………………………………………
6. Do people in this area abstract water from these rivers………………………………
   If yes, what are the main uses of water abstracted from the rivers?
   i)…………………………………………………………………………………....
   ....
   ii) ………………………………………………………………………………
   ………………………………………………………………………………………
   iii) ……………………………………………………………………………………
   ……………………………………………………………………………………..
   iv)……………………………………………………………………………………
   …..
   v)……………………………………………………………………………………
   ………………………………………………………………………………….…
   vi)……………………………………………………………………………………
   ………………………………………………………………………………...

7. How many litres of water are abstracted from the river each day?
………………………………………………………………………………………
………………………………………………………………………………………
8. What are the methods used in abstracting water from the river (s) (e.g canals, pumps, buckets)?
………………………………………………………………………………………
…...……………………………………………………………………………………
………..………………………………………………………………………………
……………...…………………………………………………………………………
…………………...
9. Do these people have licenses from WRA to diver/abstract water……………………
If yes, what is the volume of water that you authorize them to abstract……………………………………………………………………………
………………………………………………………………………………………
10. Do officials from NEMA and WRA often visit this area to inspect the diversions/abstractions?...
....
If yes, how frequent………………………………………………………………
11. Estimate the volume of water that is abstracted/diverted from the river each month in a year
Jan……………..Feb…………….Mar…………….Apr……………..May……..…
….June……………July…………….Aug……………Sept……………Oct…….
………Nov………………Dec…………………….
12. Estimate the volume (or water level in metres) of water in the river in each month in a year
Jan……………..Feb…………….Mar…………….Apr……………..May……..…
….June……………July…………….Aug……………Sept……………Oct…….
………Nov………………Dec…………………….
13. Have you noted any changes in the flow of the river in the recent past?...........
If yes, state the changes observed…………………………………………………....
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………
14. How have these changes affected people relying on the rivers?
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………
15. Have you noted any changes in rainfall patterns in this area?..
If, yes, state the nature of changes observed in rainfall…………………………………
………………………………………………………………………………………
………………………………………………………………………………………
16. To what extent has the diversion of water in this river affected income levels
....
....
....

17. How do you ensure that when upstream users abstract water, they do not impact negatively on downstream users of the river water?
....
....
....
18. Do conflicts occur on the use of the river water?..............If yes, when do they occur most?..
19. How are the conflicts in the use of the river water resolved?
....
....
20. Who are the main people involved in diverting water from the river (state the number in each category);
    f) Individuals……………………………………….
    g) Non-governmental organizations…………….………
    h) County government…………………………………
    i) Private firms……………………………….……….
    j) Any other, specify……..……………………………………………………

SECTION B

Changes in sediment load following diversion of water from rivers in upper Tana basin

1. How is the color of the water in each month of the year?
   Jan……………..Feb…………….Mar…………….Apr……………..May……..…
   …..….June……………July…………….Aug……………Sept……………Oct……
   .………..…Nov………………Dec…………………….
2. In which months is the water most turbid?
   Jan……………..Feb…………….Mar…………….Apr……………..May……..…
   …..….June……………July…………….Aug……………Sept……………Oct……
   .………..…Nov………………Dec…………………….
3. In which months does the water become clear?
   Jan……………..Feb…………….Mar…………….Apr……………..May……..…
   …..….June……………July…………….Aug……………Sept……………Oct……
   .………..…Nov………………Dec…………………….
4. In which months does the water become greenish in colour?
   Jan……………..Feb…………….Mar…………….Apr……………..May……..…
   …..….June……………July…………….Aug……………Sept……………Oct……
   .………..…Nov………………Dec…………………….
5. What is the estimated time that these diversions take for them to be filled up with sediments during rainy season;
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………..………………………………………………………………………………
   ………………………………………………………………………………………
   ……………………………………………………………………………………..
6. Have these diversions led to an increase of sediments (and turbidity) in the river?
   a)YES b) NO
    a. Explain……………………………………………………………………
       ……………………………………………………………………………
       ……………………………………………………………………………
       ……………………………………………………………………………
       ……………………………….

7. Have these diversions led to decrease in sediments in these rivers?
   a) YES b) NO
   Explain……………………………………………………………………………
   ……………………………………………………………………………………
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   ……………………………………………………………………………………
8. Have you noted an increase or decrease of water turbidity in the recent past?.................
   If, yes, state the nature of increase or decrease
   ………………………………………………………………………………………
9. How does changes in the water turbidity and sediment deposition affect activities of people in this area?

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10. How do farmers upstream affect activities of those downstream?

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11. Explain more about the amount of alluvium after diversion as compared to when the river was not diverted

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12. How does this change in alluvium impact on farming practices?

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13. Has the river water diversion improved or decreased agricultural yields in this area?

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14. Compare the colour of water on the upper course of the river before diversion and lower course after diversion?

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15. What changes on the riparian vegetation in the lower course of the river have you seen after diversion?

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16. In your assessment, have the authorities done enough to regulate water diversions in this area?
    a. Yes………b) No…………………………………………………………..

Provide reasons for your answer…………………………………………………………
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17. What are the challenges that you face in enforcing regulations on river water diversions?

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18. What are the possible solutions to these challenges?

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Appendix III

Rainfall data for Thika Meteorological Station

	Thika meteorological station			**LAT. 1^o 1′S**			**LONG. 37^o 6′E**		**ALT. 4800FT**			
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	3.5	0.0	18.8	74.9	29.4	5.0	5.9	2.2	7.9	11.5	136.1	62.1
2001	358.4	32.7	170.2	106.0	66.5	4.6	0.8	16.1	1.7	48.7	368.2	20.7
2002	16.3	n/r	227.4	313.5	250.5	3.7	2.2	5.5	80.2	83.1	137.7	243.1
2003	14.2	3.0	93.5	215.9	254.3	1.0	3.6	17.3	0.1	83.3	180.9	44.2
2004	53.5	74.7	47.9	376.2	120.9	1.2	0.0	0.0	20.9	78.2	129.3	78.7
2005	21.4	25.1	52.3	245.1	205.1	15.2	7.5	1.9	5.5	38.1	154.3	2.1
2006	17.5	27.8	100.7	195.7	185.4	9.4	7.6	21.7	22.7	33.6	393.3	226.7
2007	30.8	102.9	24.1	239.3	85.0	3.3	14.7	13.7	20.2	54.8	114.2	25.6
2008	104.8	27.1	100.4	270.9	7.4	6.4	28.3	n/r	n/r	n/r	n/r	n/r
2009	49.3	19.0	51.5	173.4	91.1	10.1	1.1	1.7	0.0	134.5	119.2	94.2
2010	138.3	113.5	209.0	176.1	133.5	24.7	4.8	6.3	1.3	98.0	153.5	80.6
2011	10.8	47.9	155.4	109.6	71.2	50.3	1.0	10.7	39.4	135.2	177.2	63.2
2012	0.0	20.9	0.0	248.5	184.5	3.8	8.9	40.9	19.9	50.8	177.1	168.4
2013	73.3	0.0	239.7	425.6	20.6	9.1	4.0	5.2	9.2	1.4	112.6	110.2
2014	n/r	96.3	128.4	97.2	40.1	35.9	5.0	34.9	29.0	22.3	222.8	69.9
2015	9.1	26.3	68.9	228.8	125.8	61.8	5.0	0.0	0.0	193.6	279.2	146.8
2016	91.1	50.2	40.8	399.7	80.0	29.6	0.0	2.6	0.0	10.9	187.0	35.6
2017	3.2	38.9	27.0	145.7	61.7	0.0	18.7	32.1	30.5	114.3	11.5	11.5
2018	0.6	43.3	1.9	80.5	0.0	14.9	6.4	0.1	0.1	177.1	98.8	173.8
LTM	**44.1**	**38.6**	**108.5**	**216.0**	**119.8**	**23.9**	**15.2**	**13.9**	**17.3**	**69.7**	**169.1**	**81.0**

Legend
LTM- Long Term Mean Rainfall
Source: KMD, 2018

Appendix IV

Rainfall data for Gatare Forest Station

	Gatare forest station			**LAT. 0^{o} 43'S LONG. 36^{o} 46'E ALT. 8500FT**								
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000	27.9	8.4	66.9	234.6	24.5	64.8	N/R	47.3	78.9	97.7	342.8	235.8
2001	548.4	74.1	238.0	692.8	207.2	83.6	60.7	69.4	16.7	177.2	368.8	101.2
2002	124.3	97.4	150.3	605.6	489.5	75.2	41.5	57.5	67.7	308.7	381.3	287.5
2003	96.4	41.2	67.9	466.6	610.0	171.9	26.1	154.1	87.9	310.4	302.9	274.1
2004	N/R	100.0	132.5	558.8	316.3	15.1	51.6	34.0	N/R	360.9	211.3	275.7
2005	78.0	87.1	51.6	239.0	358.4	74.5	49.3	115.0	123.7	108.8	168.3	2.1
2006	4.0	22.8	30.0	89.4	84.7	82.4	29.4	47.4	20.2	156.1	288.5	113.9
2007	84.0	24.8	72.1	493.5	542.1	276.0	254.5	261.5	129.3	456.1	154.4	143.2
2008	55.4	98.0	224.5	384.1	183.5	16.1	155.7	88.6	235.4	361.4	310.6	0.0
2009	40.3	9.0	41.5	133.4	81.1	21.1	1.1	1.7	0.0	104.5	119.2	94.2
2010	118.3	93.5	109.0	156.1	139.5	17.7	5.1	6.3	1.3	98.0	153.5	80.6
2011	10.9	18.6	40.9	39.6	63.2		28.0	28.3	39.6		61.8	54.1
2012	20.1	10.9	59.0	228.5	174.5	2.8	7.9	30.9	11.9	60.8	187.1	108.4
2013	81.1	50.2	70.8	368.7	180.0	19.6	15.0	2.6	12.0	90.9	197.0	35.6
2014	60.0	46.3	118.4	76.2	100.1	44.9	4.0	14.9	17.0	122.3	300.8	59.9
2015	30.1	15.3	78.1	338.8	105.8	65.8	3.0	12.0	9.0	198.2	299.2	155.8
LTM	**112.5**	**106.0**	**182.2**		**158.0**	**135.6**	**98.3**	**99.3**	**78.1**	**79.4**	**321.4**	**147.1**

Legend
LTM- Long Term Mean Rainfall
Source: KMD, 2018

Appendix V

Rainfall data for Kimakia Forest Station

	Kimakia forest station			**LAT. 0° 46'S**		**LONG. 36° 46'E**		**ALT. 8080FT**				
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2000		6.0	32.0	187	34.6				72.8			216.5
2001	436.5	40.0	211.1	566.3	196.4	109.9	49.0	57.8	7.9	100.6	215.4	34.6
2002	140.3	116.1	113.9	435.0	404.0	37.6	19.5	45.0	45.4	226.5	317.1	310.5
2003	110.0	55.4	71.7	368.1	550.7	58.6	12.0	111.3	71.4	235.9	208.9	53.0
2004	50.6	119.0	123.1	351.5	220.4	31.3	21.1	20.1	96.8	235.7	307.8	194.5
2005	97.5	50.7	171.5	340.8	457.6	97.5	69.1	60.1	69.7	128.2	177.3	15.1
2006	28.4	205.4	222.0	332.0	412.2	53.1	23.2	15.1	19.3	132.2	224.6	43.1
2007	33.4	20.1	59.3	355.1	225.1	13.7	8.1	1.7	15.3	40.1	162.3	22.4
2008	17.5	27.8	100.7	195.7	185.4	9.4	7.6	21.7	22.7	33.6	393.3	226.7
2009	30.8	112.9	35.1	227.3	85.0	3.3	14.7	13.7	20.2	54.8	114.2	25.6
2010	104.8	27.1	100.4	280.8	9.4	5.6	28.3	10.0	29.0	105.0	254.0	60.0
2011	49.3	19.0	51.5	173.4	91.1	10.1	1.1	1.7	0.0	134.5	119.2	94.2
2012	138.3	113.5	209.0	176.1	133.5	24.7	4.8	6.3	1.3	98.0	153.5	80.6
2013	20.8	57.3	165.7	119.2	91.1	30.3	2.0	16.7	33.4	145.1	189.2	60.2
2014	50.9	102.3	137.4	87.9	60.1	25.4	9.0	30.3	21.3	112.3	300.8	61.9
2015	41.0	24.3	78.9	246.8	131.8	71.6	7.0	12.0	19.1	183.5	289.3	126.8
LTM	**97.1**	**93.9**	**179.8**	**421.4**	**375.6**	**108.9**	**73.8**	**76.6**	**65.6**	**208.9**	**284.3**	**130**

Legend
LTM- Long Term Mean Rainfall
Source: KMD, 2018

Appendix VI

Water Abstraction Data

NAME	NAME OF RIVER	District	County	Total Allocation (N/F&FF)	PURPOSE	REMARKS
GATUNDU UNITY SELF HELP GROUP	KARICHIUNGU TRIB OF THIKA	MARAGUA		1800	GENERAL IRRIGATION	PE
ROBERT NJOROGE KAMAU	RUCHU RIVER TRIB OF THIKA RIVER	MARAGUA		20.55	DOMESTIC USE &MINOR IRRIGATION	AU
GIKAKIMA WATER PROJECT	GITHIKA RIVER	MARAGUA		308.46	DOMESTIC & GENERAL IRRIGATION	PE
NGECHA HYDRO POWER SELF HELP PROJECT	GITHIKA RIVER	MARAGUA		0	POWER GENERATING	AU
ATHI WATERC SERVICES BOARD - NAIROBI CITY WATER AND SEWERAGE COMPANY LIMITED	THIKA RIVER	THIKA		450000	PUBLIC USE	PR
EDWARD THUKU KAMAU	GATHIKA TRIB OF THIKA RIVER	MARAGUA		2.25	MINOR IRRIGATION	AU
NAHASON MWANGI NJOROGE	THIKA RIVER	THIKA		27.3	IRRIGATION	AU
THIKA SPORTS CLUB	THIKA RIVER	THIKA		177.2	DOMESTIC USE &IRRIGATION	AU
GAKINGO WAIRAGO	KAGUTHA TRIB. OF THIKA	NYERI		28.045	DOMESTIC AND GENERAL IRRIGATION	PR
BAHATI ESTATE (HARDY ESTATE LIMITED)	THIKA RIVER	MURANG'A		633.286	GENERAL IRRIGATION	PR
BARAGU HOLDING LIMITED	THIKA RIVER	THIKA		1457.952	DOMESTIC & GENERAL IRRIGATION	PR
GITUAMBA COMMUNITY WATER PROJECT	THIKA	THIKA		417	DOMESTIC	AU
GEORGE THUO IBUTHI	THIKA	THIKA		5	DOMESIC& MINOR IRRIGATION	AU
NG'ARARIA SEC SCH.	THIKA RIVER	MARAGUA		43.4	DOMESTIC & MINOR IRRIGATION	AU
SALAMBO INVEST. LTD	THIKA	THIKA		19.5	DOMESTIC & MINOR IRRIGATION	AU
P. MAINA KIBE	MAKINDI TRIB OF THIKA RIVER	MARAGUA		27.4	DOMESTIC	AP
JENARD DEV. LIMITED	THIKA	MARAGUA		474.94	DOMESTIC, GENERAL IRRIGATION & INDUSTRIAL	AU
CYRUS KAGIRA NJUGUNA	THIKA	THIKA		9.1	MINOR IRRIGATION	AU
DANIEL MBUGUA NJOROGE	KAGONDO STREAM TRIBUTARY OF THIKA RIVER	MURANG'A		9.9	DOMESTIC & MINOR IRRIGATION	AP
WILFRED KIGO NJIRI	THIKA	MURANG'A		30	GENERAL IRRIGATION	AU
EPHRAIM K. KIMARU (ALFRED HENRY MUTAHI)	THIKA	THIKA		47.72	DOMESTIC & GENERAL IRRIGATION	PR

SAMUEL MUCHIRI NJOROGE	THIKA	MURANG'A		9.1	MINOR IRRIGATION	AU
DAVID NJOROGE KAGIRA	THIKA	MURANG'A		139.9	DOMESTIC & GENERAL IRRIGATION	PR
WANJA KARUGU	THIKA RIVER	MURANG'A		9.771	DOMESTIC & MINOR IRRIGATION	AU
MRS ROIS MUIKARI c/o NDULA PRIMARY SCHOOL	THIKA	KIAMBU		28.181	DOMESTIC & GENERAL IRRIGATION	AU
KARANJA KINUNGI & P. MWAURA	THIKA	THIKA		1363.636	GENERAL IRRIGATION	AU
DIRECTOR WATER DEVELOPMENT (ITHANGA WATER SUPPLY)	THIKA	THIKA		5453.2	PUBLIC	AU
MINISTRY OF AGRICULTURE & LIVESTOCK DEV. (NATIONAL HORTICULTURAL RESEARCH STATION)	THIKA RIVER	MURANG'A		193.15	DOMESTIC & GENERAL IRRIGATION	AU
GREEN KENYA LIMITED	THIKA RIVER	KIAMBU		410.4	DOMESTIC & GENERAL IRRIGATION	AU
BETHUEL KINYANJUI WAIRIUKO	THIKA RIVER	MURANG'A		731.85	DOMESTIC & GENERAL IRRIGATION	AU
MWANA WIKIO FARMERS CO-OPERATIVE SOCIETY LIMITED	THIKA RIVER	MURANG'A		1830.26	DOMESTIC, COFFEE PULPING & GENERAL IRRIGATION	AU
MBUGUA GITACHU	THIKA RIVER	THIKA		683.7	DOMESTIC & GENERAL IRRIGATION	AU
J.G. KIBE & KIBE MRS. (PLANFARM COMPANY LIMITED)	THIKA RIVER	MURANG'A		363.098	GENERAL IRRIGATION	AU
JOHN MBUTHIA KAMAU	THIKA RIVER	THIKA	MURAN GA	1841.12	INDUSTRIAL & GENERAL IRRIGATION	PE
HON. G.N. MWICIGI & C.N. MWICIGI	THIKA RIVER	MARAGUA		3033.82	DOMESTIC, INDUSTRIAL & GENERAL IRRIGATION	AU
PLANFAM COMPANY LIMITED (BAHATI ESTATE) c/o E.A. ACCEPTANCES (E.M.D) LIMITED	THIKA RIVER	THIKA		1206.9	DOMESTIC, INDUSTRIAL & GENERAL IRRIGATION	PE
KARIUKI NJOGU	THIKA	NYERI		9.99	MINOR IRRIGATION	AU
PETER NJUGUNA MUHIA & SIMON MBURU MUHIA	THIKA	MURANG'A SOUTH		10.629	DOMESTIC & MINOR IRRIGATION	AU
KIANDA KOGI FARMERS CO-OPERATIVE SOCIETY LIMITED	THIKA	MURANG'A		45.43	PULPING & WASHING COFFEE	PR
KARURUMWE FARMERS CO-OPERATIVE SOCIETY LIMITED - KIANJUKI COFFEE FACTORY	THIKA			136.26	INDUSTRIAL	AU
GEORGE THUO S/O FRANCIS G. NJUGUNA	THIKA RIVER	MURANG'A		29.54	DOMESTIC & GENERAL IRRIGATION	AU

GATANGA COMMUNITY WATER SCHEME	THIKA	THIKA		13636.36	DOMESTIC	PE
NYAGA WATER PROJECT	THIKA RIVER	THIKA		274.58	DOMESTIC	AU
MUTHUMBE WAWERU	KANDERE TRIB OF THIKA RIVER	THIKA		87.21	DOMESTIC, INDUSTRIAL &GENERAL IRRIGATION	AU
MR. WILSON MUTURI MUGURO	THIKA RIVER	THIKA		454.54	GENERAL IRRIGATION	PR
GATUNDU COFFEE GROWERS CO-OPERATIVE SOCIETY LIMITED	THIKA RIVER	THIKA		1229.09	DOMESTIC & GENERAL IRRIGATION	AU
SOLOMON KAGIRA	THIKA RIVER	MURANG'A		23.18	DOMESTIC & MINOR IRRIGATION	CA
IRERA FARMERS CO-OPERATIVE SOCIETY - IRERA ESTATE	THIKA	MURANG'A SOUTH		4.6	GENERAL IRRIGATION	AU
CONSERVATOR OF FORESTS - GATARA FOREST STATION	GITHIKA	MURANG'A		101.105	DOMESTIC & MINOR IRRIGATION	PE
NAIROBI CITY WATER & SEWARAGE COMPANY LIMITED	THIKA RIVER	NAIROBI CITY		100224	DOMESTIC & IRRIGATION	PE
MAHOTI PLANTATIONS LIMITED	THIKA	MURANG'A		719.022	GENERAL IRRIGATION	PE
GACHARAGE COFFEE GROWERS CO-OPERATIVE SOCIETY LIMITED - GACHARAGE COFFEE FACTORY	THIKA	THIKA		544.8	INDUSTRIAL & GENERAL IRRIGATION	PE
AYUB NDABARI	THIKA	THIKA		8.64	DOMESTIC & MINOR IRRIGATION	AU
STEPHEN MWANGI GATHENYA	THIKA RIVER	THIKA		36.363	GENERAL IRRIGATION	AU
MOSES IRUNGU MACHARIA	THIKA RIVER	KIAMBU		28.17	DOMESTIC & GENERAL IRRIGATION	AU
MATAARA WATER PROJECT	RAGIA STREAM TRIB OF THIKA RIVER	THIKA		366	DOMESTIC & GENERAL IRRIGATION	AU
THIKA NURSERIES LIMITED	THIKA	THIKA		1500	GENERAL IRRIGATION	AU
ERASTUS IRUNGU MUTURI	THIKA	THIKA		1.854	DOMESTIC & MINOR IRRIGATION	AU
GITU KAHENGERI	THIKA	THIKA		190.89	DOMESTIC & GENERAL IRRIGATION	PR
NAIROBI CITY WATER & SEWERAGE COMPANY LIMITED	THIKA RIVER	NAIROBI CITY		37700	PUBLIC USE	PE
SOCFINAF CO.LTD. (GETHUMBUINI ESTATE 2)	THIKA	THIKA		5037.04	GENERAL IRRIGATION	PE
SOCFINAF CO.LTD (GARTON LTD WANGU ESTATE 2)	THIKA	THIKA		2579.7	DOMESTIC	CAL
SOCFINAF CO. LTD (KARANGAITA ESTATE	THIKA	THIKA		5266	IRRIGATION	CAL

SOCFINAF CO. LTD (KARANGAITA ESTATE 2)	THIKA	THIKA		136.3	INDUSTRIAL	PE
WANYAGA COMMUNITY SELF HELP GROUP	THIKA	THIKA		40000	POWER GENERATION 100% RETURNABLE	AU
TERRA FLEUR LIMITED	THIKA	THIKA		600	IRRIGATION	AU
MAGANA HOLDINGS LTD - KIGANDA ESTATE	THIKA	THIKA		1002	IRRIGATION FOR COFFEE FARM	PE
VERT LIMITED	THIKA	THIKA	KIAMBU	2400	IRRIGATION	PE
HAVEREST LAND INVESTMENT	THIKA	THIKA		450	DOMESTIC & IRRIGATION	PE
ZENA ROSES LIMITED	THIKA	THIKA		250	IRRIGATION HORTICULTURAL FARMING	PE
ZENA ROSES LIMITED	THIKA	THIKA		400	IRRIGATION HORTICULTURAL FLOWER FARMING	PE
SANSORA INVESTMENTS LTD	THIKA	THIKA		450	IRRIGATION	PE
GATANGA COMMUNITY WATER SCHEME	THIKA	THIKA		13636.36	PUBLIC	PE
NDIARA 'C' HYDRO-ELECTRIC WATER PROJECT	THIKA	THIKA		2073.6	HYDRO-POWER	AU
AAA GROWERS LTD	THIKA	MARAGUA		1000	IRRIGATION	PE
AAA GROWERS LTD	THIKA	MARAGUA		1000	DOMESTIC, IRRIGATION & INDUSTRIAL	PE
JAMES KIEHA NDUNGU	THIKA	KANDARA		20.5	DOMESTIC & IRRIGATION	AU
GATANGA COMMUNITY WATER SCHEME	THIKA	GATANGA		3000	DOMESTIC	AU
NDAKAINI WANDUHI IRRIGATION WATER PROJECT	THIKA RIVER	THIKA		1000	COMMERCIAL IRRIGATION	AU
MARION NJERI GATHENDA	THIKA RIVER			3840	DOMESTIC AND IRRIGATION	
ANTONY NJOROGE GACHERA	MIKINDI TRIBUTARY OF THIKA RIVER	MURANGA	MURAN GA	14	DOMESTIC, LIVESTOCK & SUBSISTENCE IRRIGATION	AU
LAUREN INTERNATIONAL FLOWERS L.T. D	THIKA	GATANGA	MURAN GA	583.152	DOMESTIC/IRRIGA TION	AU
MARIGU GREEN GROWERS S.H.G	MAKINDI TRIB OF THIKA	KANDARA	MURAN GA	1255.824	IRRIGATION	AU
MR. PATRICK NJOROGE	KABUKU TRIB THIKA	KANDARA	MURAN GA	24.46	DOMESTIC & IRRIGATION	PR
NATIONAL HORTICULTURAL RESEARCH STATION	THIKA	GATANGA	MURAN GA	1551	DOMESTIC &IRRIGATION	PE
SAMMY MBUGUA WARUINGE	THIKA RIVER	THIKA		3	42241	PR
SILVER OAK INVESTMENT	GITAMURU TRIB OF THIKA	THIKA	KIAMBU	130	SUB IRRIGATION	PR
WHITESTONE COFFEE ESTATE	THIKA RIVER	MURANGA		559.68	DOMESTIC & IRRIGATION	PE
ATHI WATER SERVICES BOARD (ITHANGA WATER SUPPLY)	THIKA RIVER	THIKA EAST	MURAN GA	7200	DOMESTIC	DEFFERED