SOUTH EASTERN KENYA UNIVERSITY

SCHOOL OF WATER RESOURCES SCIENCE AND TECHNOLOGY

Impacts of expansion of agriculture and land use change on flow regime of Thiba river, Kenya

by

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DECLARATION

This thesis is my own original work and has not been submitted for examination in any other university

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ABSTRACT

Soil and Water Assessment Tool (SWAT) was used to model the impacts of land cover changes on stream flow regime in the Thiba River basin a sub-catchment of Tana River Basin covering a surface area of 1648 km2 in central region of Kenya. The basin is characterized by intensive agricultural activities including the largest rice irrigation scheme in Kenya. A study was undertaken to test the capability of the model in predicting stream flow response under changing land use conditions in a typical tropical river basin. Classified land use maps of 1984, 2004 and 2014 were analyzed to investigate land use changes in the basin. Field based survey, National Irrigation Board (NIB), Kenya Meteorological Department and Water Resources Management Authority (WRMA) provided hydro-meteorological data for the study. The results of the study shows that forest cover in the Thiba River basin has decreased by 18.39 % between 1984 and 2014 while area under rice cultivation increased by 9.38 % in the same period. About 35% of dry season flow and 3% of wet season flow was found to have been directly abstracted for irrigation purposes from the Thiba River between 2007 and 2014. The SWAT Model results showed that there is a significant relationship between the observed and simulated average monthly stream flows in the Thiba River Basin. The Nash-Sutcliffe Efficiency (NSE) and coefficient of determination (R^2) during calibration period (1983-1988) were 0.82 and 0.9, respectively, while for the validation period (1989-1993) they were 0.79 and 0.87, respectively. The average monthly stream flows increased by 6.01 m^3/s during the wet season and decreased by 1.92 m^3/s during the dry season. The changes in stream flow were attributed to the land cover change and rainfall variability. The results implies that future expansion of irrigated agriculture would result to increase in flooding during the wet season and low base flow during the dry season. This can consequently result to water conflicts between upstream and downstream water users. The recommends construction of water storage reservoirs to harvest the high runoff during the wet months for agricultural use during the dry season when base flow is low. Also, it's important that further research on impact of land use change on the water quality.

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LIST OF ABBREVIATIONS AND ACRONYMS

ARICOVER	Africa land Cover
ARS	Agricultural Research Service
DEM	Digital Elevation Model
ENVI	Environment for Visualizing Images
ET	Evapo-transpiration
FAO	Food and Agriculture Organization
FDC	Flow Duration Curve
GWC	Green Water Credits
HEP	Hydro Electric Power
HRUs	Hydrological Response Units
IWRM	Integrated Water Resources Management
JICA	Japan International Cooperation Agency
KENSOTER	Kenya Soil Terrain
KMD	Kenya Meteorological Department
LCSS	Land Cover Classification System
LULC	Land Use Land Cover
MIS	Mwea Irrigation Scheme
NIB	National Irrigation Board
NSE	Nash-Sutcliffe coefficient
PPU	95 % Prediction Uncertainty
R2	Coefficient of determination
SRTM	Shuttle Radar Topography Mission
SUFI 2	Sequential Uncertainty Fitting (SUFI 2
SUFI	Sequential Uncertainty Fitting
SWAT	Soil Water Assessment Tool
SWAT-CUP	SWAT-Calibration and Uncertainty Program
TRB	Thiba River Basin
UNEP	United Nations Environmental Programme
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WRMA	Water Resources Management Authority

CHAPTER ONE

INTRODUCTION TO THE STUDY

1.1. Introduction

This chapter presents the background information on the study based on information obtained from literature review and field surveys. The aspects of land use change impacts on hydrology in both the study area have been broadly highlighted . The study is focused on the impacts of land use change and agriculture on catchment hydrology. The research is narrowed down to three key objectives to guide on the methodology of the study. The statement of the problem and significance of the research are provided to show how important this research is to the social, economic and environmental sustainability.

1.2. Background

This study is focused on establishing the impacts of agriculture and land use change on the flow of Thiba River in Eastern Kenya. Thiba River is mainly affected by both subsistence and commercial agricultural activities particularly paddy rice irrigation farming at Mwea Irrigation Scheme (MIS), one of the largest irrigation schemes in Kenya. The irrigation scheme was established in 1958 as resettlement scheme with the primary objective of resettling the landless and ex-detainees during the independence struggle. The scheme was managed by the government through the National Irrigation Board (NIB) until 1998 when farmers decided to form their own Cooperative (Koubaa & Severino, 2007).

Initially after establishment of the scheme, all the water abstractions were monitored and managed from common abstraction points since cultivation was restricted within the scheme. Since then, Mwea Irrigation Scheme has changed especially since 1990s according to (Koubaa & Severino, 2007) further stated that many private farmers are legally and illegally diverting irrigation water directly from the stream both upstream and downstream of the river without considerations of the environmental water requirements and potential impacts on the downstream users.

In Kenya, quantity and flow patterns of surface water resources particularly rivers depend on: basin shape, vegetation cover in the basin, rainfall intensity and seasonality plus human settlement and land use patterns (Ngaira, 2009). Upstream rainfall variability and flow abstraction for irrigation are key parameters in understanding low flows in rivers (Smakhtin, Shilpakar & Hughes, 2006). Decrease in rainfall reduce inflow into surface water bodies, while at the same time they increase the irrigation water requirements.

A number of studies have been undertaken on the impact of irrigation water abstraction on stream flow. A study in upper Ewaso Ngiro basin in North Eastern Kenya found that 60-80 percent of available water in upper reaches was abstracted for irrigation (Gikonyo, 1997). The over-abstraction of water from the river has been taking place since the introduction of horticulture crops for export market in 1984.The high level of irrigation water abstraction in the upper reaches of the river was mainly due to the hydraulic and hydrologic advantage, suitability for irrigation development and access to market. This over-abstraction has been blamed for decreasing water availability in lower reaches resulting to water conflicts as reported further by Gikonyo (1997).

A study by Ngaira (2009) on the effect of water abstraction for irrigation use in semi-arid Baringo District established that irrigation projects in the semi-arid lands of Kenya have had negative impacts on the surface water resources and the aquatic life. Abstraction of water from rivers flowing into Lake Baringo caused a reduction in the lakes surface area from 144 km2 in 1980 to 112 km2 in 1995 while the depth reduced from 2.2 m in 1985 to 1.7 m in 1995.

Studies done in Thiba River Basin (TRB) have focused on irrigation water efficiency use on the Mwea Irrigation Scheme (MIS) which has existed since 1956. Since 1998 to date, about 4000 acres of land has been developed by farmers on their own for paddy cultivation (NIB , 2009). This new area was not planned for and has worsened the situation in terms of water availability for the scheme. However there is a paucity of knowledge on actual water abstracted from the basin and land use change associated with increased commercial agricultural activities in the basin. More land is being created from existing forested and other natural vegetation for both irrigated and rain fed high value crops.

The main goal of this study was to assess the effect of land use change and increased agricultural water demand on the flow regime of Thiba River in order to generate knowledge and information that could be useful in the allocation of river water among different water uses in the basin. The study also aimed at generating recommendations on the best practices in line with Integrated Water Resources Management (IWRM) to minimize the negative impact of land use change and increased agricultural water abstractions in the Thiba River flow regime in Kenya.

1.3. Statement Of The Problem

The Thiba River Basin (TRB) located in Kirinyanga and Embu Counties in Central part of Kenya has experienced dynamic flow regimes due to changes in land use/cover, deforestation, and increased agricultural activities leading to over-abstraction. Figure 1.1 shows water abstraction scenario at one of the intakes of Mwea Irrigation Scheme (MIS) ; Nyamidi headrace to the left and dry riverbed downstream of abstraction point to the right during the month of March, 2015. This has resulted in reduced water availability during the dry season in different reaches of the basin thus catalyzing conflicts over the finite water resource between different stakeholders, environmental degradation, and reduced hydropower production at Kaburu dam (Muchiri, 2013).

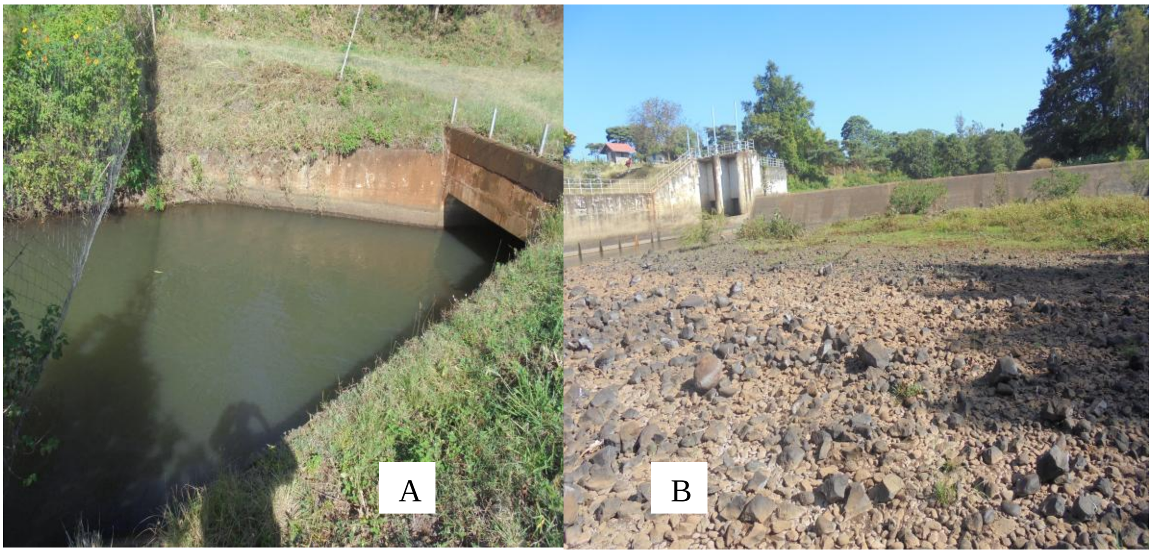


Figure 1.1 : Photo taken on March, 2015 illustrating water abstraction at Nyamidi headrace (A) and immediate dry river bed downstream of the abstraction point (B). Source: Kasuni (2016).

A conceptual model illustrated in Figure 1.2 shows the inter-linkages between root causes of stream flow change and direct and indirect impacts on the study area. The major root cause of stream flow change are land use change, fluctuating precipitation and direct water abstraction.

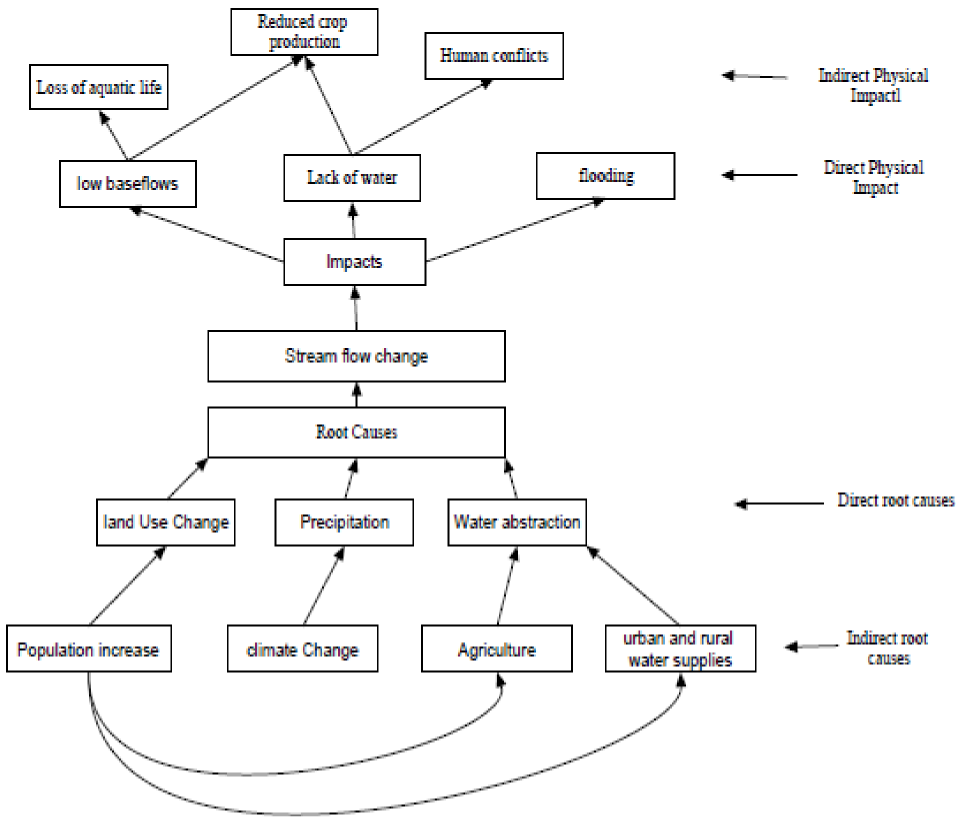


Figure 1.2 : Conceptual model illustrating direct and indirect root causes of stream flow regime change and subsequent direct and indirect impacts.

Land use change is as a result of increased population growth. This has led to increased demand of food which subsequently led to increased agricultural activities. Population growth has also increased the demand for water resulting in increased water abstraction. The impacts of stream flow change are characterized by prolonged low flows, lack of water and flooding during rainy season. Low flows or lack of water has been a catalyst of human conflict in the basin. This further highlights the significance of this study.

Few studies have attempted to investigate the impacts of land use/cover changes and irrigation on stream flow dynamics in Thiba basin. Muchiri (2013) investigated the efficiency of water use in Mwea irrigation Scheme (MIS) in the basin. However, little evidence is reported on how the efficiency of the scheme and other land use changes relates to flow regimes in Thiba River. The lack of sufficient information on Thiba flow regimes has made it challenging for policy makers to design practical and suitable integrated water and land management interventions in the basin.

This study aims to provide more information on the dynamics of the flow regimes of Thiba river by assessing the impacts of land use change and increased abstractions for agricultural use on the Thiba basin water balance with an aim of informing the water resources departments in Kenya. The study will therefore be useful in assisting relevant institutions to develop water allocation plans so as to avert conflicts over the finite water resource and protect the environmental flow requirements within the Thiba River Basin.

1.4. Objective of The Study

The main objective of the study is to determine the impacts of irrigation water abstractions and land use changes on the flow regime in the Thiba River Basin (TRB) of upper Tana River Catchment, Kenya.

The specific objectives of this study are to:

1. Investigate changes in land use through analysis of historical satellite observed land cover data from 1984 to 2014.

2. Determine stream flow response to abstraction water pattern through analysis of historical water abstraction data from 2007 to 2014.

3. Establish the impacts of land use changes to river flow regime of Thiba River through simulation modeling with Soil and Water Assessment Tool (SWAT).

1.5. Research Hypotheses

1. Ho: There is no statistically significant land use change in the Thiba River Basin in the period between 1984-2014.

   H1: Alternative

2. Ho: There is no statistically significant relationship between water abstraction and stream flows in the Thiba River Basin in the period between 2007-2014.

   H1: Alternative

3. Ho: There is no statistically significant relationship between land use change and stream flow of Thiba River Basin in the period between 1984 and 2014.

   H1: Alternative

1.6. Significance of the Study

Water scarcity and reliability are major constraints for development in most of the developing countries. Information is required by policy makers and administrators in order to make decision concerning water allocation for various uses (Mati, 2002).

This study is important on basis of the following: Firstly irrigation expansion is inevitable in Kenya because only 19.6% of the Kenya's irrigation potential has been utilized so far (Mati, 2002) with more than half of the water withdrawal being used in the process. The corollary to this situation is that any expansion of irrigation will lead to a significant water deficit for other sectors. Yet, the current national approach is focused on exploiting the vast untapped irrigation potential, with disproportionate focus on the efficiency with which the current irrigation activities are undertaken. Since irrigation is water-intensive, this imbalanced emphasis may threaten the sustainability of both current and future irrigation projects.

Secondly, increased water abstraction can lead to reduction in river flow water entering Kaburu dam, one of the hydro-electric Dams in Kenya and this can impact on the generation of electricity. A huge segment of Kenya's population is dependent of electricity generated in Hydro Electric Power (HEP) dams. Any reduction in HEP generation due to decrease in dam water level can have serious repercussions on overall economy of the country. Therefore, it's important to simulate the effects of expansion of irrigation agriculture and land use change on stream flows particularly those draining into dams generating hydropower to understand long term impacts.

The major challenge planners and managers are facing is to balance irrigation water requirements of streams with the various other stream water uses including sustainability of downstream aquatic ecosystems. There is also the challenge of balancing demand and supply under the scenario of declining water resources. For many countries, the solution is to manage the available water resource in a more efficient and sustainable manner through Integrated Water Resources Management (IWRM). This research will contribute in generating data and information that will aide in understanding the impact of irrigation agriculture on the flow of tropical rivers. This is expected to influence policies on the allocation of river water for various uses paying special attention on the allocation of water for irrigation schemes.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

This chapter is focused on the review of past studies that have been carried out globally, regionally, nationally and at local level. The information was obtained from past studies, published journals, technical reports and government reports. The literature review focused on several major issues namely: the concepts of land uses especially agriculture and their impacts on the river flow regime, the impact of water abstraction on river flow regime ,application of modeling in understanding watershed response to land use change and the combined effect of land use change and water abstraction on river flow regime.

2.2. Effects of Irrigation Water Abstraction on River Flow Regime

It has been estimated that about 250 million hectares are irrigated worldwide today, nearly five times more than at the beginning of the 20th century. Currently agriculture uses 70% of world water abstractions, while domestic, municipal and industrial uses collectively account for the remaining 30% (Siebert, Burke, Faures, Frenken, Hoogeveen & Pormann, 2010).

It is estimated, for example, that approximately 60% of the world's rivers have been diverted, and many of the rivers, including the Colorado, Murray and Yellow, no longer reach the sea (Smakhtin, 2006).

The comparison of past global agricultural water abstractions to the present show a remarkable increase and there is an indication that the demands will continue to rise. The world population estimated at six billion is expected to near eight billion by 2025 and to meet future food demand for the growing population, at least 2000 Km3 of water will be required (Siebert et al., 2010).Similar estimates by Ashley & Cashman (2006) have warned that by 2025 global water withdrawals for agriculture will rise to 3200 km3 more than the withdrawals for domestic and industrial uses. These projections illustrate the fact that the increasing global water demand for agriculture is likely to affect food production considering that water resources are finite and unevenly distributed.

Irrigation in many developing countries is the main water user accounting for at least 80% of the total use (Zaag & Savenije, 2010). Figure 2.1 illustrates the ever increasing demand for water throughout the world. This is caused by development of economies and improved living standards as a result of increased food production. Due to its predominant proportion of water use, agricultural water demand brings about competition with other users and subsequently causes conflicts over the use of water. In an effort to manage and develop the scarce world water resources and balance the demands of different water users, various interventions have been formulated. In recent years IWRM has come to the fore as means of resolving water conflicts, balancing the water needs for different water users, inclusive of the environment.

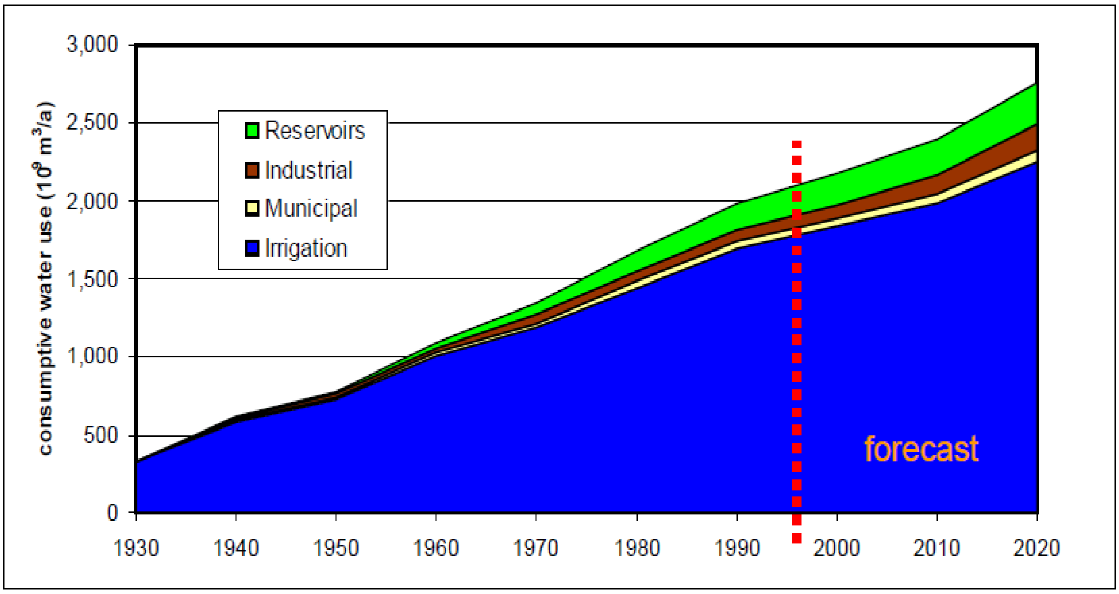


Figure 2.1 : Global consumptive water use illustrating increasing trend of water consumption. (Shiklomanov, 2000)

Abstractions of water from surface and groundwater bodies for multiple uses including irrigation purposes affect the natural hydrological cycle. In Hare basin of Ethiopia, most upstream irrigation activities benefiting from the diverted irrigation water do not consider water availability for downstream users (Mengistu, 2009 a).The major concern is to maximize production in anticipation for more economic returns.

However, the diversion of water for upstream irrigation projects directly affects the supply of water downstream. A reduction in discharge alters the width, depth, velocity patterns and shear stress within the river channel (Armitage & Petts, 1992). A study by (Mengistu, 2009 a) in Hare watershed, Ethiopia showed that analysis made on intervention of small scale irrigation in the upper and middle reach of the watershed resulted in substantial decrease in mean monthly discharge during the dry season, while increased discharge during the wet season.

In Kenya a study by (Gichuki, 2000) in upper Ewaso Nyiro showed that water abstraction for Agriculture in upper reaches for Ewaso Nyiro had resulted to water unavailability in lower reaches of the river. He further found out that where the irrigation potential was greatest, the more was the water scarcity.

2.3. Impact of Land Use Land Cover Change on Hydrologic Catchment Response.

In general, a change in land use from natural vegetation to agricultural crops often results in a drop in interception rates, a rapid delivery of storm flow to streams, and a reduction in infiltration capacity of the soils due to compaction (Stipinovich, 2005).
Catchment characteristics and local management can affect flood hydrology. Agricultural activities leads to changes in vegetation of river catchment area, and this alters their hydraulic characteristics that, in turn, may lead to changes in the flood regime. Agricultural fields in a catchment or utilized wetlands may retard floods more than in less-dense vegetation, reducing downstream flood peaks. The reverse effect is also possible. Different crop types will also alter the water budget of the catchment and affect flow rates during periods of low flow.

The relationship between land use and hydrology is of greater interest to scientists as it can provide crucial information for water resources management actions in order to avoid or minimize the negative effects of specific land use activities on the hydrology of river systems. However, there are still uncertainties on the impact of specific land use practices to different processes of the hydrological cycle due to the complexity and specificity of catchment characteristics. Much of the present understanding of land use effects on hydrology is derived from controlled experiments and manipulations of the land surface coupled with observations of hydrological processes, commonly precipitation inputs and stream discharge outputs (DeFries & Eshleman, 2004).

The largest changes in terms of land area, and arguably also in terms of hydrological impacts, often arise from a afforestation and deforestation activities . One of the direct effects of land use changes on hydrology and hence on water resources is through its link with the evapo-transpiration regime. Any change in land use and vegetation cover can have impacts on potential and actual evapo-transpiration as well as on the discharge regime, which reflects the integrated behavior of all the hydrological processes acting in the catchment (Newcastle, 1999).

2.4. Stream Flow Response to Land Use Change.

Stream flow and the processes related to stream flow are of great importance both for a range of different hydrological and ecological disciplines and for the general management of water resources (Louis & Irizarry, 2009). Stream flow is also one of the readily visible components of the water cycle and is consequently an obvious marker for the ecological, chemical and hydrological conditions in the stream as well as in adjacent catchments. Hence, it is crucial that stream flow and processes related to stream flow can be accurately detected, quantified and understood.

Many studies associate higher catchment forest cover with lower base flows, attributed to high evapo-transpiration rates of forests, while other studies indicate increased base flow with higher watershed forest cover due to higher infiltration and recharge of subsurface storage. The demonstrated effects of agriculture and urbanization are also inconsistent, due to varied additions of imported water and extremely variable background conditions (Price, 2011).

According to (Ngigi, Savenije, & Gichuki, 2007) Ewaso Ngiro river flow progressively decreased by about 30% since 1960 mainly due to increasing water abstraction upstream mainly for agriculture and drought cycles, despite corresponding decline in rainfall trend. Water abstraction has increased from 20% in the wet season to over 70% in the dry season.

2.5. Impact of Land Uses Change on Low Flows

Low flow' and 'base flow' according to (Price, 2011) are commonly used interchangeably to denote stream flow occurring between precipitation and/or snowmelt events, resulting from sustained subsurface inputs to the stream channel. In this review, low flows have been generally used to represent dry season minimum flows according to (Smakhtin, 2001).

The study of low flows and their characteristics is important to determine the probability of the river system to provide adequate and assured water supply for meeting the expected demands. In the analysis of low flow, hydrologists are mainly concerned with the magnitude of flow, its duration and the frequency of occurrence of low flows (Pandey & Ramasastri, 2003).

The magnitude of low flow is the quantity of water flowing through a given section of a stream for a specified period and it determines the amount of water available for use. The low flow duration depends on natural conditions as well as man-made effects and may reflect some specific water use and catchment management practices. The frequency of occurrence of low flow reflects the risk of failure of a water supply scheme. In low flow studies, therefore, data are normally specified in terms of the magnitude of flow for a given period within a year or a season. The time-periods usually considered in flow duration analyses are: 1 day, 7 days, 10 days or 30 days (TNC, 2005).

There are three main factors, which generally affects the low flows in a watershed. These are geomorphic, land use management and climate change factors (Price, 2011). The geomorphic factors, the local geological characteristics, prevailing topography, soils and sub-subsurface-topography affect the low flows. Similarly, human activities also affect low flows. These activities include change of land cover, urbanization and agricultural development. Finally, the prevailing climatic changes will also affect the low flows in area. All these factors could act singly or in combination to affect the local prevailing climatic conditions. Naturalized flows or present day historical flow data over specific durations are usually used in the flow duration analysis. In some cases the 90 percentile flow (Q 90) may be set as the minimum environmental flow (Wallingford, 2003). The 90 percentile flow is the flow that is equaled or exceeded 90 percent of the time. In other cases 95 percentile (Q 95) is used in regulating abstractions and as an index to define the environmental flow as is the case in the United Kingdom .(Dunbar, J.M., and Acreman, 2004). Figure 2.2 illustrates typical flow duration with Q 90 flow. Flow Duration Curve (FDC) is a relationship between any given discharge value and the percentage of time that this discharge is equaled or exceeded at a given location over some historic period. It is a plot of discharge (Q) versus the percent of time (t) during the period of the record in which the particular discharge is equaled or exceeded, without consideration for the chronology of the individual flows.

Thus, the curve is a graphical representation of the variability of stream flow at a site over an entire period of interest. It gives a summary of the flow variability at a site and represents perhaps the most informative method of displaying the complete range of river discharges from low flows to flood events (Smakhtin, 2001).

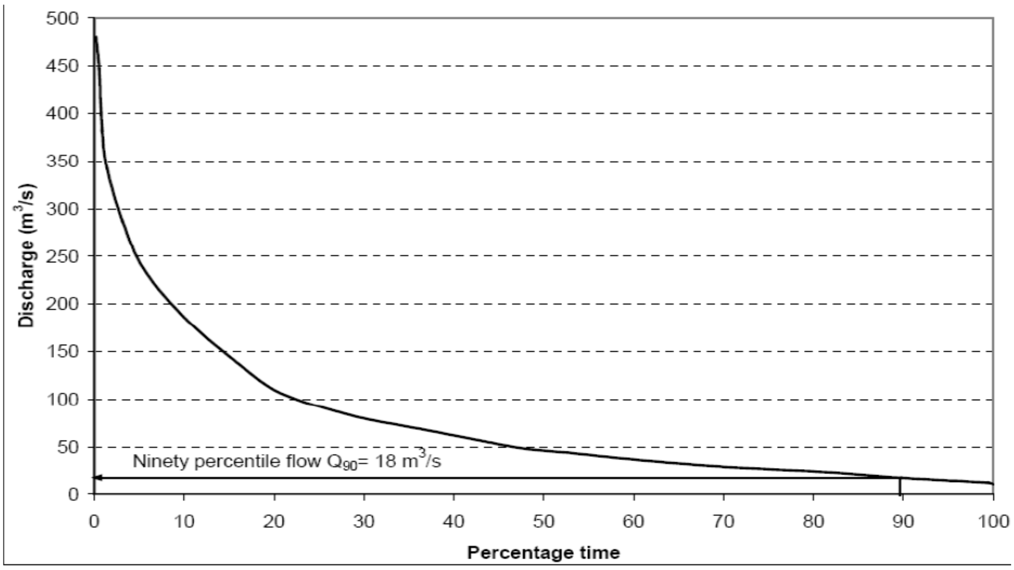


Figure 2.2 : Flow duration curve showing low flow at ninety percentile (source: (Wallingford, 2003).

The shape of the flow-duration curve is a function of the basin hydrological and physical characteristics. FDC may be constructed from either daily (1-day FDC) or monthly(1-month FDC) data. Both 1-day and 1-month FDCs may be calculated based on the completely available record period or based on all similar calendar months from the whole period (e.g. all Januaries). The former curves are sometimes referred to in the literature as "period of record FDC" (Vogel and Fennessey, 1994) and the latter as "long-term average monthly FDC" (Smakhtin and Watkins, 1997).

FDCs have long been used as means of summarizing catchment hydrologic response, such as in low-flow studies to characterize the low flow regimes of a river. FDCs are also frequently used in water quality calculations, design of run-of-river abstraction schemes and estimation of required environmental flows. Significant land use change such as dam construction can have a significant impact on the FDCs, implying that FDCs may also be used as an indicator of land use change in a catchment.

2.6. The Use and Selection of Hydrological Model

The catchment hydrologic models have been developed for many different reasons and therefore have many different forms. However, they are in general designed to meet one of the two primary objectives. One objective of catchment modeling is to gain a better understanding of the hydrologic phenomena operating in a catchment and of how changes in the catchment may affect these phenomena. Another objective of catchment modeling is the generation of synthetic sequences of hydrologic data for facility design or for use in forecasting. This provides valuable information for studying the potential impacts of changes in land use or climate (Xu, 2002).

There are a wide variety of hydrological models available and the choice of which to employ can depend on several factors. (Hughes et al., 1994) identified some of these and referred to the type and resolution of output required, catchment response and climate characteristics and the amount of information available for defining the input data and quantifying model parameter values. (Schulze,1995) acknowledges that different models are used for different purposes depending on the purpose of the model and data availability. The following criteria was formulated as recommended by (Mengistu, 2009 b) for selecting suitability of model in the study area.

1. The model must be able to simulate agricultural/rural areas because the Thiba watershed can be classified as agricultural watershed
2. It should incorporate tools that would allow land use and land cover, changes to enable assessment of the impacts of land use and land cover on water resources.

3. The minimum input data requirements for the model must be available or can be met with some efforts through gathering data from a data-poor watershed such as the Thiba.
4. The model must be readily and freely available, both for research and for future use in the catchment area.
5. The model should be one that can be applied over a range of watershed sizes from small to large catchments/basins so that the Thiba watershed and other similar watersheds could be modeled

Based on the above criteria, six models as summarized in Table 2.1 were carefully studied for suitability in modeling the Thiba catchment area. SWAT model was chosen as most suitable as described in the next chapter.

2.7. Soil Water Assessment Tool (SWAT)

SWAT is a continuous, physically based, semi-distributed hydrologic model developed by the USDA-Agricultural Research Service and the Texas Agricultural Experiment Station. The model calculates and routes water, sediments and contaminants from individual drainage sub-basins towards the outlet and has been widely used to predict the impact of management practices on water, nutrient and sediments in basins with varying soils, land use and management conditions (Arnold , 2005). The simulation of the watershed's hydrological cycle is divided into two phases: the land phase and the routing phase. For modeling the land phase, the river basin is divided into sub-basins, which can be further subdivided into one or several Hydrological Response Units (HRUs). HRUs are areas of relatively homogeneous Land Use Land Cover (LULC) and soil types. The characteristics of the HRUs define the hydrological response of a sub-basin. For a given time step, the contributions to the discharge at each sub-basin outlet point is controlled by the HRU water balance calculations (land phase). The river network connects the different sub-basin outlets, and the routing phase determines movement of water through this network towards the basin outlet (Neitsch, 2005). The major feature of the model is the use of SCS method which implicitly considers the relations between land use and soil characteristics suitable for assessing impacts of land use change. Further description can be found in (Neitsch, 2005).

Table 2.1: Different types of models and their applications in catchment management practices

Description	SWAT	HSPF	HEC-HMS	WaSiM-ETH	DWSM	HBV
Model Type	Semi-distributed Physically-based Long-term	Semi-distributed Conceptual model	Semi-distributed Physically based	Semi-distributed Physically based model	Semi-distributed Physically based	Semi-distributed Conceptual model
Model Objective	Predict the impact of land management practices on water and sediment	Simulate water shed hydrology and sediment-chemical interactions	Simulate rainfall-runoff processes of dentritic watersheds	Simulate watershed water balance	Simulations of surface and subsurface storm water runoff, flood and sediment transport.	Simulate rainfall-runoff processes and floods
Temporal scale	Day	Flexible	Day	Day	Day	Day
Watershed representation	Sub-watersheds grouped based on climate,HRU,ponds,ground water and main channel	Uses sub-basins as primary hydrological units	Uses sub-basins as primary hydrological units	Grid based	Sub-watersheds (1-D) overland elements, channel and reservoir units	Uses sub-basins as primary hydrological units

Processes modeled	Continuous	Continuous & event	Continuous &event	Continuous	Single event	Continuous &event
Runoff on overland	Runoff volume using CN and flow peak using Rational formulae	Chezy_Mannings equations	Clark's,Snyder's,SCS UHs,ModClark,Kinematic wave	Using saturation time after Peschke (1977)	Kinematic wave equations	Uses response function to transform excesses rainfall to runoff.
Evapo-transpiration	Hargreaves,priestley-Taylor &Penman	Hamon,Jensen methods	Monthly average	Penman-Monteith Wendling,Hamon	Little information	Monthly average
Subsurface flow	Lateral flow using kinematic storage model an d groundwater flow using empirical relations	Interflow outflow and groundwater flow flow using empirical relations	Constant monthly, Exponential recession or linear reservoir	Empirical equation	Combined interflow and base flow using kinematic storage equation	Simple functions of actual water storage and a soil box
Water Routing	Variable storage coefficient method or Muskingum method	Inflows enter upstream point, and outflow is a function of reach	Kinematic wave,Lag,Muskingum,Muskingum-Cunge	Translation - retention approach using hydraulic	Same as overland flow	Muskingum method or simple time lag

		volume		parameters		
Management practices	Agricultural mngt,tillage,irrigation etc	Agricultural mngt,tillage,irrigation etc	Account human impact on runoff	Irrigation, water management options	Detention basins, alternative ground covers	Different management practices
References	Neitsch et al.(2005)	Bicknell et al.(2001)	US-ACE (2001)	Schulla,2000	Bora and Bera (2004)	SHMI(2003)

CHAPTER THREE

DESCRIPTION OF THE STUDY AREA

3.1. Introduction

This chapter presents the key characteristics of Thiba River Basin. The main issues dealt with include: location of study area, climatic conditions, hydrology and drainage, geology and geomorphology and land use. The data has been obtained from analysis of climate data , government reports and literature review from past studies and field surveys.

3.2. Location of the Study Area

The Thiba River Basin is located in Kirinyanga and Embu Counties in central region of Kenya. It is located within longitude 37°40' and 37º 20' E and Latitude 0° 5' and 0º10' S. The basin covers approximate land area of about 1648 km2 as shown in Figure 3.1.The basin is situated in the upper region of the Tana River Catchment that is drained by the Thiba, Nyamidi, and Rupigazi Rivers and other several streams. Thiba watershed was selected as case study for this research because it represents watersheds where there is high irrigation water abstraction and intensive agricultural activities. Data availability though not good for thorough conclusive research was another factor considered. The land use systems together with considerable human interventions in the upper part of Thiba watershed makes it feasible for LUCC impact analysis on hydrological regime.

3.3. Climatic Characteristics

3.3.1. Rainfall

The Thiba River Basin has a tropical climate and bimodal rainfall pattern Figure 3.2. The Long Rain season lasts from around March to May with peaks in April with rainfall average of 2146 mm and the short rain season from September to November with peaks in November with an average of 1212 mm (Kirinyaga County, 2013). The rain seasons varies from year to year in their duration and rainfall amounts. The average annual rainfall increases from 400 mm in savannah areas to 2300 mm on the slopes of Mt.Kenya (Notter, et al.,2007).

Figure 3.2 shows rainfall trend and average monthly mean rainfalls for period of 1990 to 2011. It can be seen that the low season rainfall occurs in the months of January February, June, July August and September.

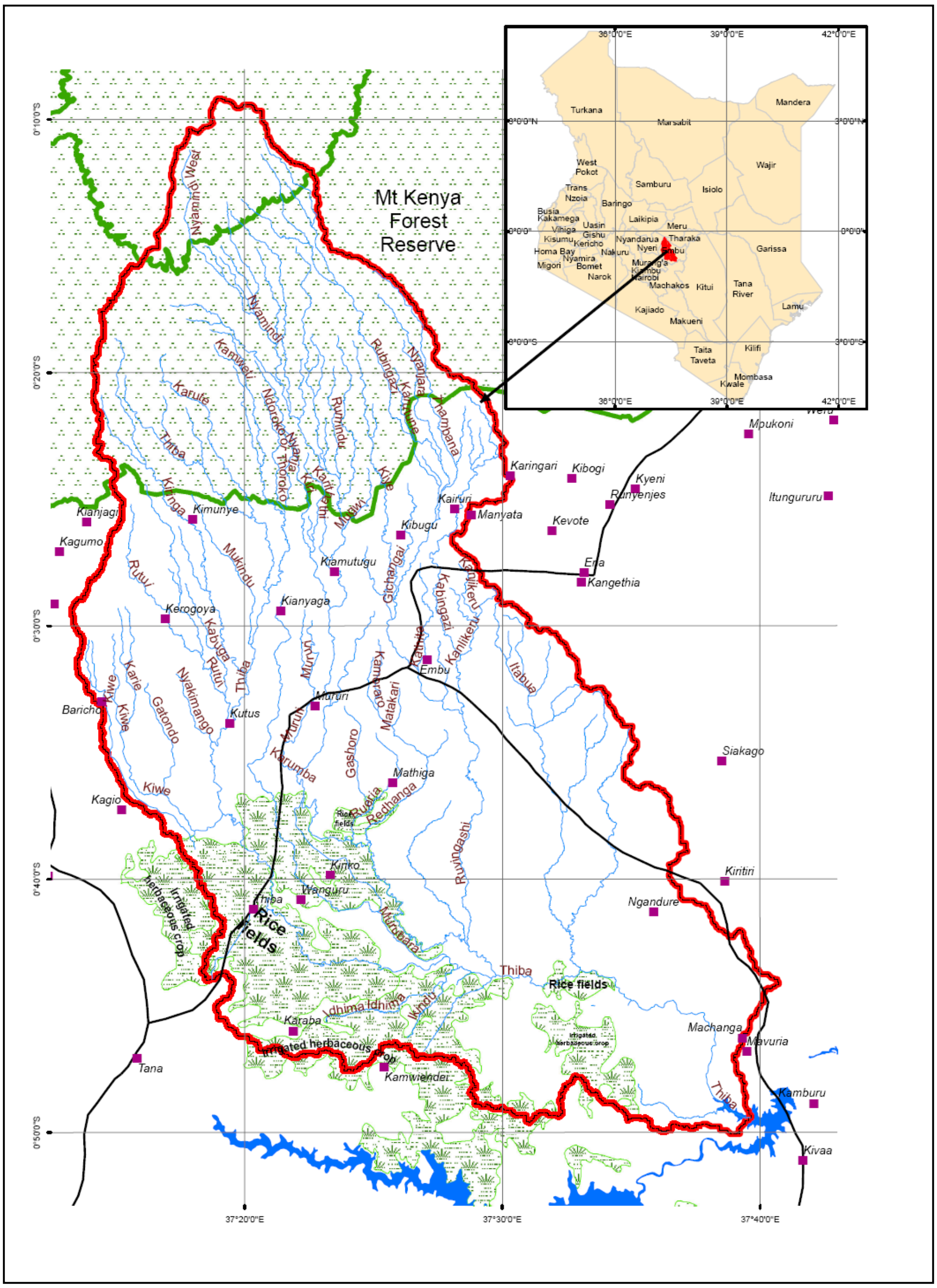


Figure 3.1 : The extent of Thiba Catchment Basin including the main roads and urban centers in the basin.(Source: Kasuni, 2016).

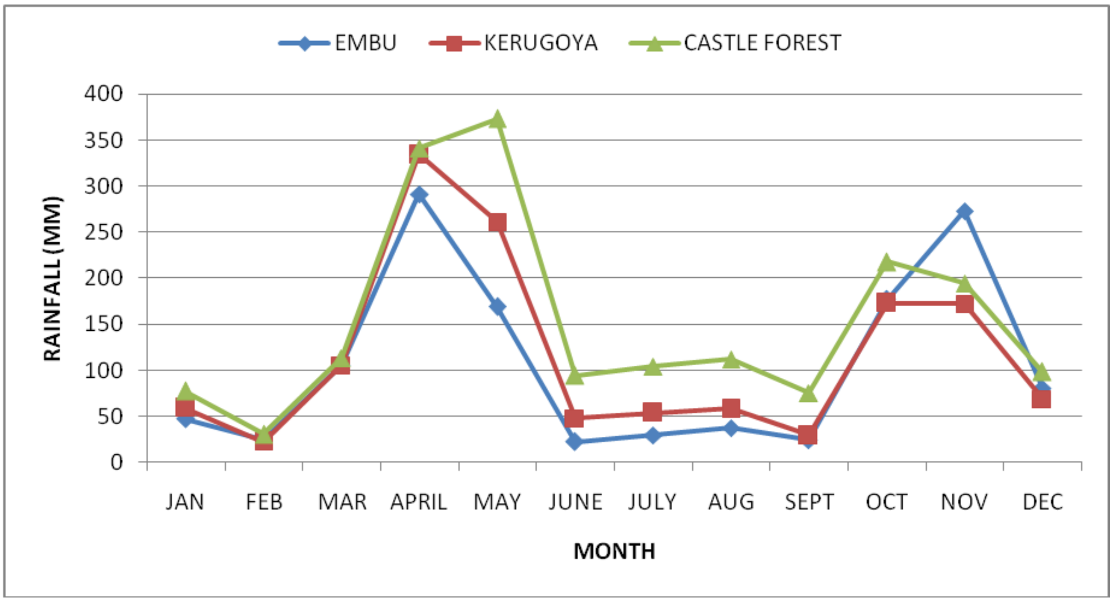


Figure 3.2 : The mean monthly rainfalls for the main stations within Thiba River Basin for the period between 1990 and 2011 showing bimodal rainfall pattern.

3.3.2. Temperature

The temperature in the Thiba River Basin ranges from a mean of 8.10º C in the upper zones to 30.3º C in the lower zones during the hot season. The hottest months are January-February while June-July are the coolest (Kirinyaga County, 2013).

3.3.3. Potential Evapotranspiration

Potential evapotranspiration in the Thiba River basin ranges from 1700 mm in the low elevation savannah zone to less than 500 mm in the upper region of the basin. All areas below the forest zone have a rainfall-evapotranspiration deficit. As a consequence, the high elevation forest and moorland zones provide most of the discharge of the rivers during the dry periods (Notter et al., 2007).

3.4. Drainage and Hydrology

Thiba river basin lies on the southern slopes of Mt. Kenya-the highest mountain block in Kenya with dendritic drainage system. Thiba river is 78 km long and drains a surface area of about 1648 km2. The tributaries include Murubara, Nyamidi, and Rupigazi, among other minor tributaries. This river acts as a source of water for the largest rice irrigation scheme in Kirinyanga County. Following the bi-modal type of rainfall, the river experiences peak flows during the long rains (March to May) and the short rains (September to November). The river discharges ranges between 8 m3

/s during the low rainfall season to 86 m3/s during high rainfall season as measured at the catchment outlet (4DD02).

Other rivers flowing in this system include Rupigazi sub-basin, which is found in the Mt Kenya sub-catchment area. It mainly flows through Embu County before joining Thiba River. It has an estimated length of 78 km and covers an area of 354 km2. Nyamidi sub-basin has an estimated length of 78 km and an area is 453 km2. This river flows through Kirinyanga sub-county. Murubara River flows from Mt. Kenya through Nyeri and later joins Thiba River near Kiriko town (Thiba-Murubara confluence). The river also bursts its banks during high flow, which cause flooding in the area.

Thiba river drains to Kaburu dam one of the 7 hydro-power stations in the Upper Tana. The seven hydropower stations deliver up to 65% of the country's electricity .

3.5. Topography

The Thiba River basin lies between 1,158 meters and 5,380 meters above sea level in the South and at the Peak of Mt. Kenya respectively. Mt. Kenya which lies on the northern side greatly influences the landscape of the basin as well as other topographical features.

The mountain area is characterized by prominent features from the peak, hanging and V-shaped valleys. The snow melting from the mountain forms the water tower for the rivers that drain in the county and other areas that lie south and west of the county. The Snow flows in natural streams that form a radial drainage system and drop to rivers with large water volumes downstream (Kirinyaga County, 2013).

3.6. Geology

The geology of the study area mainly originates from volcanic activities. In some low lying areas, Basement rock of Archean gneisses is exposed to the surface. Tertiary agglomerates and phonolites develop covering the basement rock, which are further covered by Pleistocene (Quaternary) basalt flow over the stretch between Nyamidi river and Tana river (NIB, 2009) .The reddish silty soil covering the ground originates from intensive weathering of those volcanic rocks or deposition of Holocene volcanic ashes. The tertiary to quaternary volcanic rocks and lave flows appear to bend almost horizontal, without noticeable tectonic disturbances, such as faulting and folding.

The volcanic rock basement has influenced the formation of magnificent natural features such as “God's bridge” along Nyamidi River, and the seven spectacular water falls within the basin. Mount Kenya, an extinct volcano formed between 100-400 million years ago, is located in the west of the catchment (NIB, 2009).

3.7. Soils

The dominant soil types of the Thiba catchment areas presented in Figure 3.3 show a clear relationship with elevation of plain land adjacent to volcanic mountain. The higher slopes of Mt. Kenya are dominated by Nitisols. These soils have been formed from volcanic ash deposits. Though they have undergone a series of weathering, they are far more productive than most other red tropical soils (FAO, IIASA, ISRIC, ISSCAS, 2012). Humic Nitisols are well drained, deep, dark friable red soils thus suitable for agricultural activities. The soils have mainly been cultivated with tea, coffee and food crops such as maize. Hitisols are highly resistant to soil erosion but if exposed to poor land management practices, high precipitation received in those high altitude areas can result to excessive soil loss resulting to soil degradation (Geertsma et al., 2010).

At lower elevations especially 1000 m above sea level, ferrasols and vertisols are the dominant soil types (FAO, IIASA, ISRIC, ISSCAS, 2012). The soils have been modified from original parent material due to weathering. Vertisols are imperfectly drained to poorly drained, very deep, dark reddish brown to very dark grey, mottled, friable to firm, silty clay to clay; in places stratified and cracking. This makes them suitable for paddy rice farming. On the other hand ferrasols found in the southeastern part of the basin are excessively drained to moderately well drained, moderately deep to deep, dark red to dark grey, loose to friable, sandy loam to clay; in places stony, rocky and bouldery.

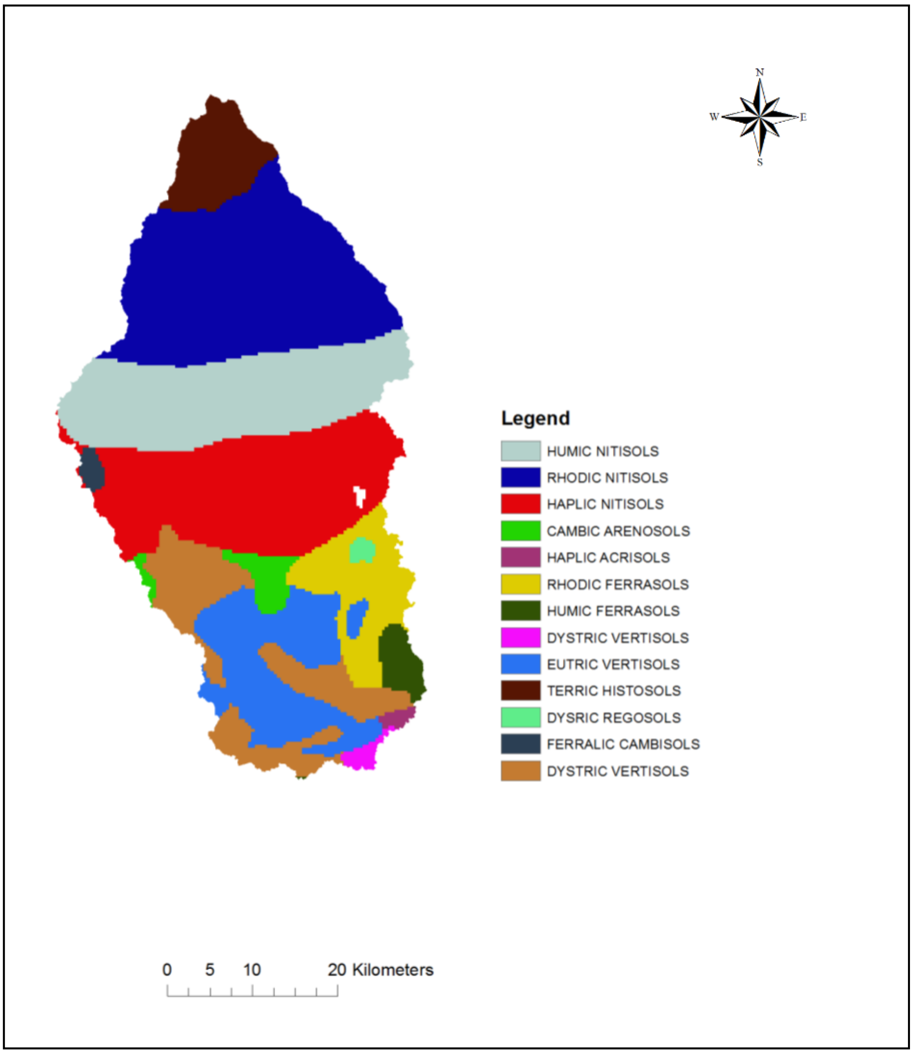


Figure 3.3 : Spatial distribution of soils in Thiba River Basin

3.8. Agriculture and land Use

Land use in Thiba basin can be divided into three classes: natural vegetation (forest, grassland and wetlands), rain-fed and irrigated agriculture (maize, horticulture and rice) and rangeland. The pre-dominant land-use activity in the area is commercial flood-irrigation of rice in a scheme (MIS). The scheme started back in 1956 with irrigated area of 5,890 acres. Currently it has a gazette area of 30,350 acres of which 16,000 acres is for rice production while the rest is used for settlement, public utilities, subsistence and horticultural crop farming (Ndegwa, 2014). The scheme is served by two main rivers namely Nyamidi and Thiba. Irrigation water is abstracted from the rivers by gravity by the help of fixed intake weirs, conveyed and distributed in the scheme via unlined open channels. There is a link canal joining the two rivers which transfers water from Nyamidi to Thiba River which serves about 80% of the scheme (Ndegwa, 2014). The Scheme irrigation water is supplied in bulk continuously up to the main feeder canal level. From here, it is delivered to the farms in rotation through the branch, main feeder and line feeder canals. Branch canals supply water from the main canal to one or more blocks of farms known as water management units (WMUs), whose sizes range from 55 to 508 acres. The individual farms are situated along the line feeder canals. During periods of low river discharge, the rotational water supply occurs at any level between the branch canal and line feeder canal depending on the severity of the water scarcity. Extreme scarcity (very low river discharge) results in rotational supply at the branch canal level, whereas the main feeder canal (that is, between the WMUs) rotational supply is adopted under moderate scarcity. Water use in the Scheme is regularly monitored by use of gauges installed at the main canal head works (water intake points on the river).

3.9. Population and Socio-Economic Activities

The population density in the Thiba river basin was 488 people per Km^2 in 2012 but is expected to increase to 524 people per Km^2 in 2017 (Kirinyaga County, 2013). Scattered settlement patterns are found mostly in the lower zones of the county where land sizes are large. Ecological and climatic factors influence settlement in upper zones where land is fertile and receives more rainfall. Another factor that influences settlement is the type of farming practiced in the upper zone where cash crops such as tea and coffee attract a high population because residents have a higher preference for cash crops farming compared to food crops. Another reason for clustered settlement is the growth of towns such as Kerugoya, Sagana and Wang'uru where there are many migrant workers and business people. The town with the highest population is Wang'uru with a population of 18,437; followed by Kerugoya with a population of 17,122; the least populated town is Sagana with a population of 10,344. The urban centre with the highest population is Kagio with a population of 3,512 followed closely by Kagumo with a population of 3,489. The population of Wang'uru is highest because it has a lot of economic activities, mainly rice farming while Kerugoya town had long been the District administrative headquarters (Kirinyanga County, 2013).

CHAPTER FOUR

THE METHODOLOGY

4.1. Introduction

This chapter is focused on the presentation of methods of data collection and analysis used in this research. The data was collected through field visits, desk studies and discussions with focus groups. The data was collected for investigating agricultural water abstraction, historical rainfall and stream flow, GIS layers for different thematic areas such as land cover, ground elevation and soils. Satellite downloaded data was validated with observed measured rainfall. SWAT modeled stream flow was calibrated and validated with observed gauged stream flow data. The data analysis employed both statistical and hydrological data analysis methods. The section thus describes in details the methods employed in the study as summarized in the Figure 4.1 shown below.

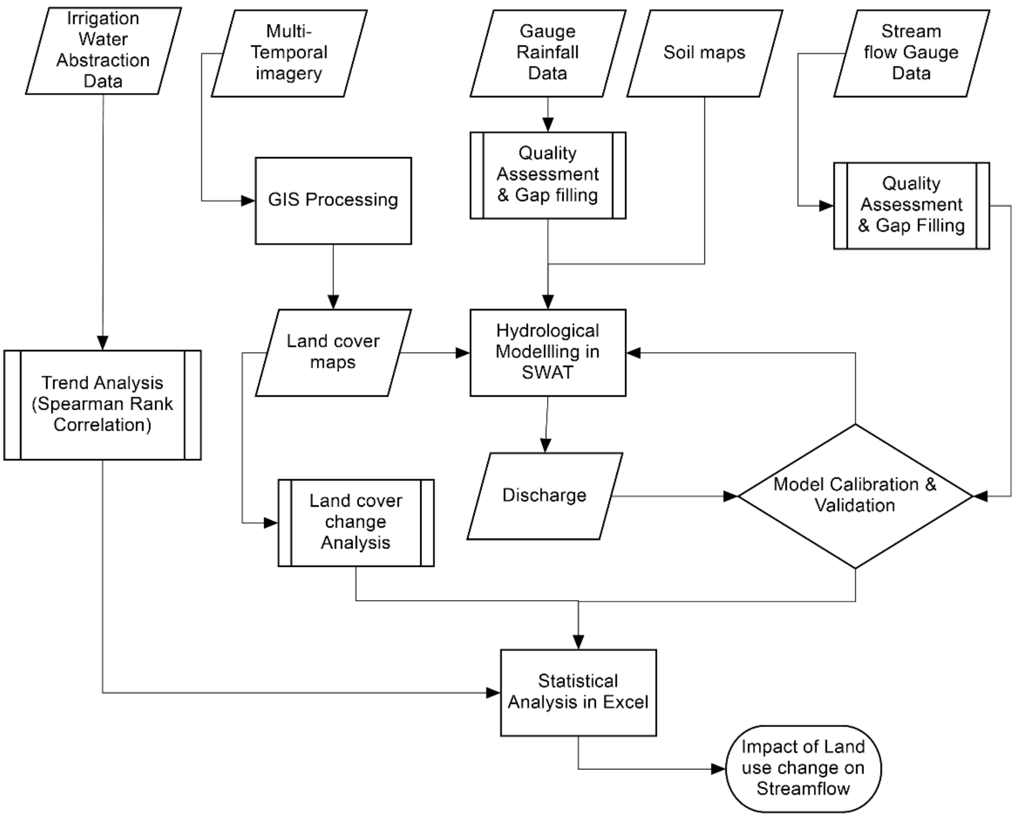


Figure 4.1 : Summary of methods applied in this study

4.2. Data Collection and Pre-Processing

The different types of data required for this study are explained in this chapter. The preliminary data validation methods are also discussed.

4.2.1. River Discharge Data

Historical stream flow data for Thiba River was obtained from Water Resources Management Authority (WRMA) in Embu. The observed river gauging stations as shown in Figure 4.1 have historical data of over 25 years spanning from 1967 to 2011. According to Burn and Elnur (2002), selection of gauging stations in impacts of land use and climate impact study requires a minimum record length of 25 years of stream flow to ensures validity of the trend results statistically. The observed historical river discharge data was used to investigate changes in stream flow in the basin as a result of water abstraction calibration and validation of SWAT model. The data used for stream flow analysis is attached as Appendix C.

Table 4.1 : River gauging stations location and period of data coverage within ThibaRiver Basin

STATION CODE	COORDINATES	PERIOD OF COVERAGE
4DA10	0.36º S 37.317º E	1968-1996,2002-2014
4DD02	0.43º S 37.506º E	1966-1992,2008-2014

4.2.2. Rainfall Data

Historical rainfall data for Thiba river basin was obtained from Kenya Meteorological Department (KMD) for Castle Forest, Embu and Kerugoya as attached in Appendix D. The observed rainfall in the stations were used in calibrating satellite rainfall data. The observed stations had data spanning from 1990 to 2013 as shown in Table 4.2.The spatial distribution of the rainfall stations are shown in Figure 4.2 .The double mass curve (APPENDIX E) was used in the present study to carry out homogeneity and consistency tests for the observed data before being used for calibrating satellite rainfall data.

Table 4.2 : Rainfall stations within Thiba River Basin

STATION NAME	STATION ID	COORDINATES	PERIOD OF COVERAGE
CASTLE FOREST	9037115	37.2ºE 0.48ºS	1990-2013
EMBU	9037202	37.4ºE 0.52ºS	1990-2014
KERUGOYA	9037031	37.2ºE 0.49ºS	1990-2013

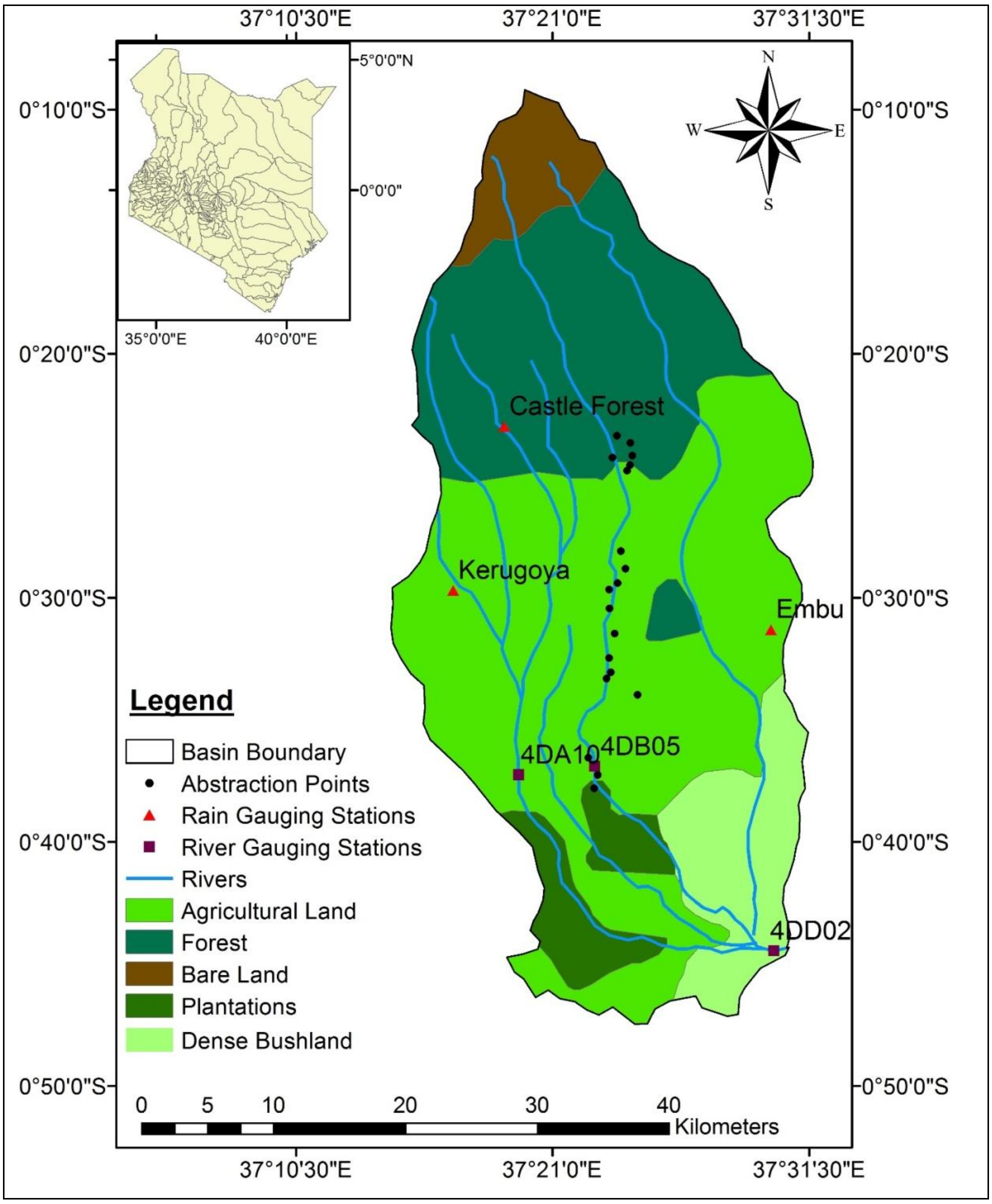


Figure 4.2 : Spatial distribution of rainfall and river gauging stations contributing to data used in this study (Source: Kasuni, 2016)

4.2.3. Water Abstraction Data

Water abstraction data was obtained through primary and secondary methods. The primary abstraction data was obtained through water abstraction survey using a questionnaire (Appendix A). The secondary data was obtained from National Irrigation Board (NIB) and Water Resources Management Authority (WRMA). The data from WRMA was mainly used to validate the water abstraction survey through visual inspection of consistencies.

4.2.3.1. Water Abstraction Survey

The Data on water abstraction from the rivers was collected from field surveys using a structured questionnaires, Water Resources Users Association and Water Resource Management Authority (WRMA) between June and September 2014 and 10th March 2015 to 20th March 2015. In the questionnaire, information relating to water abstraction method, volume of abstracted water, water abstraction time series and location were requested and obtained. The survey involved measurement of open channel abstraction rates with a two inch portable parshall flume as shown in Figure 4.3 and pipe systems by volumetric method. The volumetric method measures the outflow of pipe for certain period of time using a bucket with a known volume. The time it takes to fill the bucket gives the capacity of the gravity pipe or the pump in volume per given time as shown by Equation 1.

$$Q = \frac{Vn}{Tn}$$

....Equation 4.1

Whereby: Q is discharge in m3/s, Vn is volume of vessel in m3 and Tn time in seconds.

The discharge measured by parshall flume is calculated by Equation 2.

Q=303.4 (h*3.33) 1.55 ....Equation 4.2

Whereby Q is discharge in m3/s and h is overflow head in m.

The volumetric method was done at least three times to minimize errors. Finally, WRMA provided the additional lists of abstractors as secondary data. These data were also counterchecked during the field surveys. The information collected was used to examine historical water abstraction trend from 1997 to 2014.

Figure 4.3 : Measuring water abstraction by open channel in Thiba River using parshall flume: Source Kasuni (2016).

4.2.3.2. Water Abstraction by Mwea Irrigation Scheme

Mwea Irrigation Scheme measures water use by different irrigation sections through locations known checkpoints as shown in Figure 4.4. The daily water levels record in the checkpoints is converted to water flow by equation developed in water management by JICA in 1995.

Figure 4.4 : Staff gauge contributing to data located at checkpoint I at Nyamidi headrace used for flow measurements. Source: Kasuni (2016).

The Mwea Irrigation Scheme office observes and records water levels at 6 check points. However only two checkpoints i.e. CP1 and CP 3 as shown in Figure 4.5 contributed data for water abstraction analysis. The rest of the checkpoints are used in scheme water management of the five sections forming Mwea Irrigation Scheme namely: Tebere, Wamumu, Karaba, Thiba and Mwea.

4.2.4. Land use/cover data

Land sat image covering Thiba basin for the year 1984 was downloaded freely from www.http://earth.explorer.usgs.gov obtained by 4-5 TM MSS series. for the month of August (APPENDIX G). The image was already geometrically corrected. Classified land use polygon maps for the year 2004 and 2014 was downloaded from AFRICOVER project database. The AFRICOVER project was initiated by the Food and Agriculture Organization (FAO) on the request of several African countries to provide accurate and reliable land cover information, based on a systematic and harmonized land cover classification system and on uniform cartographic and mapping specifications for the whole continent of Africa. Di Gregorio & Latham, 2015). FAO AFRICOVER project (FAO 2004 and 2014) designates land use/land cover for points on an approximately 2400 x 4800 m irregular grid. The effective scale was 1: 250 000. The land cover was produced from visual interpretation of digitally enhanced LANDSAT TM images (Bands 4,3,2).

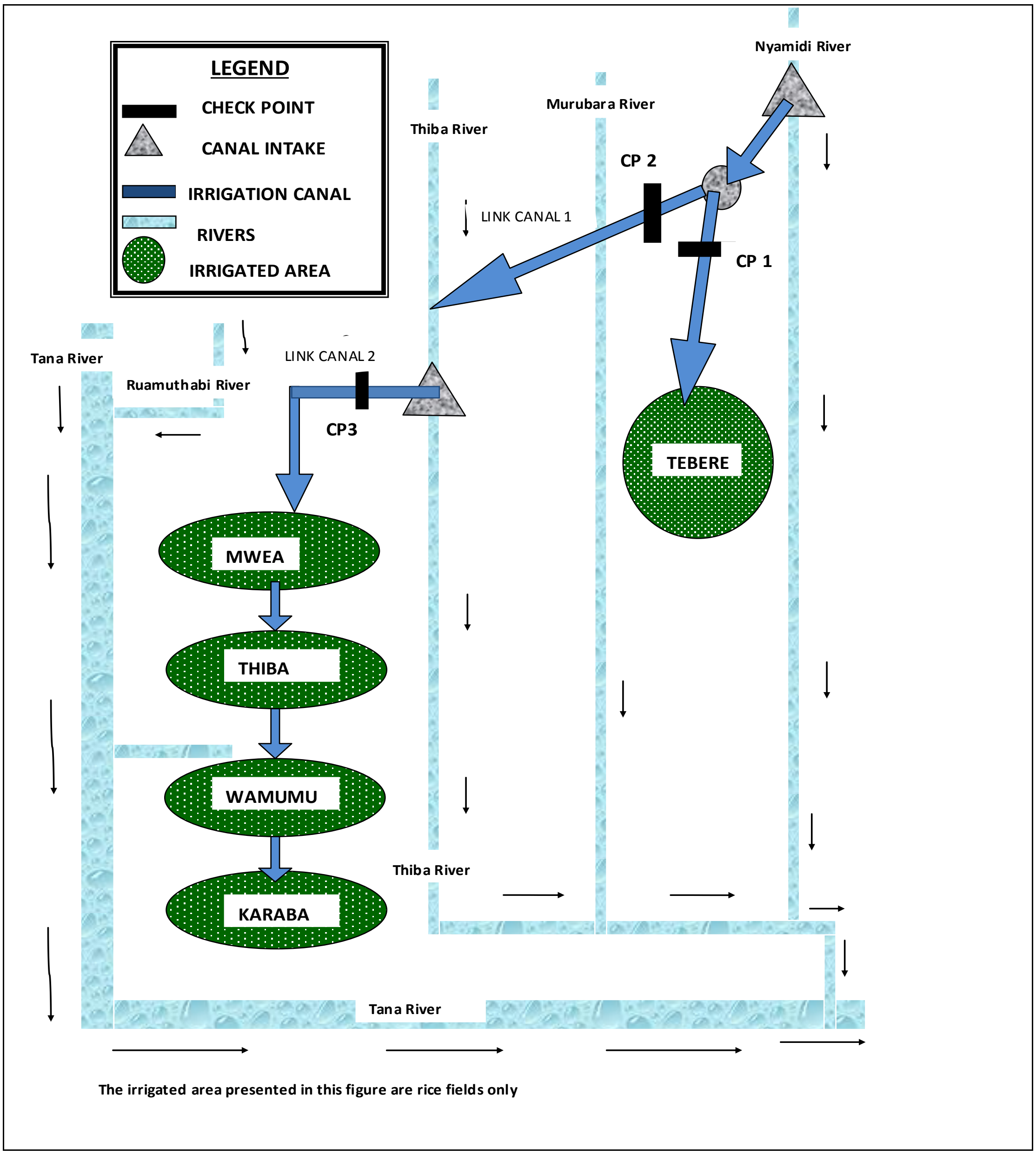


Figure 4.5 : Water abstraction points at Mwea Irrigation Scheme based on O&M plan 2008/2009 by MIS scheme office.

4.2.5. Satellite-Based Weather Data

The satellite based weather data was downloaded from the weather database of Soil and Water Assessment Tool (SWAT) website globalweather.tamu.edu. Rainfall data was used to simulate daily amount of stream flow to be generated by each catchment. According to (Thiemig and Rojas, 2013) the satellite estimate rainfall need to be corrected before being entered into model for stream flow simulation. This was made possible by using data collected from the weather stations.

Potential evapotranspiration data was used for daily basin balance on a cell by cell basis according to the Penman-Monteith equation (Entenman, 2005). Atmospheric water demand for water on the earth surface is a function of solar radiation, air temperature, wind, humidity and atmospheric pressure. The satellite generated data used for this study was for the period between 1980 to 1993.

4.2.6. Soil Data

The soil map used for this study was downloaded from Soil and Terrain (SOTER) database for upper Tana River catchment at the scale of 1:250,000 (Macharia, 2011) . The database was developed through a programme framework of Green Water Credits (GWC) in upper Tana River (GWC, 2008).The database was chosen because it was developed for use with Soil Water Assessment Tool (SWAT).

4.2.7. Digital Elevation Model (DEM)

A 30 m resolution Digital Elevation Model (DEM) derived from elevation data of the Shuttle Radar Topography Mission (SRTM) was obtained from United States Geological Survey (USGS) website (https://lta.cr.usgs.gov). The data was a basic input of the catchment delineations, stream flow networks, flow accumulation, slope and other variables.

4.3. Data Analysis

This section presents methods employed for data analysis. Data validation for satellite observed rainfall data was conducted using correlation test. Land use change detection was undertaken after classification of land use maps through tabulation comparison. Water abstraction trend hypothesis test for the year 2007 to 2014 was tested with spearman rank correlation test. Arc SWAT software was used for simulating stream flow response to land cover from classified land use maps for the years 1984 and 2014. Stream flow data at the catchment outlet gauge 4DD02 was used for calibrating the model using SWAT-CUP software. Parameters were optimized until sufficient model efficiency was obtained.

4.3.1. Statistical Methods of Data Analysis

The statistical measures used for this study were the arithmetic mean, Linear regression, correlation analysis, spearman's rank correlation test and paired T test.

4.3.1.1. Mean

Mean is the common measure of central tendency and is also known as arithmetic average (Kothari, 2004). It is defined as the value we get by dividing the total of the values of various given items in series by total number of items as shown by Equation 4.3 below.

$$\bar{x} = \frac{1}{n} \cdot \sum_{i=1}^{n} x_i$$ ....Equation 4.3

x = The symbols used for mean

xi =Value of the ith item x,i=1,2,...,n

n=total number of items

4.3.1.2. Linear regression

Regression is the determination of a statistical relationship between two or more variables. A simple regression analysis has two variables, one variable defined as independent is the cause of behavior of another one defined as dependent variable (Kothari, 2004). The analysis interprets the physical way in which independent variable X can affect dependent variable Y. In addition, it reveals the amount by which the dependent variable will change given a one unit change in the independent variable. The regression model is given by Equation 4.4

$$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i$$ .... Equation 1.4

Where:

yi = ith observation of the response (dependent variable)

xi = ith observation of the explanatory (independent) variable

β0 = y intercept

β1 = slope

εi = random error or residual for the ith observation

n = sample size

4.3.1.3. Correlation Analysis

Correlation complements regression model by measuring the strength of the relationship between the dependent and the independent variables or the degree to which the two variables change together thus valuable in testing hypothesis (C.R.Kothari, 2004). However correlation analysis does not give the cause of the relationship. If x and y is independent and dependent variables respectively, then correlation coefficient (r) is given by Equation 4.5 shown below:

$$r = \frac{n\sum xy-(\sum x)(y)}{\left(\sqrt{n(\sum_x 2)-(\sum x)^2}\right)-\left(\sqrt{n(\sum_y 2)-(\sum y)^2}\right)} \quad \text{...Equation 4.2}$$

Coefficient of determination (R^2) is measured by squaring correlation coefficient (r). The R^2 is an appropriate measure for the quality of the regression fit to the observations. The values of r are such that:$-1 \leq r \leq +1$. The positive (+) and negative signs (-) are used for positive and negative correlation respectively. If x and y have a very strong linear positive correlation, r is close to +1. An r value of exactly +1 indicates a perfect positive fit. Positive values indicate a relationship between x and y variables whereas values for x increases, values for y also increase. Similarly, an r value of exactly -1 indicates a perfect a negative positive fit. Negative values indicate a relationship between x and y variables whereas values for x increases, values for y decrease.

4.3.1.4. Hypothesis Testing

Hypothesis testing in assessment of hydrological time series can be grouped into two categories: parametric and non-parametric. In parametric tests, the researcher assumes that data probability distribution is known. On the other hand, non-parametric test is formulated in a such a way that the probability data distribution is not necessary Wilks (2006).When dealing with hydrological variables, the probability data distribution is unknown thus approximations are needed. Thus most of the researchers in hydrological studies have always preferred non-parametric tests (Chebana et al., 2013).

The assumption in hypothesis testing is that the null hypothesis should be stated prior to the data analysis so that the researcher is not influenced by time series behavior. Moreover, the sample elements must be mutually independent which does not likely occur in most hydrological time series. In analyzing monotonic trends rather than jumps in time series, Spearman rho (s) and Mann Kendall inferences are most commonly used. Both are non-parametric ranked-based tests and have very similar power in detecting trends (Yue et al., 2002). Spearman rank correlation test
was chosen for testing hypothesis of existence of water abstraction trend in this study because of its popularity in hydrological studies due to its simplicity yet high validity Altman (1991). Student t test was used for testing the significance of land use land cover change on stream flow responses during the wet and dry season.

4.3.1.5. Spearman Rank Correlation Test

The Spearman Rank Correlation Test is a non-parametric test which does not make distributional assumptions to the population under investigation. The Spearman's rank coefficient is used to measure the correlation between two sets of ranked data of the same series of observations (Kothari, 2004). According to Altman (1991) a number of correlation methods such as Spearman's and Pearson are popular in hydrological studies due to their relative simplicity and high validity. The hypothesis is tested by Equation 6 as shown below.

Rsp. = $1 - \frac{6 * \sum_{i=1}^{n} Di^2}{n^3 - n}$ ....Equation 4. 3

Where:

Rsp. = Spearman's Rank coefficient;

n = total number of data;

D = difference between rankings and it is computed through the following equation:

D=K−K

i = chronological order number;

Kxi = rank of the variable x, which is the chronological order number of the observations;

Kyi = rank of the variable y, which is the chronological order number of an observations.

The hypothesis will be tested as described below.

Null hypothesis H0: Rsp=0 (there is no trend)

Alternate hypothesis, Ha: Rsp <> 0 (there is a trend)

For n (sample size) >30, the distribution of Rs will be normal, so that the normal distribution tables can be used. In this case, the test statistic (Rs) is computed by $Z=Rs\sqrt{n-1}$.If $|Z|>Z\alpha$ at a significance level of α; then the null hypothesis of no trend (on the other word, values of observations are identically distributed) is rejected.

As the Spearman’s Rank Correlation Test only measures the relationship between two data sets, the significance of this relationship was tested using the Rsp values on the Spearman Rank significance table (Appendix f).

4.3.1.6. Paired t-test

This method is based on t-distribution and is considered by Kothari (2004) an appropriate for testing the significance of difference between the means two related samples . The t test is calculated from sample data (observed data) then compared with probable value based on t distribution (read from the students t distribution table) at specified level of significance for concerning degrees of freedom for accepting or rejecting the null hypothesis. Equation 4.7 illustrates the formulae for calculating the observed value of t denoted as t n-1.

$$t_{n-1} = \frac{\bar{d} - \mu_d}{\frac{S_d}{\sqrt{n}}}$$ ....Equation 4.7

$\bar{d}$ = mean difference between paired sample

μd= hypothesized population mean difference (usually 0)

Sd= Standard deviation of paired score differences

di= sample item difference where i=1 to n (for each pair)

n=sample size (number of paired scores in the sample)

n-1 = degrees of freedom for the t test statistic

4.3.2. Data Validation

Data validation of satellite data with observed data was conducted using correlation analysis described under statistical data analysis chapter.

4.3.3. Land Use Land Cover Classification and Change Detection Analysis

4.3.3.1. Land Use Classification

The process of land use land cover change detection started by importing the land use polygons downloaded from AFRICOVER-East Africa database to Arc-GIS software. The maps were converted to raster maps as required by Arc SWAT software. Land cover map for the year 1984 was acquired from land sat image 4-5 TM MSS series.

Error! Reference source not found. shows the steps that were undertaken in producing land use map for the year 1984. The image pre-processing techniques employed in the image were radiometric correction that involved: conversion of image Digital Number to at sensor radiance, and conversion of sensor radiance value to Top of Atmospheric Reflectance (TOA) band reduction of haze through Dark Object Subtraction (DOS) process. Environment for Visualizing Images (ENVI 5.1) Remote sensing software was used for the processes. Supervised classification was conducted for the 1984 land sat cover by applying maximum like hood classifier to produce land use images.

Image classification was thus undertaken by: 1) selecting training samples, 2) checking for overlapping classes and 3) applying maximum like hood classifier in ENVI 5.1 Remote sensing software. With guidance from historical information gathered during field survey and classified images for land use for 2004 obtained from Africover database, the image was classified to nine classes namely: Forest, rain fed agriculture, irrigated agriculture, bare land, shrubs, herbaceous plants, rice, urban area and water. Image accuracy was assessed through applying the end members of classified images of 2004.

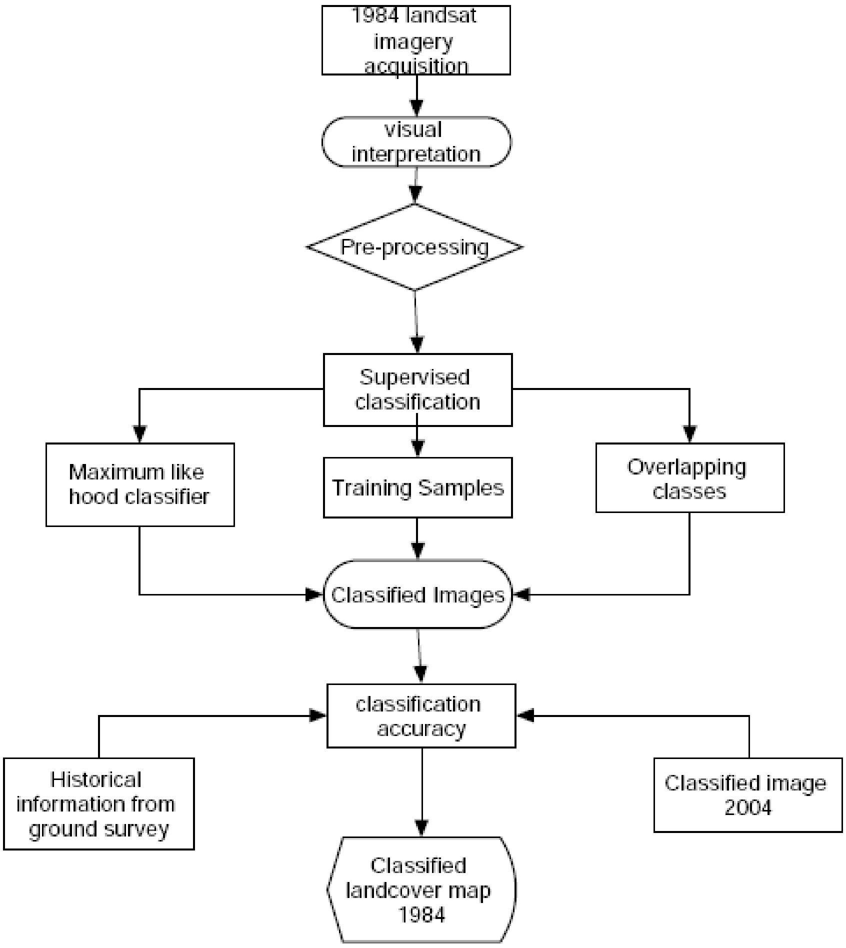


Figure 4.6 : Process of producing land use map for the year 1984

This was the major guidance to training samples and thorough observation was undertaken to ensure training samples did not fall on the changed pixels.

Land use change rationality assessment was conducted because of absence of reference data for image classification. In order to justify the accuracy of temporal image classification, rule-based rationality change detection evaluation according Liu & Zhou (2004) was applied. For this method, 300 random points were taken from the classified 2004 image. The overall accuracy was calculated based on total number of true (correctly classified) pixels based on the rules defined by (Liu & Zhou (2004) as follows;

1. If the sample pixel is classified to be the same land use for all dates, then it is regarded to be correctly classified.

2. If one change only is detected from a land use type (except settlements / infrastructures) into another land use type, the sample pixel is regarded to be correctly classified.

3. However if one change is detected from settlements/infrastructure to other land use types, the pixel is regarded not correctly classified because settlements / infrastructure classes is regarded irreversible.

4. If a pixel is detected to change from a land use type (LU1) into another land use (LU2) and reverses back to the first land use type (LU1), it is regarded as the fuzzy state. Because it can be caused by the error of the classification and it also can truly happen.

5. If a pixel has multiple changes for three dates of assessment (i.e. from LU1 to LU2 and LU3), it is regarded as fuzzy state. Even though a possibility of the multiple changes may be true, but it may also be caused by the error of the classification images. Therefore it is regarded as "fuzzy". This rule was applied by excluding the irreversible change as mentioned in rule 3.

4.3.3.2. Land Use Change Analysis

The land use change analysis was conducted by using post classification change comparison method. Post classification is regarded as one of the most accurate procedure to present changes of land use (Mas,1999). The major advantage of post classification is that it has detailed land use information. This eliminates the difficulties of analysis of images at different periods of time and sensors (Mas, 1999).

Land use trajectory changes were assessed by applying cross tabulation of the sequence maps of land use 1984, 2004 and 2014 from the results obtained from image classifications.

4.3.4. Trend Analysis of Agricultural Water Abstractions

The water abstraction data both primary and secondary was analyzed using Microsoft Excel tool to give the annual volume of water abstracted from the basin. The data was analyzed for existence of trend using spearman's rank correlation test. During fieldwork, focus discussion with key technicians advised that the best months to study water abstraction trend were July, August and September when water abstraction is highest and stream flows at the lowest. In order to investigate possible effect of the water abstraction trend on stream flow, the correlation of water abstractions and stream flow during the dry season was explored. The following criterions was used to label the correlations

1. Strongly correlated: all the correlation coefficients including R^2 , Spearman's ρ are greater than or equal to 0.5,and all p-values are smaller than or equal to 0.05.The sign of the slope of linear regression is used to determine positive (+) and negative (-ve) correlation.
2. Probably Correlated: one of the correlation coefficients is greater than or equal to 0.5, and the corresponding p-value is smaller than or equal to 0.05.
3. Not Detected: all the correlation coefficients are smaller than 0.5.

4.3.5. Modeling Stream Flow Response to Land Use Change

The SWAT model is a physically-based continuous time, spatially distributed model designed to simulate water, sediment, nutrient and pesticide transport at a catchment scale on a daily time step. The model was developed by the U.S. Department of Agricultural Research Service (ARS) and scientists at Universities and research agencies around the world (Vilaysane et al., 2015). It uses hydrological response units (HRUs) that consist of specific land use, soil and slope characteristics. The HRUs are used to describe the spatial heterogeneity in terms of land cover, soil type and slope class within a watershed. The model estimates relevant hydrological components such as evapotranspiration, surface runoff and peak rate of runoff, groundwater flow and sediment yield for each HRU (Vilaysane et al., 2015). Arc SWAT extension of Arc GIS is a graphical user interface for the SWAT model. The SWAT model is developed and refined by the water balance equation 4.8 is the base of the hydrologic cycle simulation in SWAT:

$$SW_t = sw_0 + \sum_{i=1}^{t}(R_{day} + Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad \text{.......................Equation 4.8}$$

in which SWt is the final soil water content (mm), SW0 is initial soil water content on day i (mm), t is the time (days), Rday is the amount of precipitation on day i (mm), Qsurf is the amount of surface runoff on day i (mm), Ea is the amount of evapotranspiration on day i (mm), wseep is the amount of water entering the vadose zone from the soil profile on day i (mm), and Qgw is the amount of return flow on day i (mm).

The subdivision of the watershed enables the model to reflect differences in evapotranspiration for various crops and soils. Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases accuracy and gives a much better physical description of the water balance (Arnold et al., 1999).

SWAT model requires basic data input before simulation can be performed: DEM, soil layers, land use and climatic data .The data should first be converted to format that is compatible with the SWAT model. Five step by step procedure as explained in the user manual developed by (Di Luzio et al., 2002; Neitsch et al., 2002) was followed in swat modeling: (1) data preparation, (2) sub-basin discretization, (3) HRU definition, (4) parameter sensitivity analysis, (5) calibration and uncertainty analysis.

4.3.5.1. Watershed Delineations

Watershed delineation depends on DEM to delineate the watershed and to analyze the drainage patterns of the land surface terrain. The Arc SWAT interface uses the mask area for stream delineation, and the stream networks are delineated from the DEM by using an automatic delineation to SWAT model. The model fills all of the non-draining zones to create a flow direction, and superimposes the digitized stream network into the DEM to define the location of stream networks. The Arc SWAT proposes the minimum, size of the sub-watershed area in hectare to define the minimum drainage area. Generally, the smaller the threshold area, the more detailed the drainage networks and the number of sub-basins and HRUs. In addition, more processing times and spaces are needed as noted by (Vilaysane et al., 2015). In this study a 30 DEM and smaller area (4998 ha) was input to get all sub-basin of the Thiba river basin and the outlet was defined, in which it is later taken as a point of calibration of the simulated flows. As a result, there were 17 sub-basins of the Thiba catchment.

4.3.5.2. Hydrologic Response Units Definition

In the SWAT model, the watershed was divided into sub-basins by overlaying reclassified land use, soil map and slope classes, then further sub-divided into lumped units called Hydrologic Response Units (HRUs), having unique land use and soil combinations. HRUs represent percentages of the sub-watershed area and are not identified spatially within a SWAT simulation. The overall water balance is simulated at HRUs level, including canopy interception of precipitation, ET ,lateral subsurface flow from the soil profile and return flow from shallow aquifers. Flows are summed from all HRUs to the sub-basin level and routed through the watershed outlet. The major feature of the model is the use of SCS method which implicitly considers the relations between land use and soil characteristics suitable for assessing impacts of land use change (Homdee et al., 2011).

In this study, the land use 1984 was input to the study for simulating stream flow. The land uses were first reclassified into SWAT land uses and land use codes as required by the SWAT model. Table shows the re-classification of land use to SWAT land use classes and codes.

4.3.5.3. Weather data

The weather generator data input for stream flow simulation using the SWAT model included daily rainfall, maximum and minimum temperatures, relative humidity and wind speed.

Table 4.3 : Reclassification of land use types to SWAT land use classes

No.	User Land use	SWAT Land use	SWAT Land use code
1.	Irrigated Agriculture	Generic	AGRL
2.	Rain fed Agriculture	Row Crops	AGRR
3	Forest	Mixed Forest	FRST
4.	Rice	Rice	RICE
5.	Shrubs	Range Shrub Land	RNGB

6.	Herbaceous plants	Grass land	RNGE
7.	Bare land	Quarries/Mines	SWRN
8	Urban and Buildup area	Urban medium Density	URML
9	Water	Water	WATR

The data was first compared with observed data before it could be used . The weather data input was for the year 1980 to 1993 which corresponds to available stream flow data for model calibration.

The accuracy of operational hydrological models relies primarily upon good rain fall data input in terms of temporal resolution, spatial resolution, and accuracy. The main purposes of the present analysis were to validate the satellite derived rainfall , determine its operational viability, and assess its accuracy and expected error characteristics. Visual verification, correlation analysis test with local rain gauge measurements were conducted.

4.3.6. Model Evaluation Performance

SWAT is a comprehensive, semi-distributed river basin model that requires a large number of input parameters making model complicated. The input parameters are process based and must be held within a realistic uncertainty range (Arnold et al., 2012). SWAT model evaluation is conducted through calibration and validation processes. The first step in the calibration and validation process of SWAT is the determination of the most sensitive parameters for a given watershed or sub watershed. The user has to determine which variables to adjust based on expert judgment or on sensitivity analysis. Step by step process of model evaluation: sensitivity analysis, calibration and validation used in this study is explained in the following sub-topics.

4.3.6.1. Sensitivity Analysis

Sensitivity analysis is the process of determining the rate of change in model output with respect to changes in model inputs (parameters). It is necessary to identify key parameters and the parameter precision required for calibration (Ma et al., 2000).Sensitivity analysis is practically the first step that helps in determining the predominant processes for the component of interest. This helps to reduce the time it takes to do calibration. Two types of sensitivity analysis are generally performed: local, by changing values one at a time, and global, by allowing all parameter values to change. The two analyses, however, may yield different results. Sensitivity of one parameter often depends on the value of other related parameters; hence, the problem with one-at-a-time analysis is that the correct values of other parameters that are fixed can never be known. The disadvantage of the global sensitivity analysis is that it requires a large number of simulations. Both procedures, however, provide insight into the sensitivity of the parameters thus necessary steps in model calibration. Parameters affecting stream flow (Table 4.4) and the process they affect are explained in SWAT manual 2009 (http://swatmodel.tamu.edu). In this study, global sensitivity analysis was conducted with 800 simulations giving insight to the most sensitive parameters.

Table 4.4 : SWAT parameters affecting stream flow

Name	Description	Process
CN2	SCS runoff CN for moisture condition II	Runoff
SURLAG	Surface runoff lag coefficient	Runoff
SOL_AWC	Available water capacity of the soil layer (mm/mm soil)	Soil
SOL_K	Soil conductivity (mm/hrs)	Soil
SOL_Z	Soil depth	Soil
EPCO	Plant evaporation compensation factor	Evaporation
ESCO	Soil evaporation compensation factor	Evaporation
SOL_ALB	Soil albedo	Evaporation
ALPHA_BF	Base flow alpha factor (days)	Groundwater
GW_DELAY	Groundwater delay (days)	Groundwater
GW_REVAP	Groundwater ‗revap‘ coefficient.	Groundwater
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	Groundwater
RCHR_DP	Groundwater recharge to deep aquifer (fraction)	Groundwater
REVAPMN	Threshold depth of water in the shallow aquifer for ‗revap‘ to occur (mm).	Groundwater

SLOPE	Average slope steepness (m/m)	Geomorphology
SLSUBBSN	Average slope length (m).	Geomorphology
CH_N1	Manning coefficient for tributary channel	Channel
CH_K1	hydraulic conductivity in tributary channel (mm/hrs)	Channel
CH_ S1	Average slope of tributary channel (m/m)	Channel
CH_N2	Manning coefficient for main channel	Channel
CH_ S2	Average slope of main channel (m/m)	Channel
CH_K2	hydraulic conductivity in main channel (mm/hrs)	Channel

Source: SWAT manual, 2009 (http://swatmodel.tamu.edu)

4.3.6.2. Model Calibration and Validation

Calibration is the process of estimating the values of model parameters which cannot be accessed directly from field data. It enables parameterization of model to a set of local conditions thereby reducing prediction uncertainty. Hydrological models like SWAT contain many parameters which can be classified into two groups: physical and process parameters. A physical parameter represents physically measurable properties of the watershed and whereas process parameters represent properties of the watershed which are not directly measurable (Sorooshian and Gupta, 1995). Model calibration is performed by carefully selecting values for model input parameters (within their respective uncertainty ranges) and comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions (Arnold et al., 2012).

In general, graphical and statistical methods with some form of objective statistical criteria are used to determine when the model has been calibrated and validated. Calibration can be accomplished manually or using auto calibration tools in SWAT (Van Liew et al., 2005) or SWAT-CUP (Abbaspour et al., 2007)

Model validation is the process of demonstrating that a given site-specific model is capable of making sufficiently accurate simulations, although “sufficiently accurate” can vary based on project goals (Refsgaard, 1997). Validation involves running a model using parameters that were determined during the calibration process, and comparing the predictions to observed data not used in the calibration.

Ideally, calibration and validation should be process and spatially based, while taking into account input, model, and parameter uncertainties. If a longer time period is available for hydrology, it is important to use all the hydrology data available for calibration and validation to capture long-term trends (Arnold et al., 2012). This process-based calibration should be done at the sub watershed or landscape level to ensure that variability in the predominant processes for each of the sub watersheds is captured instead of determining global (watershed-wide) processes. There are, however, generally insufficient observed data to enable a full spatial calibration and validation at the watershed scale as in the case of this study.

Calibration and validation are typically performed by splitting the available observed data into two datasets: one for calibration, and another for validation. Data are most frequently split by time periods, carefully ensuring that the climate data used for both calibration and validation are not substantially different, i.e., wet, moderate, and dry years occur in both periods (Gan et al., 1997). The time series of discharge at the outlet of a watershed is the most important data to calibrate and validate a hydrological model (Tadele & Förch, 2007). The calibration observed data for the watershed; 4DD02 used in this study was average monthly stream flow data for the year 1983 to 1988 and validation 1989 to 1993 following an advice by WRMA that data from the year 1993 onwards was deteriorated. This was evident from the raw data provided by WRMA which showed discharge data from 1993 onwards had many years and months with missing stream flow data. Data limitation for calibration and validation has also in the past been experienced in a similar study assessing the impact of climate change on stream flow within lake Victoria basin in Kenya (Githui et al., 2009). Data available for model calibration covered only 5 years, however, leading the authors to use aggregated monthly data rather than daily data.

An extensive array of statistical techniques can be used to evaluate SWAT hydrologic and pollutant predictions; for example, Coffey et al. (2004) described nearly 20 potential statistical tests that can be used to judge SWAT predictions, including coefficient of determination (r2), NSE, root mean square error (RMSE), no-par ametric tests, t-test, objective functions, autocorrelation, and cross-correlation. He further recommended using NSE and r2 for analyzing monthly outputs based on comparisons of SWAT results with measured flow. By far, the most widely used statistics reported for calibration and validation are r2 and NSE described by equation 8 and Equation 9.

$$R^2 = \left\{ \frac{\sum_{i=1}^{n}(q_{obs} - \overline{q_{obs}})(q_{sim} - \overline{q_{sim}})}{[\sum_{i=1}^{n}(q_{obs} - \overline{q_{obs}})^2]^{0.5} \, [\sum_{i=1}^{n}(q_{sim} - \overline{q_{sim}})^2]^{0.5}} \right\}$$ …Equation 4.9

Where r^2 is coefficient of determination, qobs is observed discharge and qsim is simulated discharge. The r^2 statistic can range from 0 to 1, where 0 indicates no correlation and 1 represents perfect correlation, and it provides an estimate of how well the variance of observed values are replicated by the model predictions (Krause et al., 2005). A perfect fit also requires that the regression slope and intercept are equal to 1 and 0, respectively; however, the slope and intercept have typically not been reported in published SWAT studies. If r^2 is the primary statistical measure, it should always be used with slope and intercept to ensure that means are reasonable (slope = 1) and bias is low. NSE values can range between -∞ to 1 and provide a measure how well the simulated output matches the observed data along a 1:1 line (regression line with slope equal to 1). A perfect fit between the simulated and observed data is indicated by an NSE value of 1. NSE values ≤0 indicate that the observed data mean is a more accurate predictor than the simulated output. Both NSE and r2 are biased toward high flows. To minimize this bias, some researchers have taken the log of flows for statistical comparison or have developed statistics for low and high flow seasons (Krause et al., 2005).

$$E = \frac{\sum_{i=1}^{n}(Q_o - Q_{av})^2 - \sum_{i=1}^{n}(Q_o - Q_s)^2}{\sum_{i=1}^{n}(Q_o - Q_{av})^2}$$ ....Equation 4.10

Where E is the Nash and Sutcliffe Efficiency, Q0 is the observed discharge,Qav is the average observed discharge, Qs is the simulated discharge. The risk of adverse impacts arising from model prediction uncertainty or error for a particular application should be a consideration during the calibration. However, for a more typical application, Moriasi et al.(2007) proposed that NSE values should exceed 0.5 in order for model results to be judged satisfactory for hydrologic and pollutant loss evaluations performed on a monthly time step.

In this study monthly data was used for calibration because according to Grizzetti et al .(2005) various studies have shown that monthly data gives better results since using daily stream flows yielded the poorest results.

4.3.6.3. Automated Model Calibration

This study adopted automated model calibration as opposed to manual calibration which is considered outdated and unacceptable according to Abbaspour, (2015). Automatic calibration and uncertainty analysis capability is now directly incorporated in SWAT model (Gassman et al., 2010) via the Soil Water Assessment Tool-Calibration Uncertainty Procedures (SWAT-CUP).SWAT-CUP developed by Eawag (2009). A number of previous SWAT application projects have reported good results using automated calibration/validation and uncertainty analysis using SWAT-CUP. Abbaspour et al .(2007) performed a multi-objective calibration and validation of the Thur watershed in Switzerland using discharge, sediment, nitrate, and phosphate in the objective function with uncertainty analysis. (Schuol, J., K. C. Abbaspour, R. Srinivasan, 2008) calibrated with uncertainty analysis and validated models of west Africa and the entire continent of Africa.

4.3.6.4. Sequential Uncertainty Fitting (SUFI 2)

The SUFI-2 algorithm Abbaspour (2015) was selected for this study as the most adapted algorithm for the calibration of the flow. The SUFI-2 algorithm is included in SWAT-CUP software and combines parameter calibration and uncertainty prediction. Figure 4.7 : Link between SWAT and SUFI 2 input file illustrates the coupling between SUFI-2 and SWAT output parameters. In SUFI-2, the uncertainty of input parameters is represented by uniform distributions, while model output uncertainty is quantified by the 95% prediction uncertainty (95PPU) calculated at the 2.5% and 97.5% levels of the cumulative distribution of output variables obtained through Latin hypercube sampling. The SUFI-2 algorithm introduces two efficiency criteria, P factor and R factor, that provide a measure of the model's ability to capture uncertainties and a measure of the quality of calibration, respectively. In particular, the P factor is the percentage of the measured data bracketed by the 95PPU and ideally it should have a value of 1, indicating 100% bracketing of the measured data. The R factor indicates the thickness of the 95PPU band and it is calculated as the average distance between the upper and lower 95PPU divided by standard deviation of the observed data. The R factor should be ideally near zero, thus coinciding with the measured data. Evaluating these two factors, SUFI-2 quantifies the best parameter values through an interactive procedure, minimizing or maximizing a selected objective function.

The most important SUFI-2 procedure steps required during the calibration are:

1. Selection of an objective function (gi) from six different types in SUFI-2.
2. Definition of the parameters to calibrate and their minimum and maximum ranges. We assumed that all parameters are uniformly distributed within the calibrated sub-basins.
3. Drawing of n combinations of random values of selected parameters using Latin hypercube sampling. the model has to be run n times for each generated set of parameters.
4. Calculation of objective function (gi) for each of n simulations.
5. Execution of the post-processing of the n simulations in order to calculate the best goodness-of-fit parameter sets for each sub-basin between simulated and observed data.
6. Calculation of the P and R factors
7. Calculation of further rounds of sampling and model runs with updated ranges of parameters due to the large uncertainties of the initial parameters.

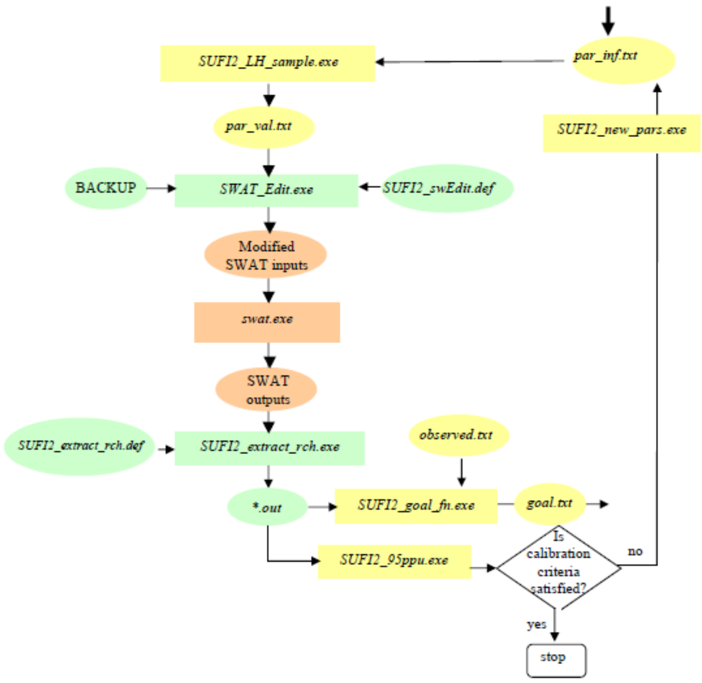


Figure 4.7 : Link between SWAT and SUFI 2 input file

The following rules in Figure 4.8 Abbaspour et al.(2015) shown were used in parameter optimization

4.3.6.5. Impacts of land use change on stream flow

SWAT is a deterministic model thus each successive model run that uses the same inputs will produce the same outputs. This type of model is preferred for isolating hydrologic response to a single variable, such as land cover and land use change (e.g., management decisions), allowing the impact of any change to be isolated and analyzed for its effect on hydrologic response (Baker & Miller, 2013). Ideally, a model should be non-stationary (such as SWAT) or be able to account for parameter variation through time.

Hydrological monthly stream flow simulations as result of two land use maps generated i.e.1984 and 2014 were independently conducted while keeping all other data inputs constant to understand the impact of land use change on stream flow. Of particular interest were the peak flows and low flows since land use has great impact on proportion of rainfall that converts to stream flow. Seasonal stream flow variability of 1984 and 2014 due to the land use and land cover change was assessed and comparison were made on surface runoff contributions to stream flow based on the two simulation outputs.

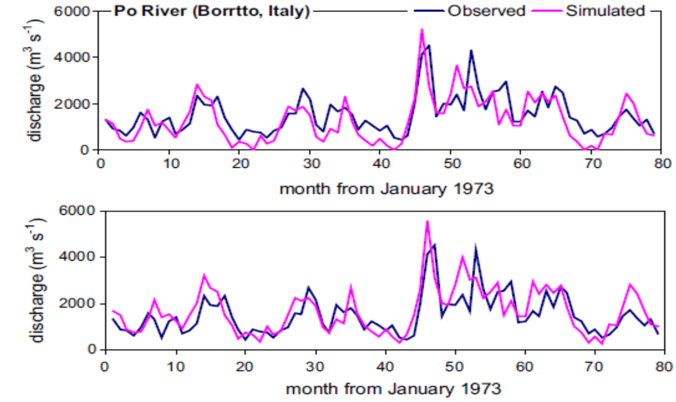
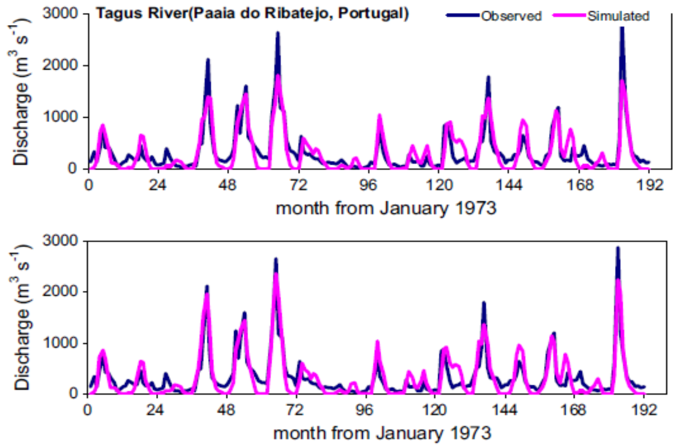
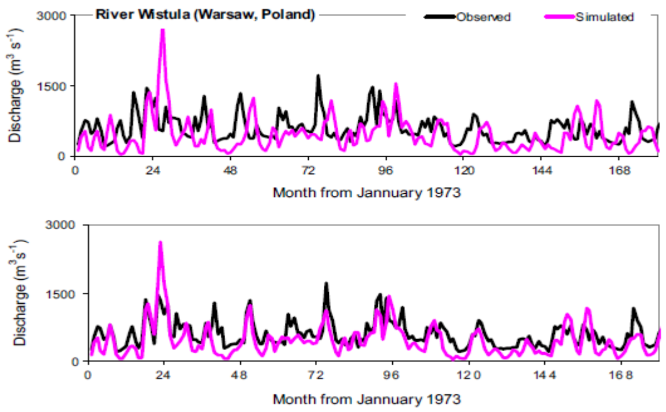
Simulated condition and significant Parameters	Before (top) and after (below) parameter regionalization
– Base flow too low **–Evapotranspiration too high** GWQMN.gw ↓ GW_REVAP.gw ↓ REVAMPM.gw ↑	
Peak flow too low CN2.mgt ↑ SOL_AWC.sol ↓ ESCO.hru ↓	
Discharge shift to the right HRU_SLP ↑ OV_N.hru ↓ SLSUBBSN.hru ↓	

Figure 4.8 : Table showing parameter optimization guideline

CHAPTER FIVE

RESULTS OF THE STUDY

5.1. Land Use Change in the Thiba River Basin

Land use in Thiba river basin is characterized by significant spatial changes between the year 1984 and 2014. The major land use types include agriculture and forestry accounting for 80% of the land use in the basin. The analysis of land use maps led to nine types of classifications as illustrated in ,the for the years 1984, 2004 and 2014. The analysis of percentage of the land changes between 1984 and 2004 and also between 2004 and 2014 is presented in Table 5.1

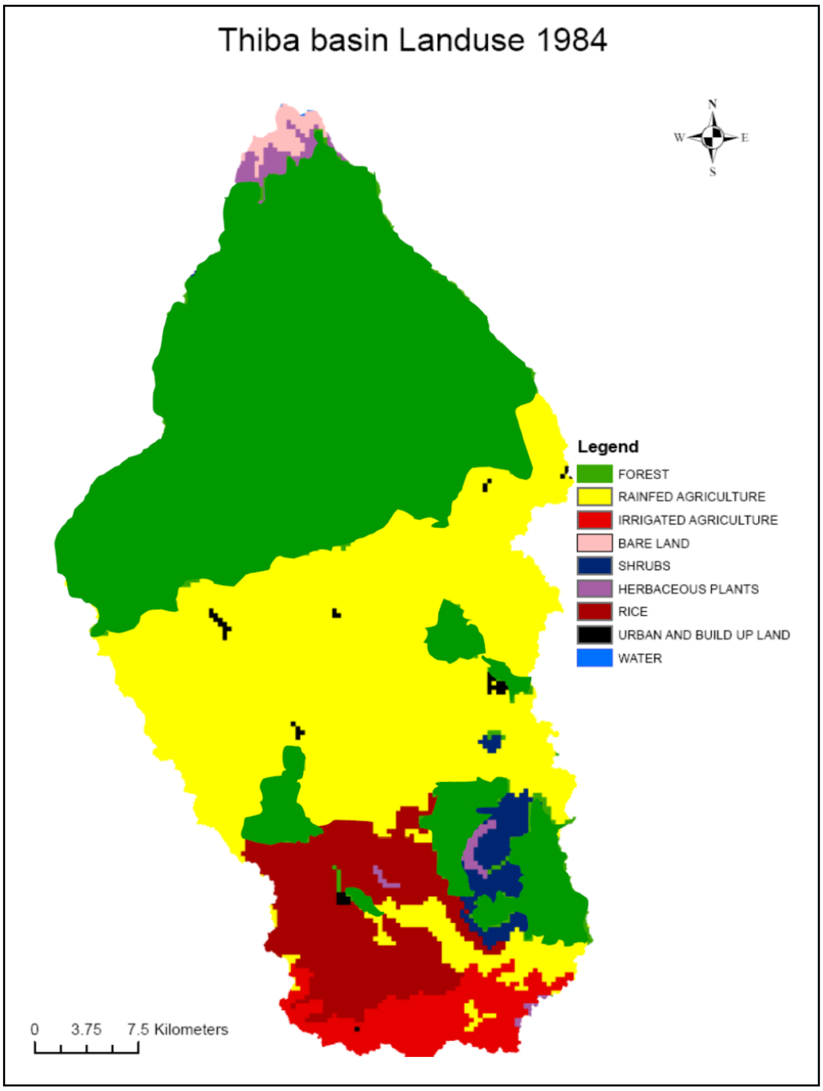


Figure 5.1 : Spatial distribution of land use in Thiba basin for the year 1984.

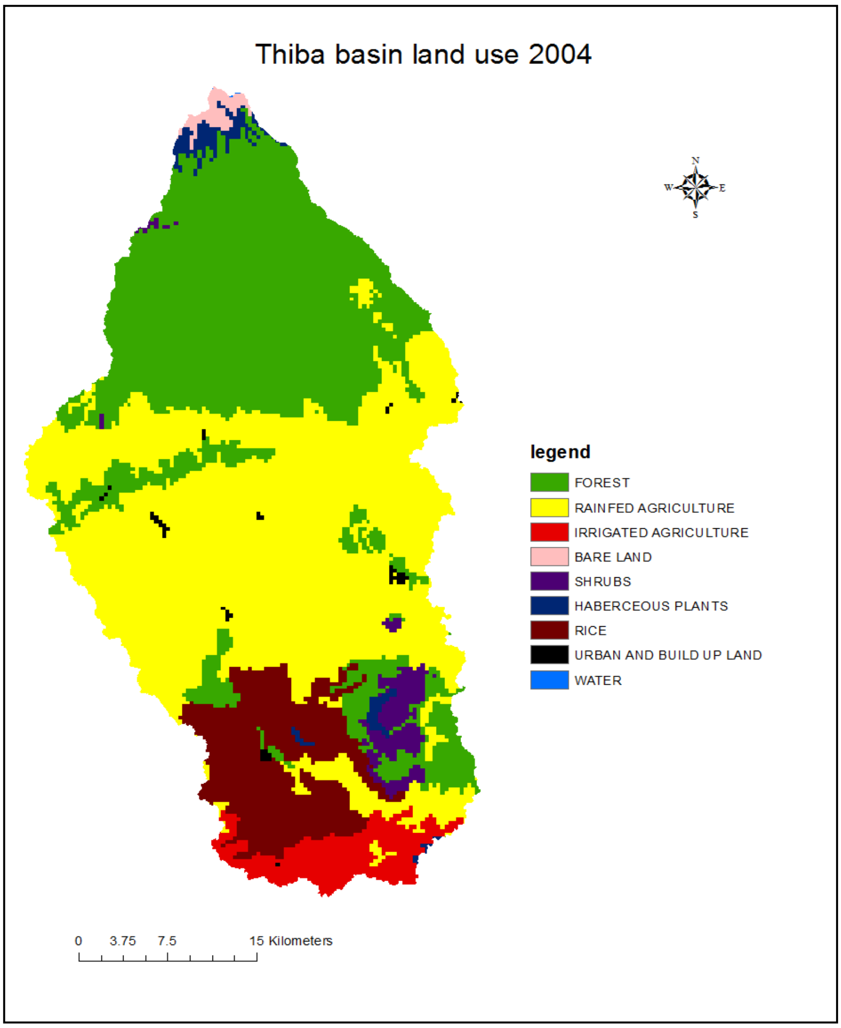


Figure 5.2 : Spatial distribution of land use in Thiba basin for the year 2004

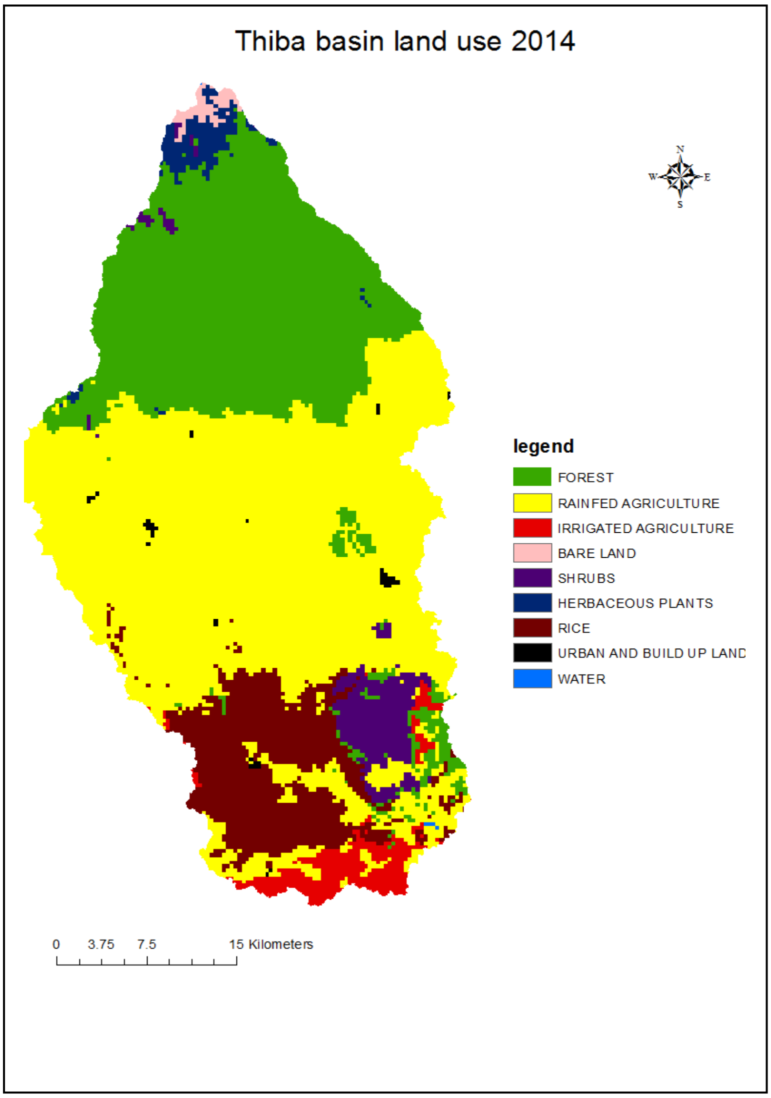


Figure 5.3 : Spatial distribution of land use in Thiba basin for the year 2014

Table 5.1 : Analysis of land use changes in Thiba Basin for the year 1984, 2004 and 2014.

Type of Land Use	Area (Ha)	% Area	Area (Ha)	% Area	Area (Ha)	% Area	1984-2004 % Change	2004-2014 % Change
	1984.0		2004.0		2014.0			
FOREST	79430.5	48.2	59347.5	36.0	49137.0	29.8	-12.2	-6.2
RAINFED AGRICULTURE	60972.1	37.0	74977.7	45.5	83199.2	50.5	8.5	5.0
IRRIGATED AGRICULTURE	4132.2	2.5	6993.2	4.2	6120.0	3.7	1.7	-0.5
BARE LAND	2933.0	1.8	1064.1	0.6	923.3	0.6	-1.1	-0.1
SHRUBS	6490.0	3.9	3534.6	2.1	3520.9	2.1	-1.8	0.0
HERBACEOUS PLANTS	6946.5	4.2	2083.2	1.3	2376.7	1.4	-3.0	0.2
RICE	3383.4	2.1	16224.5	9.8	18852.6	11.4	7.8	1.6
URBAN AREA	501.2	0.3	567.2	0.3	664.2	0.4	0.0	0.1
WATER	11.0	0.0	8.0	0.0	6.1	0.0	0.0	0.0
TOTAL	164800.0		164799.9		164799.9			

5.2. Agricultural Water Abstraction Trend

Abstraction of water from Thiba River is considered to be one of the main drivers of changes in the flow of the river. The largest proportion of water abstraction is due to increased requirements for irrigation, occasioned by increased area of land under irrigation. The data provided from NIB and analysis of water abstraction survey showed an increasing trend of water abstraction in Thiba basin. Figure 5.4 shows an increasing trend of water abstraction for the period between 2007 and 2014. The highest abstraction of 14 million m^3/s happened in 2013 while the lowest of 9 million m^3/s occurred in the year 2009.

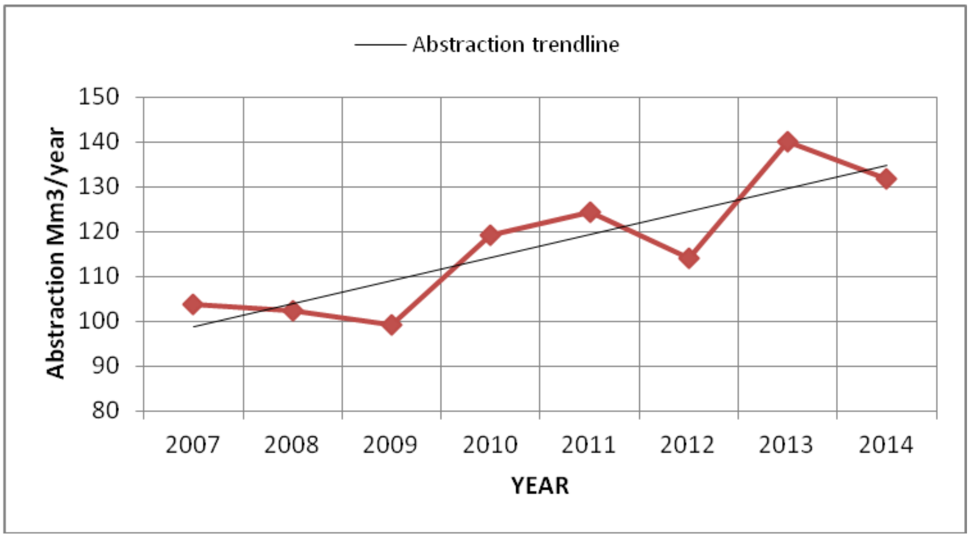


Figure 5.4 : Annual water abstraction (m^3/year) trend in Thiba basin for the year 2007 to 2014

The examination of water abstraction pattern for the nine years demonstrates a pattern whereby irrigation water demand is highest during the season months of January to February and June to October as shown in Figure 5.6. A graph of current stream flows verses naturalized flows (Figure 5.5) shows the highest impact of stream reduction occurs when the flows are at the lowest. Water abstraction analysis revealed that about 35% of the dry season flow and 3% of the wet season flow is abstracted from the Thiba River.

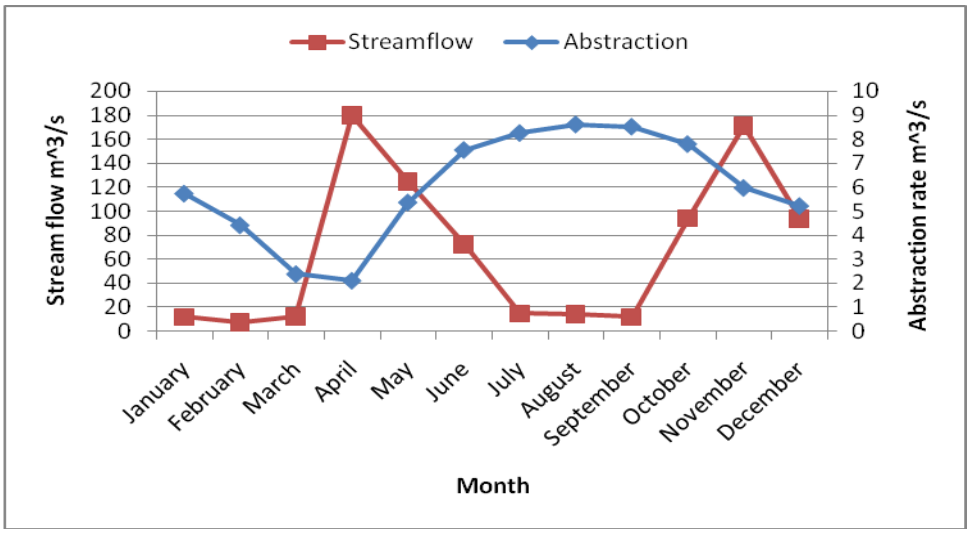


Figure 5.5 : Comparison of average monthly stream flow and water abstraction data for the period between 2007 and 2014.

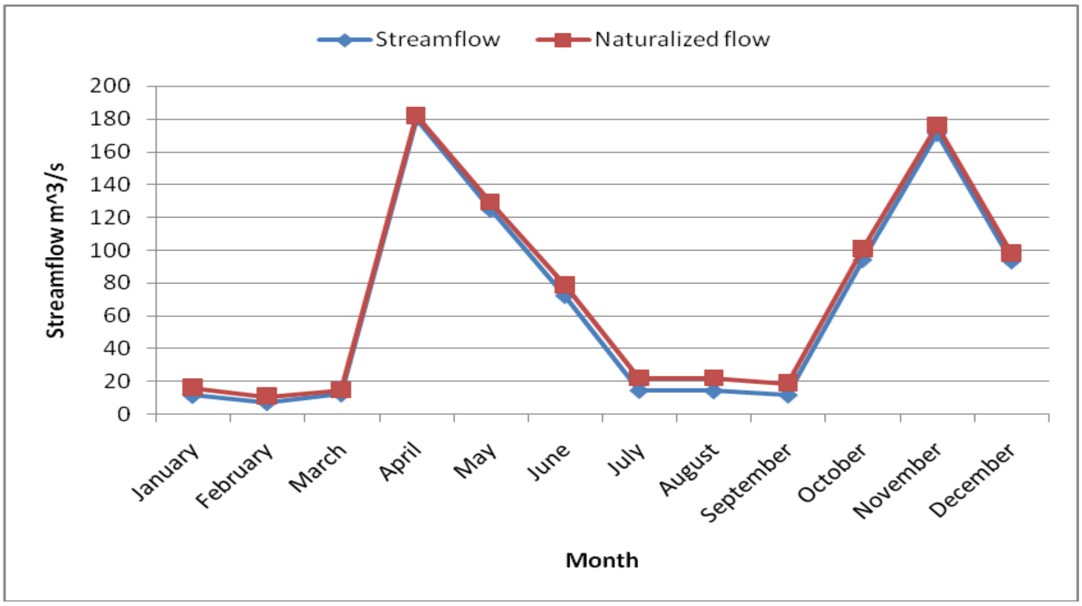


Figure 5.6 : Comparison of average monthly stream flow and naturalized stream flow data for the period between 2007 and 2014.

The hypothesis of water abstraction trend tested using spearman's rank correlation test showed an observed r value of 0.809. From the table attached as appendix G and as such value comes in the rejection region (± 0.7143) and therefore the null hypothesis was rejected at 5 % confidence level and hence alternative hypothesis accepted. We thus conclude that there is significant relationship between water abstraction and stream flow in Thiba catchment.

The irrigation interface presents a positive effect on irrigation water supply, in terms of reduced dry season river abstractions.

5.3. Simulation Modeling With SWAT

SWAT is a deterministic model thus each successive model run that uses the same inputs will produce the same outputs (Baker & Miller, 2013). This model was thus able to isolate the hydrologic response of land use of 1984 and 2014 by isolating it from other land use management decisions.

SWAT-modeling of the Thiba river watershed was carried out by delineating the catchment with the outlet defined by river gauging station 4DD02. Though it would have better to calibrate simulations at basin level, good quality observed data for the basins was lacking. Thus calibration and validation was only done for one station defining the catchment area of 1,647 km^2 delineated at the watershed outlet point

5.4. Rainfall Data Validation

Figure 5.7 shows the comparison between observed rainfall data for castle forest and generated rainfall by SWAT weather database generator. It can be seen that there is in general an agreement between the two types of rainfall data, what is even much more prominent in months of low rainfall. However, it can be seen that in some months there have been over and under-estimation on rainfall and this can be associated to many reasons, among which could be: the recording errors by the gauge readers, evaporation and wind influences Figure 5.8, Figure 5.9 and Figure 5.10,

shows the relationship between the observed and forecasted rainfall. It can be seen that forecasted rainfall can be used as data for modeling or another kind of exercises with a good degree of confidence, as shown below by the significantly high regression coefficients obtained for Castle forest (0.6), Embu (0.63) and Kerugoya (0.5).

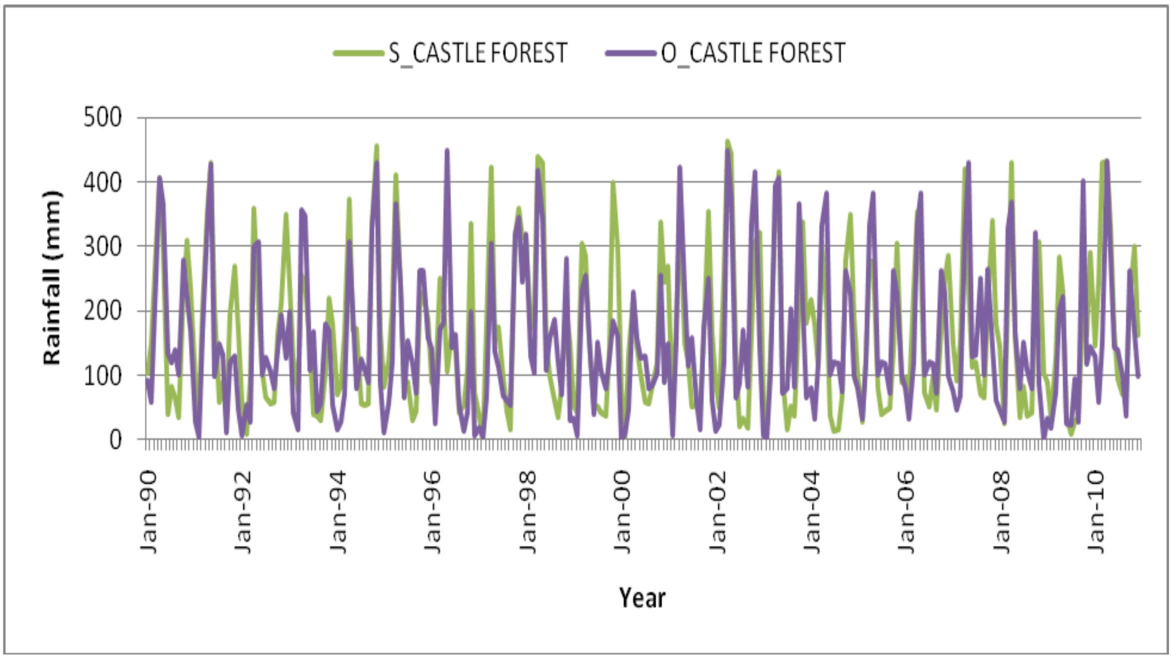


Figure 5.7 : Comparison between observed and satellite-derived monthly rainfall from (forecasted) for Castle forest station located in the basin.

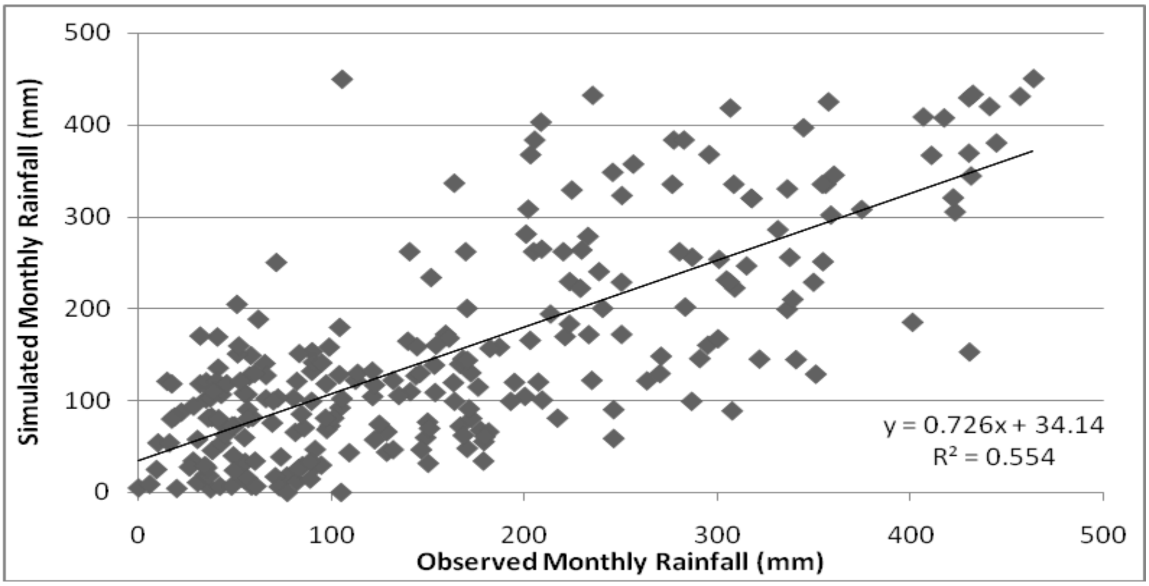


Figure 5.8 : Regression between observed and simulated monthly rainfall for New-Castle Forest Station.

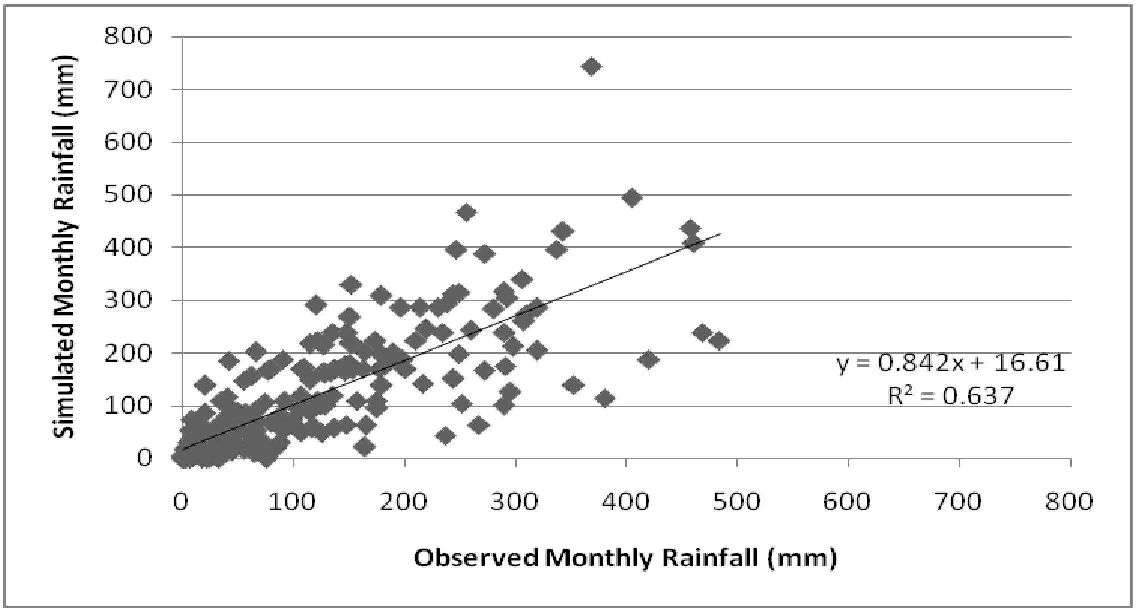


Figure 5.9 : Regression between observed and simulated monthly rainfall for Embu Station.

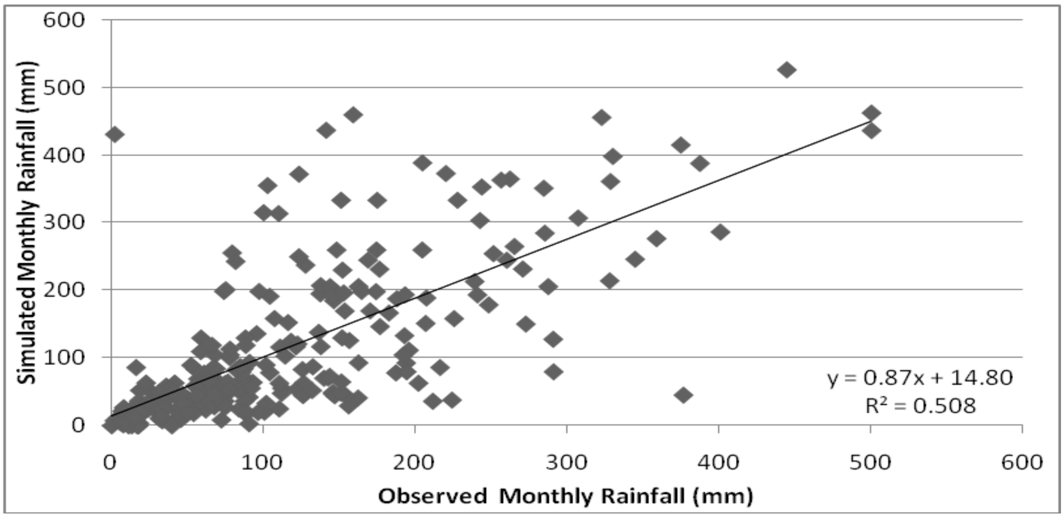


Figure 5.10 : Regression between observed and simulated monthly rainfall for Kerugoya Station.

5.5. Rainfall-Runoff Relationships in The Thiba Catchment Area.

The relationship between monthly stream discharge out from Thiba catchment and average monthly rainfall was investigated to greater depth using regression analyses as shown in Figure 5.11. The results shows weak but significant relationship between monthly rainfall and monthly average stream flow (r^2 =0.3; p=0.008).

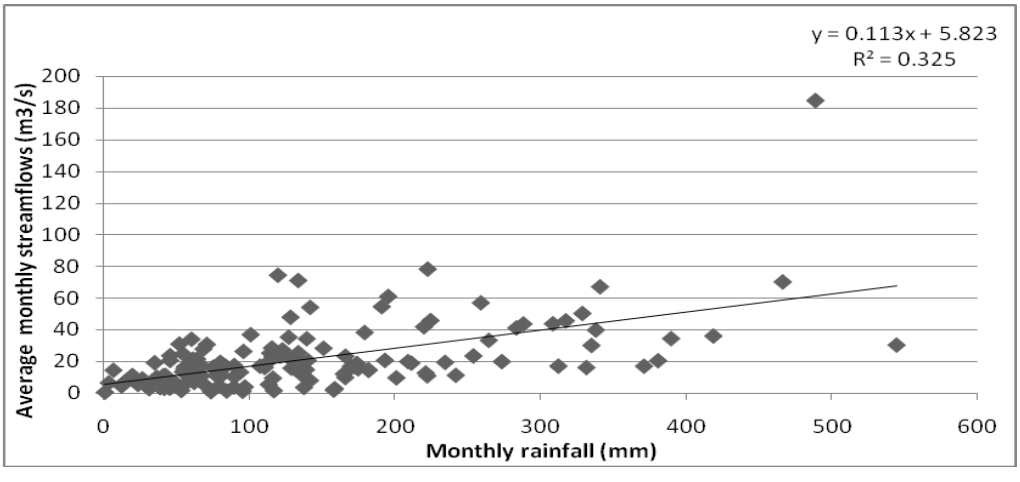


Figure 5.11 : Regression between rainfall and stream flow out of Thiba Catchment Basin

5.6. Model Evaluation

The model suitability for simulating stream flows for Thiba basin was conducted through three automated model procedures namely: sensitivity analysis, calibration and validation.

5.6.1. Sensitivity Analysis

The study evaluated the relative sensitivity values found in the parameter estimation process. Calibration and validation are usually difficult with a large number of parameters. Thus, one important aim of parameter sensitivity analysis is to reduce the number of input parameters, thereby reducing the computation time for the calibration according to Seyoum & Koch (2013). Soil Water Assessment Tool-Calibration and Uncertainty Programme (SWAT-CUP) was used to test sensitivity of 22 parameters with SUFI 2 algorithm being used for optimization of the parameters. Nine parameters were found to be sensitive with the relative sensitivity values shown in Table 5.2. These sensitive parameters were considered for model calibration in SWAT-CUP model. T-stat provides a measure of sensitivity with larger absolute values indicating a sensitive parameter value determines the significance of the sensitivity value closer to zero denotes more significance. Table 5.2 indicates that the most sensitive parameters explaining the stream flow at the outlet of Thiba watershed are surface runoff lag time [SURLAG_bsn], curve number [CN2.mgt], soil available water capacity [SOL_AWC(1).sol] and soil evaporation compensation factor [ESCO.hru]. The SWAT user manual (Shekhar, 2008) explains the effect of each parameter on watersheds.

Table 5.2 : Relative sensitivities for the optimized parameters for the Thiba watershed

No.	Parameter	T-stat	P-value
1	v_SURLAG.bsn	3.13	0.00
2	v_CN2.mgt	1.49	0.15
3	v_SOL_AWC (1).sol	1.34	0.20
4	v_ESCO.hru	1.28	0.21
5	v_GW_DELAY.gw	1.23	0.23
6	v_GWQMN.gw	-0.91	0.37
7	V_REVAPMN.gw	-0.50	0.62
8	v_GW_REVAP.gw	-0.28	0.78
9	v_ALPHA_BF.gw	-0.11	0.91

5.6.2. Model Calibration and Validation

The sensitive parameters in Table 5.2 were used for SWAT model calibration using SWAT-CUP again. The final fitted values are indicated in Table 5.3. The flow calibration and validation were performed for eleven years from 1983 to 1988 and 1989 to 1993 respectively. However, the flow had been simulated for fourteen years, including three year of the warm-up period to allow hydrologic processes to achieve initial equilibrium.

The simulated daily flow matches the observed values for the calibration and validation periods with the regression coefficient of determination R^2 = 0.9, 0.87 and NSE = 0.82, 0.79 respectively. Values of $R^2 > 0.6$ and $NS > 0.5$ for the calibration of the daily or monthly simulated stream flow are usually considered as adequate for an acceptable calibration (Santhi et al. 2011). The graphical presentation of results of the simulation during calibration period are shown in Figure 5.12 and Figure 5.13 in which there is a good agreement between simulated and observed flows. Validation results are also illustrated by Figure 5.14 and 5.15. There was however challenges in mimicking low flows.

Table 5.3 : Final fitted SWAT parameter values

	Parameter	Lower bound	Upper bound	Final fitted value	Parameter
1.	SURLAG.Bsn	0	24	5.3	Surface runoff lag coefficient
2.	CN2.Mgt	0.9	1	0.6	Initial SCS CN II
3.	SOL_AWC .Sol	0	1	0.8	Available Water Capacity
4.	ESCO.Hru	0.01	1	0.76	Soil evaporation compensation factor
5.	GW_DELAY.Gw	0	60	20.95	Ground water delay
6.	GWQMN.Gw	0	1000	2.54	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)
7.	REVAPMN.Gw	0	1000	0.154	Threshold depth of water in shallow aquifer for

					revaporization (mm)
8.	GW_REVAP.Gw	0.02	0.2	0.19	Ground water revamp coefficient
9.	ALPHA_BF.Gw	0	1	0.8	Base flow alpha factor

The results show that SWAT is able to simulate the hydrological characteristics of the Thiba River basin very well. Hence, the model was used to conduct hydrological response as result of land use change using the land use maps for the years 1984 and 2014 in the Thiba basin. Each of the two simulations used the same climate and soil data so that the effects of land cover change on hydrologic response were isolated as recommended by (Miller et al. (2002).

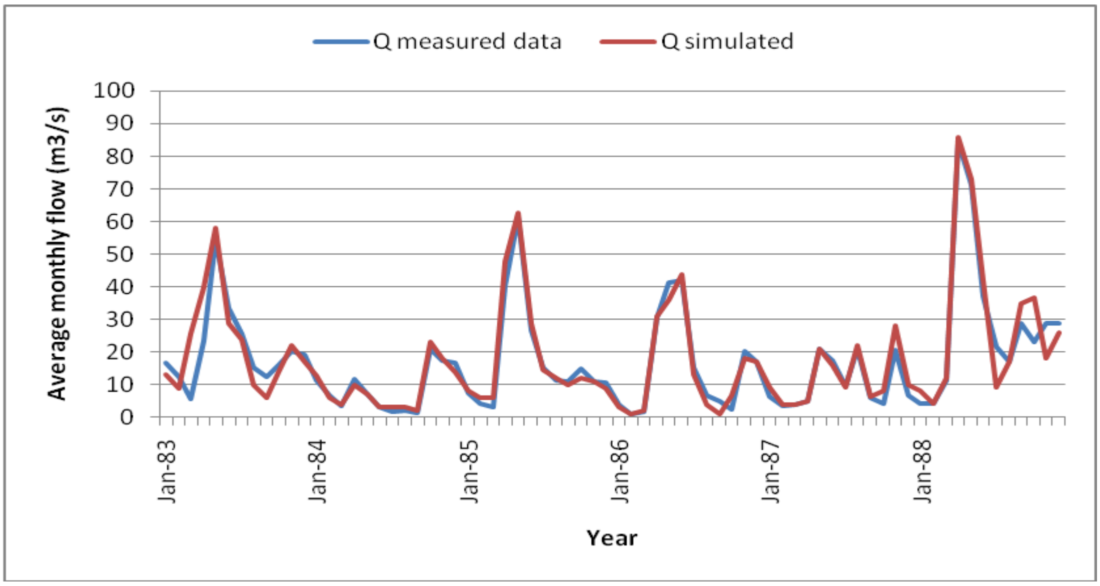


Figure 5.12 : Observed and calibrated stream flow for Thiba River at catchment outlet 4DD02 between 1983 and 1988.

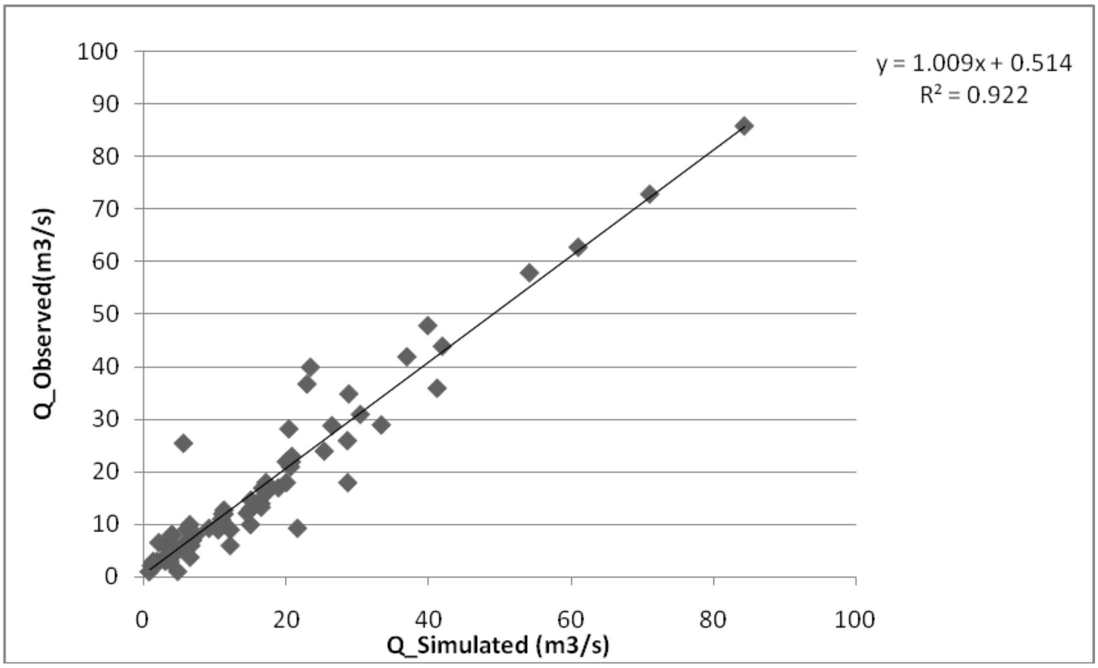


Figure 5.13 : Comparison of observed and simulated stream flows of Thiba River Catchment outlet 4DD02 for calibration period between 1983 and 1988.

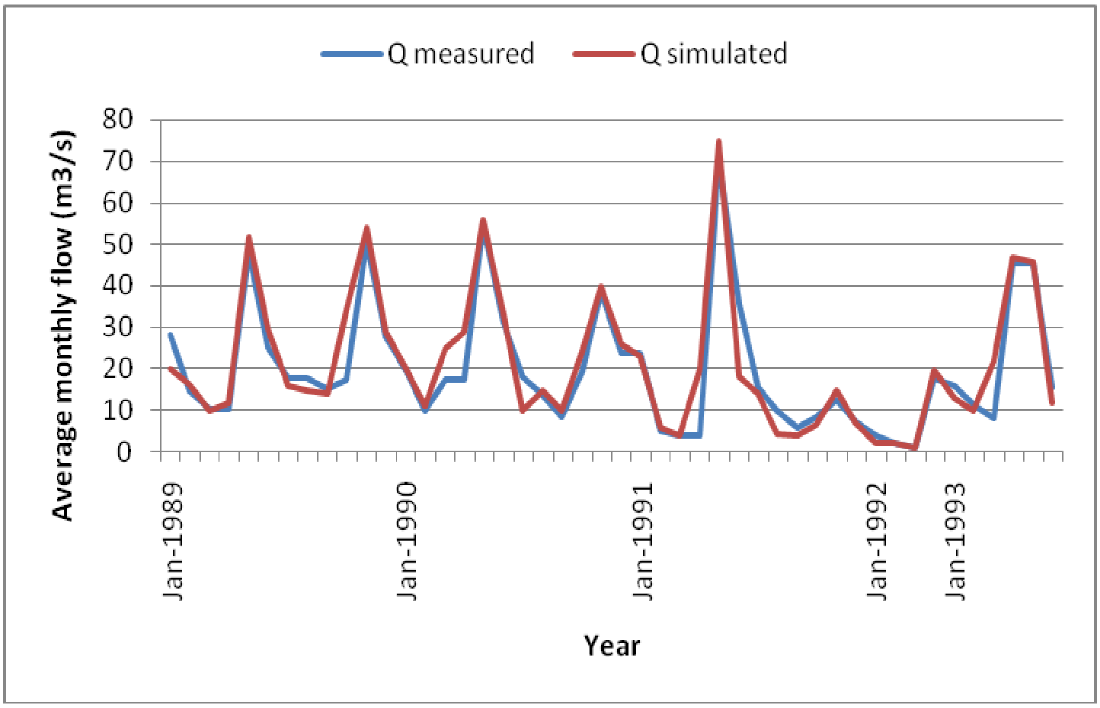


Figure 5.14 : Observed and validated stream flow for Thiba River at catchment outlet 4DD02 between 1989 and 1993.

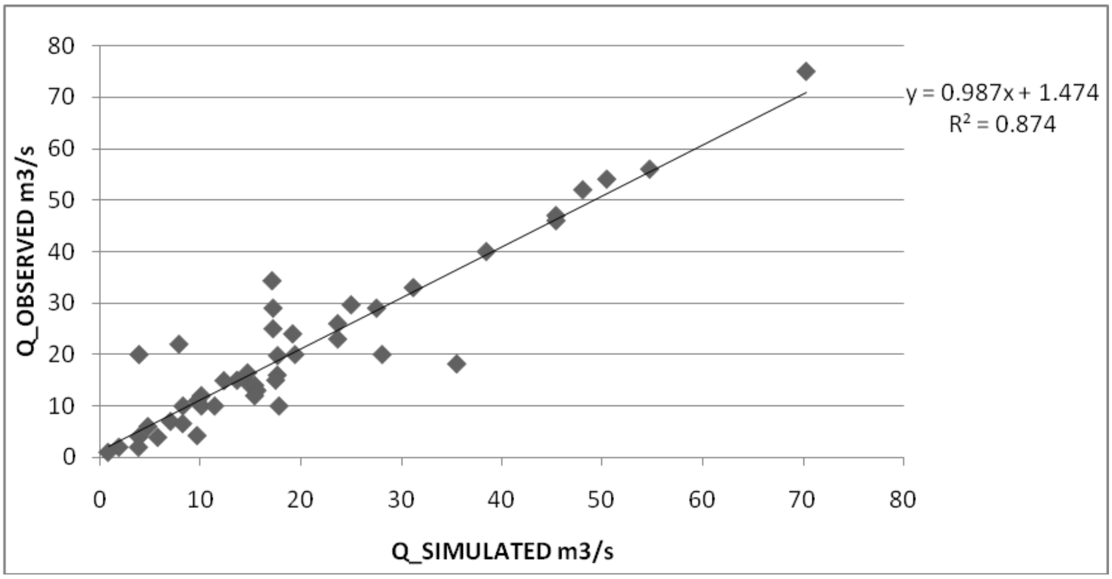


Figure 5.15 : Comparison of observed and simulated stream flows of Thiba River catchment outlet 4DD02 for the validation period between 1988 and 1993.

The measured and simulated average monthly flow for Thiba watershed during the calibration period, were 17.22 m^3/s and 17.89 m^3/s, respectively. The measured and simulated average monthly flow during validation period was 19.92 m^3/s and 21.15 m3/s, respectively. These indicate that there is a reasonable agreement between the measured and the simulated values in both calibration and validation periods as shown on table 5.4 below.

Table 5.4 : Comparison of Measured and simulated monthly flow for calibration and validation simulations

Period	Average monthly flow (m^3/s)		ENS	R^2
	Measured	Simulated		
Calibration Period (1983-1988)	17.22	17.89	0.82	0.9
Validation Period (1989-1993)	19.92	21.15	0.79	0.87

The results in Table 5.4 indicates that the physical processes involved in the generation of stream flows in the watershed were adequately captured by the model. Hence, the model simulations can be used for various water resource management and development aspects. Assessing the impacts of land use change on stream flow

One of the objectives of the study was to evaluate the impact of land use and land cover changes on Thiba watershed. After calibrating and validating of the model using the land use and land cover map for 1984, SWAT was run using the two land cover maps (1984 and 2014 maps) for the period of 1983 to 1993 while putting the other input variables the same for both simulations to quantify the variability of stream flow due to the changes of land use. This process gave the discharge outputs for both land use and land cover patterns. Then, these outputs were compared and the discharge change during the wettest months of stream flow taken as April, and November and driest stream flow are considered in the months of January, February and March were calculated and used as indicators to estimate the effect of land use and land cover change on the stream flow. Table 5.5 presents the mean monthly wet and dry month's stream flow for1984 and 2014 land use and land cover maps and its variability.

Table 5.5 : Mean monthly wet and dry month's stream flow and their variability (1983-1993).

Mean monthly flow m^3/s				Mean monthly flow change	
Land use/Landover map 1984		Land use/Landover map 2014			
Wet months (April,Nov)	Dry months (Jan, Feb,Mar)	Wet months (April,Nov)	Dry months (Jan, Feb,Mar)	Wet	Dry
40.00	10.22	46.01	8.33	+6.01	-1.92

As indicated in the Table 5.5 the mean monthly stream flow for wet months had increased by 6.01 m^3/s while the dry season decreased by 1.92 m^3/s during the 1984-2014 periods due to the land use and land cover change. When the simulated stream flow data for the wet months was subjected to students t test, the observed value of t (-3.81) came under rejection region (1.72) at 5% significance level. We thus reject the null hypothesis and conclude that land use change has significant impact on stream flow during the wet season between the period of 1984 and 2014. Similarly, the simulated stream flows during the dry season were tested at 5% level of significance. The observed value of t (5.30) fell under the acceptance region (1.69).We thus accept the null hypothesis and conclude that Land use change between 1984 and 2014 has no significant impact on stream flow variability during the dry season.

The increase in stream flows can be attributed to the expansion of agricultural land over forest that results in the increase of surface runoff following rainfall events. We can explain this in terms of the crop soil moisture demands. Crops need less soil moisture than forests; therefore the rainfall satisfies the soil moisture deficit in agricultural lands more quickly than in forests there by generating more surface runoff where the area under agricultural land is extensive. And this causes variation in soil moisture and groundwater storage. This expansion also results in the reduction of water infiltrating in to the ground. Therefore, discharge during dry months (which mostly comes from base flow) decreases, whereas the discharge during the wet months increases. These results demonstrate that the land use and land cover change have a significant effects on infiltration rates, on the runoff production, and on the water retention capacity of the soil.

A similar study conducted in Hare River watershed, Southern Rift Valley Lakes Basin, Ethiopia by Tadele & Förch (2007) showed a 12.5% increase in mean monthly discharge for wet months while in the dry season decreased by up to 30.5% during the 1992-2004 period due to the land use/cover change. Githui et al. (2009) observed that higher runoff flows are expected in cropland than in forests due to the fact that rainfall satisfies the soil moisture deficit in agricultural land more quickly than in forests thereby generating more runoff in agricultural land. Lower infiltration rates are associated with agricultural land due to compaction and increase in soil bulk density .A similar study in Njoro catchment (Baker & Miller, 2013) found that forest conversion to agriculture led to a higher proportion of rainfall is being converted into surface runoff, rather than infiltrating into the soil and recharging the regional aquifer.

CHAPTER SIX

DISCUSSION OF RESULTS

6.1. Land Use Change in the Thiba River Basin

As can be seen in 2014 land use, a major part of the catchment is used for rain fed agriculture (principally maize, coffee and tea). Around 15% of the basin is used for irrigated agriculture with major crop being rice. Forest areas cover almost a third of the watershed area. The area can thus be categorized as agricultural land.

The analysis showed that between 1984 and 2004, there has been 12.19% decrease in forest cover while in the period between 2004 and 2014, there has been a 6.2% decrease in forest cover. This reduction can be attributed to clearing of forests for agriculture, and increased demand of timber and fuel due to increase in population. The forest land has mainly been cleared to create room for rain fed agriculture as it can be seen from the land use maps for 1984, 2004 and 2014. Rain fed agriculture increased by 8.5 % between 1984 and 2004 while between 2004 and 2014, there was 4.99 % increase. The analysis also showed that the area under rice production has increased by 7.79 % between 1984 and 2004 and 1.59 % between 2004 and 2014. The decrease in irrigated agriculture mainly maize at the lower elevations of study area can be attributed to people turning to rice production due to high profitability.

It can also be observed that the dominant land use in the basin is rainfed agriculture accounting for more than 50% of the land use due to availability of relief rainfall from Mount Kenya throughout the year. The major crops grown are coffee, maize, banana and napier grass.

In many instances, farmers are engaged in unsustainable agricultural practices such as continuous tillage, which leads to an increase in runoff volume (Kitheka & Ongwenyi, 2002).

A study by Ngigi et al. (2007) found that population growth had induced agricultural intensification at an unprecedented rate in parts of Ewaso Ngi'ro river basin. The study further noted that land use changes were accompanied by reduction in river flows, environmental degradation and declining agricultural production.

The upper Molo River catchment has experienced rapid land use land cover changes according to study by Kirui (2008). Forested land was reduced by about 48% due to encroachment by farmers between 1986 and 2001.The increased demand of agricultural land was attributed to increased population.

6.2. Irrigation Water Abstraction and its Impacts on Stream Flow

Thiba basin has experienced increasing trend of agricultural water abstractions between 2007 and 2014.This can be attributed to increase in land area under rice production which is the major economic activity in the basin. The highest demand of water occurs in August when at the same time stream flows are lowest. It was noted during data collection that full water diversion occurs in Nyamidi river, a tributary to Thiba river during the dry season months.

According to Ngigi, 2005, a study in Ewaso Nyiro River, an agricultural basin with similar water abstraction pattern found that the dry months consist mainly of base flow, which is derived from groundwater sources in the lower moorland and upper forest zones. Irrigation water abstractions have been identified as one of the main contributing factors to reduce river flows, especially during the dry periods when many farmers along the streams abstract water illegally and uncontrollably without due regard to downstream water users.

In Ewaso Nyiro river, there is usually excess water during the rainy season followed by severe drought during the subsequent dry season. The situation was further aggravated by land use changes. The water abstraction resulted to decline in water flow by 30 % between 1960 and 2005 (Aeschbacher et al., 2005). A water assessment in the river by (Ngigi et al., 2007) found that about 62 % of dry season flow and 43% of wet season flow is abstracted from Naro Moru river just before the confluence with Ewaso Nyiro. These findings are similar to my findings where 35% of dry season flows and 3% of wet season flows are abstracted from Thiba river basin.

Irrigated agriculture has been discussed by Fereres (2006) as the primary user of diverted water globally reaching a proportion of 70-80% of total abstractions in arid and semi-arid areas.

The demand of irrigation water on slopes of Mount Kenya has been reported by IFAD/UNEP/GEF (2004) for supporting horticultural farming. The usage in the upstream areas however affects water availability in the downstream areas leading to water conflicts.

6.3. Modeling Impacts of Land Use Change on Stream Flows

A study by Mango et al. (2011) in Mara basin compared the performance of SWAT model on using satellite based rainfall data and gauge rainfall data in stream flow simulations. The performance was considered poor following low NSE and R2 values of -0.53 and 0.085 on using gauge rainfall data while on the other hand using satellite rainfall data produced good NSE and R2 values of 0.43 and 0.56 for calibration values respectively. These findings agrees with this study .Good results for calibration period were obtained with satellite rainfall data with NSE and R2 values reading 0.82 and 0.9 respectively. Mango et al. (2011) further stated that researchers are taking advantage of the available and virtually un-interrupted supply of satellite based rainfall in undertaking studies across Africa as alternative and supplement to gauged data characterized by missing or incorrect observed values.

SWAT model potential for modeling land use change impacts on stream flow has been reported in the past. Li (2009) reported the model was able to show estimated impacts of land use changes on annual and monthly stream flow in Agricultural catchment of Loess of China. A study by Homdee et al.(2011) in Chi river basin in Thailand found that conversion of forest area into farmland resulted in an increase of 2.1 % in annual flows and an increase in wet season flows by 2.4 % but flows decreased by 1.7 % in the dry season. Further reduction of the forested area by 50% of previous forested area (10 % of entire basin area) still resulted in small changes in the water yield. Past studies have also reported that climate change variability has more significant impact on surface water hydrology than land use changes (Homdee et al., 2011). Mango et al. (2011) studied the impact of land use change on SWAT outputs, mainly on the Nyangores River discharge. He developed three land use scenarios mainly 1) partial deforestation, conversion to agriculture, 2) complete deforestation, conversion to grassland, and 3) complete deforestation, conversion to agriculture 3). The data analysis results indicated that conversion of forests to agriculture and grassland in the catchment headwaters reduced dry season flows and increased peak flows, leading to greater water scarcity at critical times of the year and exacerbating erosion on hill slopes. A study on hydrologic response to land use change in Upper Molo River basin found that surface runoff increased by 13.3% due to change of forest land to agriculture. These studies are in agreement with this research findings where runoff of Thiba River increased by 6.01 m3/s due to reduction of forest cover by 18.39 % for the period between 1984 and 2014.

The strength of SWAT as noted by Gassman et al. (2007) are flexibility in combining upstream and channel processes and simulation of land management. He further noted that each process is simplification of the reality hence it can be improved. Gassman et al.(2007) also discussed weaknesses of SWAT simulation which includes: simplification of HRUs simulation of certain management practices, pathogen fate and transport, in-stream sediment routing and kinetic functions, static soil carbon, subsurface tile flow and nitrate losses, and routines for automated sensitivity, calibration, and input uncertainty analysis. The major setbacks in addressing these weaknesses include: some processes are difficult to characterize accurately due to insufficient monitoring data, in adequate data to parameterize inputs and insufficient understanding of the processes themselves.

SWAT is a comprehensive semi-distributed watershed model which uses readily available input data. The major challenge of comprehensive watershed model is that it uses large number of parameters which complicates model parameterization and calibration. The development of auto calibration and uncertainty SWAT-CUP Eawag (2009) overcame this challenge by reducing multiple objective functions into a single global criterion in objective way hence solving the weighting problem.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1. Key Findings

Thiba catchment has been experiencing land cover and land use changes. The analysis of land use change using GIS showed that between 1984 and 2004, there has been 12.19 % decrease in forest cover while 2004 and 2014, there has been a 6.2 % decrease in forest cover. Rain fed agriculture increased by 8.5 % between 1984 and 2004 while between 2004 and 2014 there was 4.99 % increase.

The analysis further showed that the area under rice production has increased by 7.79 % between 1984 and 2004 and 1.59 % between 2004 and 2014. The decrease in irrigated agriculture mainly maize at the lower elevations of study area was attributed to farmers turning to rice production due to high profitability. It can be presumed that deforestation and increase in farmland that was manifested by the rapid increase in food demand has altered the whole Thiba watershed in general and some sub-watershed in particular. Modifications of land uses especially forest to small scale rain fed and irrigated agriculture are expected in the near future, since farmers in the upper watershed have already started using surface water to cultivate market oriented cash crops such as rice and horticultural vegetables that are in high demand.

Water abstraction in the basin has been increasing between the year 2007 and 2014. Analysis of data showed that the highest irrigation water demand occurs in dry season in the months of January, February and June to October. This is also the same period when stream flow is at its lowest. About 35 % of the dry season flow and 3% of the wet season flow is abstracted from the basin. Spearman Ranks correlation test showed a R value of 0.809 resulting to rejection of null hypothesis thus accepting alternative hypothesis that there exists positive trend of water abstraction in Thiba Catchment area.

Arc SWAT 2012 was useful in analyzing the impacts of land use/cover changes on stream flow within acceptable hydrological performance. Accordingly, this study reveals the successful application of the SWAT model in areas with limited readily available data and hence can be utilized in similar watershed elsewhere. This study provides an understanding of historical land use/cover changes and consequent impacts on stream flow and this can enhance our capability to predict future impacts of land use modifications.

SWAT model was evaluated by coefficient of determination R^2 and NSE evaluation tools. The simulated flow matched the observed flow whereby during calibration period (1983-1988) the obtained R^2 and NSE was 0.9 and 0.82 respectively while during model validation period (1989-1993) R^2 and NSE were 0.87 and 0.79 respectively. The measured and simulated average monthly flow for Thiba watershed during the calibration period were 17.22 m3/s and 17.89 m3/s, respectively. The measured and simulated average monthly flow for the validation period were 19.92 m3/s and 21.15 m^3/s, respectively. The changes in land use have significant impact on stream flow during the wet season with possible increase by 6.01 m3/s and insignificant impact on stream flow during the dry season with possible decrease of stream flow by 1.92 m^3/s. This stream flow change can be attributed to land use change whereby high runoff is expected in cropland than in forests during the wet season. Conversion of forests to agricultural fields results to low stream flow during the dry months because stream flow is sustained by base flow thus with low infiltration during the wet season, the contribution will also be low during the dry months. This study was thus able to demonstrate the synergetic role of SWAT and Arc GIS technologies in improving watershed management.

7.2. Conclusion of the study

The study concluded that irrigation water abstraction had significant modification of the flow of Thiba river during the dry season but during the wet season the impact was insignificant. The land use changes have significant impacts on stream flow modifications during the wet season given normal seasonal inter-annual variability exhibited by simulated stream flow results. The results also show that water abstraction for irrigation has greater impacts on stream flow than conversion of forest land to agricultural land. Land use changes, especially upgrading of rain fed agriculture, are unavoidable due to increased food demand and declining agricultural productivity. Such changes are bound to have positive socio-economic impacts geared towards improving livelihoods, but could lead to negative impacts downstream.

The study has been able to showcase capability of RS,GIS and hydrologic modeling through optimization techniques in analyzing water management in catchment basin. The process of domesticating SWAT for given catchment basin has also been greatly facilitated by the development of GIS based interfaces which provides more straight forward means of translating digital land use, topographic, and soil data into model inputs .

The uses of automatic calibration techniques were found to be convenient and highly efficient in model evaluation. The main limitation faced in this work was related to availability of reliable stream flow data . The data had several missing months and years thus limiting the length of calibration and validation period. Water abstractions data for Mwea Irrigation Scheme was lacking for the year 2007 backwards. This limited the performance of much detailed flow analysis in the basin.

7.3. The Recommendations of The Study

The study came up with a number of key recommendations to key stakeholders in water resources planning and management as detailed below.

7.3.1. Recommendations to the Catchment Management

Water demand in the basin is highest during the dry months when stream flow is at the lowest. The demand of water can be resolved by constructing water storage reservoirs to harvest the increased runoff during the wet months and release the water during the dry months.

The modeling approach presented in this thesis can serve as important tool in understanding the impacts of management decisions on the Thiba and other watersheds. Some details of the methodologies of the study can adjusted based on case study needs to domesticate fully the model for specific studies. Thus there is need for catchment basin management to priotize resources optimization tools based on available land and water with greater cooperation with researchers.

Hydrological models especially distributed models are driven by the quality of input data especially. Thus data quality and availability of good data should be emphasized.

The Government agencies concerned with water resources utilization and management should come together to establish a central water resources database inventory. Data availability and quality was a major challenge in this study. Of great concern were many missing stream flow and water abstraction records which probably would have been available if central hydrological database inventory system was put in place. Modern data collection and storage techniques should be embraced at the same time incorporating regional and local communities for ownership for well coordinated water resources management.

7.3.2. Recommendations for Further Studies

Further research is needed to investigate the combined effect of climate and land use change on the Thiba stream flow. Future climatic predications are necessary to forecast on appropriate measures to be undertaken to prevent such effects. Therefore, further scenario simulations and optimization strategies that take into account upstream-downstream water users can provide valuable information to devise more effective watershed management strategies to sustain the livelihoods both inside and outside livelihoods

Further research also needs to be conducted on the possible impacts of land use change on the water quality and river ecosystems. The expansion of agriculture is associated with increase in agro-chemicals and fertilizers.

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APPENDIXES

Appendix A: Sample Questionnaire For Collecting Water Abstraction Data

ABSTRACTION SURVEY SHEET NO…………….

1.1 Abstraction Point

Date………………………………………………………(Date of data collection)

Abstraction Point Name……………………………………………………

Current water use…………………………………………………………

1.2 Position

Map sheet zone 37: UTM X………………………UTMY…………………….

Altitude (M ASL)…………………………………………………………………

1.3. Water abstraction details

Type of water abstraction method: (a) Pump [ ]

(b) Metered channel diversion [ ]

(c)Un-Metered channel diversion [ ]

If pump, state the size (M3/hr)…………………………………………………

If metered amount abstracted (M3/hr)…………………………………………

If unmetered amount diverted (M3/hr)……… ………………………………

1.4. Water use details

Date pumping commenced (DD/MM/YYYY)……….. …………………

Pumping hours per day……………………………………………………

Date unmetered channel diversion started DD/MM/YYYY)………………………

Time in hours per day channel is diverted……………………………………

Date metered channel diversion started (DD/MM/YYYY)……………………

Time in hours per day channel is diverted…………………………………………

1.5. Irrigation water abstraction pattern

Which months is water abstraction done.

January [ ]

February [ ]

March [ ]

April [ ]

May [ ]

June [ ]

July [ ]

August [ ]

September [ ]

October [ ]

November [ ]

December [ ]

Signed by data collector:…………………….Name:………………………………

Issued by: S.M.Kasuni……………………….Sign:…………………… …………

Appendix B :Water Abstracted By Mwea Irrigation Scheme

CP1 (M^3/MONTH)													
YEAR	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**TOTAL**
2007	203947.69	583620.3636	682557.7143	599248	986240	1724297.143	2487822	1965451.03	2361744	2452464	1962576	1840752	17850719.5
2008	1660176	1286357.14	1114992.00	719280.00	1072656	2464992.00	2687774	2255472.00	2278800	1651104	2151360	1641168	20984131.5
2009	988947.69	683620.3636	692557.7143	589248	786240	2042496	1967700	1864512	1662768	2216160	2332368	2326320	18152938.2
2010	2036448	1498733.419	1547668.8	1849824	536976	2042496	2892672	2707776	2413152.00	2318976	1897776	1969920	23712418.2
2011	1699488	904176	801792	754704	730512	2372976	1928016	2264112	2392416	1744416.0	1348704	4438800	21380112
2012	1937952	1605312	1136160	527337.931	4297536	1683504	2573775	2012738.82	2629701.82	2080377.93	1533302	1592352	23610049.6
2013	1762128	1146960	332208	398736	466560	1686096	2280960	2501625.6	2223072	6680016	1755216	1920672	23154249.6
2014	1719086.4	1198368	784944	688608	824896	1924128	2103408	3431376	2915136	2280377.93	2433302	2892352	23195982.4

CP3 M3/MONTH													
YEAR	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**TOTAL**
2007	5098976	4467944	3420576	1475504	3415648	7475976	6510655	5736811.03	6883056	6958656	6677177	6476371	64597350.4
2008	5062176	3231776.57	3106080.00	2091744.0	7269696	8336304.00	6801797	5993136.00	5708016	6524064	6109344	5063472	65297605.4
2009	5090505.2	2764603.636	1287545.143	2116368	5028048	4178304	2248009	2398464	1895616	4109184	7302960	7346160	45765766.8
2010	6098976	4967944.258	3420576	1575504	3915648	5073408	7451136	7065360	5985792.00	6242400	5090256	6216480	63103480.3
2011	4624560	2674512	1998000	2876256	6970752	8146224	5166288	5507136	6083424	6183216	3447360	1916352	55594080
2012	1937952	3207600	2360880	527337.931	4297536	7856784	7396920	2629701.82	6480589.09	6327027.31	3132298	2036016	48190642.1
2013	2749680	2107728	1864080	1864080	5316624	1686096	6183648	7456219.2	6680016	6506352	4562784	5588352	52565659.2
2014	4493664	2717280	1245888	1978560	6833376	8065872	8428752	8418384	39011760	5506352	4462784	5488352	96651024

Appendix C: Water Abstracted Outside Mwea Irrigation Scheme In Thiba River Basin

YEAR	JAN (M3/ MONTH)	FEB M3/ MONTH)	MAR M3/ MONTH)	APRIL M3/ MONTH)	MAY M3/ MONTH)	JUNE M3/ MONTH)	JULY M3/ MONTH)	AUGUST M3/ MONTH)	SEPT M3/ MONTH)	OCT M3/ MONTH)	NOV M3/ MONTH)	DEC M3/ MONTH)	TOTAL
1980	16032	12024.00	3600.00	2404.00	18036	17634	18000	17800	24000	18000	12000	8000	167532
1981	40080	30060.00	9000.00	6010.00	45090	44085	45000	44500	60000	45000	30000	20000	418830
1982	56112	42084.00	12600.00	8414.00	63126	61719	63000	62300	84000	63000	42000	28000	586362
1983	64128	48096.00	14400.00	9616.00	72144	70536	72000	71200	96000	72000	48000	32000	670128
1984	80160	60120.00	18000.00	12020.00	90180	88170	90000	89000	120000	90000	60000	40000	837660
1985	88176	66132.00	19800.00	13222.00	99198	96987	99000	97900	132000	99000	66000	44000	921426
1986	96192	72144.00	21600.00	14424.00	108216	105804	108000	106800	144000	108000	72000	48000	1005192
1987	120240	90180.00	27000.00	18030.00	135270	132255	135000	133500	180000	135000	90000	60000	1256490
1988	160320	120240.00	36000.00	24040.00	180360	176340	180000	178000	240000	180000	120000	80000	1675320
1989	320640	240480.00	72000.00	48080.00	360720	352680	360000	356000	480000	360000	240000	160000	3350640
1990	360720	270540.00	81000.00	54090.00	405810	396765	405000	400500	540000	405000	270000	180000	3769470
1991	721440	541080.00	162000.00	108180.00	811620	793530	810000	801000	1080000	810000	540000	360000	7538940
1992	769536	577152.00	172800.00	115392.00	865728	846432	864000	854400	1152000	864000	576000	384000	8041536
1993	801600	601200.00	180000.00	120200.00	901800	881700	900000	890000	1200000	900000	600000	400000	8376600
1994	841680	631260.00	189000.00	126210.00	946890	925785	945000	934500	1260000	945000	630000	420000	8795430
1995	849696	637272.00	190800.00	127412.00	955908	934602	954000	943400	1272000	954000	636000	424000	8879196
1996	881760	661320.00	198000.00	132220.00	991980	969870	990000	979000	1320000	990000	660000	440000	9214260
1997	897792	673344.00	201600.00	134624.00	1010016	987504	1008000	996800	1344000	1008000	672000	448000	9381792
1998	921840	691380.00	207000.00	138230.00	1037070	1013955	1035000	1023500	1380000	1035000	690000	460000	9633090

1999	1002000	751500.00	225000.00	150250.00	1127250	1102125	1125000	1112500	1500000	1125000	750000	500000	10470750
2000	1042080	781560.00	234000.00	156260.00	1172340	1146210	1170000	1157000	1560000	1170000	780000	520000	10889580
2001	1050096	787572.00	235800.00	157462.00	1181358	1155027	1179000	1165900	1572000	1179000	786000	524000	10973346
2002	1066128	799596.00	239400.00	159866.00	1199394	1172661	1197000	1183700	1596000	1197000	798000	532000	11140878
2003	1074144	805608.00	241200.00	161068.00	1208412	1181478	1206000	1192600	1608000	1206000	804000	536000	11224644
2004	1090176	817632.00	244800.00	163472.00	1226448	1199112	1224000	1210400	1632000	1224000	816000	544000	11392176
2005	1122240	841680.00	252000.00	168280.00	1262520	1234380	1260000	1246000	1680000	1260000	840000	560000	11727240
2006	1250496	937872.00	280800.00	187512.00	1406808	1375452	1404000	1388400	1872000	1404000	936000	624000	13067496
2007	1258512	943884.00	282600.00	188714.00	1415826	1384269	1413000	1397300	1884000	1413000	942000	628000	13151262
2008	1282560	961920.00	288000.00	192320.00	1442880	1410720	1440000	1424000	1920000	1440000	960000	640000	13402560
2009	1298592	973944.00	291600.00	194724.00	1460916	1428354	1458000	1441800	1944000	1458000	972000	648000	13570092
2010	1314624	985968.00	295200.00	197128.00	1478952	1445988	1476000	1459600	1968000	1476000	984000	656000	13737624
2011	1322640	991980.00	297000.00	198330.00	1487970	1454805	1485000	1468500	1980000	1485000	990000	660000	13821390
2012	1362720	1022040.00	306000.00	204340.00	1533060	1498890	1530000	1513000	2040000	1530000	1020000	680000	14240220
2013	1410816	1058112.00	316800.00	211552.00	1587168	1551792	1584000	1566400	2112000	1584000	1056000	704000	14742816
2014	1442880	1082160.00	324000.00	216360.00	1623240	1587060	1620000	1602000	2160000	1620000	1080000	720000	15077880
AVERAGE	785109.9	588832.4571	176297.1429	117727.314	883248.7	863562.2	881485.7	871691.4	1175314	881485.7	587657.1	391771.4	

Appendix D: Stream Flow Data For River Gauging Station 4DD02

Year	Mean Daily Annual Flows (M3/S)	Mean Maximum Flow (M3/S)	Mean Minimum Flow (M3/S)
1966	28.87694	135.0078	3.29445
1967	32.33786	238.7212	1.216226
1968	36.80754	204.4551	8.558298
1969	16.25483	82.33858	4.356155
1970	21.3222	128.7151	2.548653
1971	13.69007	69.68678	0.077827
1972	26.94372	134.3752	0.194577
1973	24.45338	110.2893	0.831468
1974	15.31459	133.7434	0.653383
1975	19.37131	154.3128	1.421144
1976	11.30282	72.1899	0.194577
1977	77.37291	292.4128	5.456268
1979	31.45621	203.4121	7.837799
1980	12.96116	80.17829	1.92642
1981	23.31809	143.0075	2.306182
1982	25.8328	108.1003	2.032295
1983	21.44163	122.7563	5.200294
1984	8.522982	89.217	0.199002
1985	19.40322	181.9088	1.030817
1986	14.94457	129.7581	0.457459
1987	10.50544	37.78531	0.95634
1988	38.04046	283.9409	1.533234
1989	24.55027	75.73875	5.770425
1990	23.0737	63.317	6.120136
1991	19.01898	125.23	2.697529
2010	31.38284	231.1228	0.8154
2011	88.57533	127.0749	0.916469

2012	354.9171	117.9491	0.674409
2013	121.7152	602.8793	2.289789
2014	39.2586	662.7963	1.387451

Appendix E: Monthly (MM)Rainfall Data Used In The Study

YEAR	MONTH	KERUGOYA	CASTLE FOREST	EMBU
1990	1	130	92	90
1990	2	18	60	17
1990	3	188	253	224
1990	4	287	408	430
1990	5	246	367	180
1990	6	64	135	21
1990	7	0	0	27
1990	8	20	140	22
1990	9	25	101	72
1990	10	232	278	218
1990	11	170	222	308
1990	12	125	172	109
1991	1	32	29	18
1991	2	11	4	0
1991	3	101	165	79
1991	4	0	0	184
1991	5	527	918	205
1991	6	45	100	10
1991	7	64	149	36
1991	8	71	132	46
1991	9	8	11	1
1991	10	83	120	107
1991	11	117	129	168
1991	12	42	48	49
1992	1	14	7	6
1992	2	8	54	4
1992	3	22	30	12
1992	4	351	302	294
1992	5	389	569	238

1992	6	41	102	7
1992	7	79	127	29
1992	8	49	107	24
1992	9	28	82	20
1992	10	87	139	155
1992	11	314	194	215
1992	12	128	129	104
1993	1	167	200	139
1993	2	27	44	68
1993	3	26	18	85
1993	4	356	357	217
1993	5	372	548	22
1993	6	50	109	25
1993	7	78	169	45
1993	8	24	45	15
1993	9	27	58	17
1993	10	136	179	80
1993	11	153	169	290
1993	12	48	55	49
1994	1	0	17	55
1994	2	24	29	0
1994	3	70	72	55
1994	4	415	308	467
1994	5	437	586	202
1994	6	36	80	19
1994	7	58	127	55
1994	8	58	108	33
1994	9	42	90	31
1994	10	460	606	245
1994	11	388	430	437
1994	12	79	91	57
1995	1	9	12	7

1995	2	36	57	69
1995	3	103	120	166
1995	4	365	366	305
1995	5	353	520	119
1995	6	30	65	11
1995	7	70	153	20
1995	8	0	0	61
1995	9	0	0	34
1995	10	0	0	277
1995	11	133	264	221
1995	12	130	158	100
1996	1	40	141	52
1996	2	11	26	14
1996	3	195	172	165
1996	4	117	183	101
1996	5	256	449	185
1996	6	112	145	52
1996	7	48	164	35
1996	8	33	54	19
1996	9	3	14	2
1996	10	20	43	14
1996	11	152	199	242
1996	12	9	6	1
1997	1	0	19	1
1997	2	0	5	0
1997	3	58	67	92
1997	4	437	305	494
1997	5	85	138	89
1997	6	63	115	21
1997	7	25	68	16
1997	8	32	63	8
1997	9	7	54	2

1997	10	658	735	396
1997	11	399	345	409
1997	12	215	246	139
1998	1	277	319	166
1998	2	93	130	165
1998	3	159	104	163
1998	4	307	420	212
1998	5	463	344	389
1998	6	69	109	88
1998	7	83	158	67
1998	8	94	188	63
1998	9	34	120	17
1998	10	42	70	10
1998	11	192	281	268
1998	12	18	32	0
1999	1	24	33	53
1999	2	4	7	11
1999	3	199	231	197
1999	4	255	256	178
1999	5	238	350	88
1999	6	18	40	10
1999	7	69	151	37
1999	8	57	106	37
1999	9	38	82	14
1999	10	64	127	43
1999	11	232	185	396
1999	12	194	160	186
2000	1	0	0	0
2000	2	4	9	0
2000	3	25	46	16
2000	4	138	229	60
2000	5	121	158	25

2000	6	45	128	21
2000	7	39	129	25
2000	8	36	80	23
2000	9	54	85	29
2000	10	36	104	41
2000	11	230	256	198
2000	12	78	90	62
2001	1	185	148	109
2001	2	4	7	2
2001	3	119	157	149
2001	4	456	425	312
2001	5	90	234	147
2001	6	44	117	30
2001	7	55	159	29
2001	8	41	60	18
2001	9	9	15	4
2001	10	147	172	52
2001	11	179	251	283
2001	12	67	62	30
2002	1	19	15	26
2002	2	4	24	17
2002	3	117	121	95
2002	4	681	450	744
2002	5	265	380	274
2002	6	38	66	15
2002	7	43	87	19
2002	8	84	170	55
2002	9	52	82	37
2002	10	243	336	173
2002	11	213	418	150
2002	12	126	145	142
2003	1	37	7	0

2003	2	2	4	0
2003	3	90	105	67
2003	4	304	397	314
2003	5	245	407	317
2003	6	33	72	11
2003	7	40	80	15
2003	8	110	204	138
2003	9	50	82	53
2003	10	207	367	202
2003	11	189	210	175
2003	12	44	66	94
2004	1	0	0	33
2004	2	0	0	54
2004	3	0	0	135
2004	4	0	0	152
2004	5	0	0	63
2004	6	0	0	21
2004	7	0	0	4
2004	8	0	0	16
2004	9	84	75	38
2004	10	0	0	238
2004	11	0	0	373
2004	12	0	0	50
2005	1	0	0	3
2005	2	0	0	1
2005	3	0	0	22
2005	4	0	0	238
2005	5	0	0	249
2005	6	0	0	32
2005	7	0	0	36
2005	8	0	0	47
2005	9	0	0	23

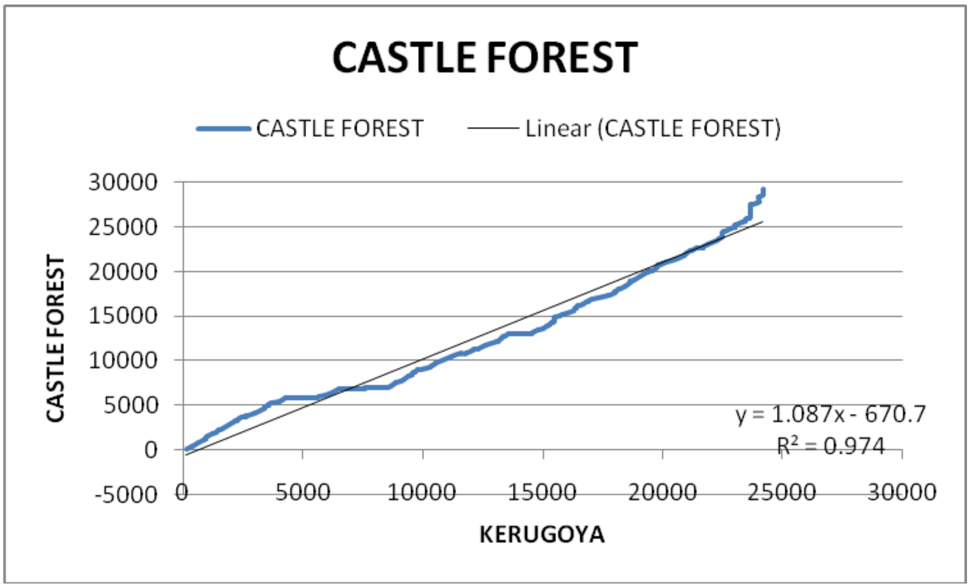
2005	10	0	0	168
2005	11	0	0	130
2005	12	0	0	5
2006	1	0	0	0
2006	2	0	0	0
2006	3	0	0	0
2006	4	0	0	0
2006	5	0	0	0
2006	6	0	0	0
2006	7	0	0	0
2006	8	0	0	0
2006	9	0	0	0
2006	10	0	0	0
2006	11	0	0	0
2006	12	0	0	0
2007	1	63	76	67
2007	2	53	47	0
2007	3	119	70	74
2007	4	361	320	261
2007	5	373	432	177
2007	6	45	130	10
2007	7	52	132	33
2007	8	201	250	46
2007	9	25	102	19
2007	10	250	265	330
2007	11	130	144	126
2007	12	53	61	57
2008	1	42	46	67
2008	2	27	28	0
2008	3	192	329	161
2008	4	364	369	340
2008	5	63	168	13

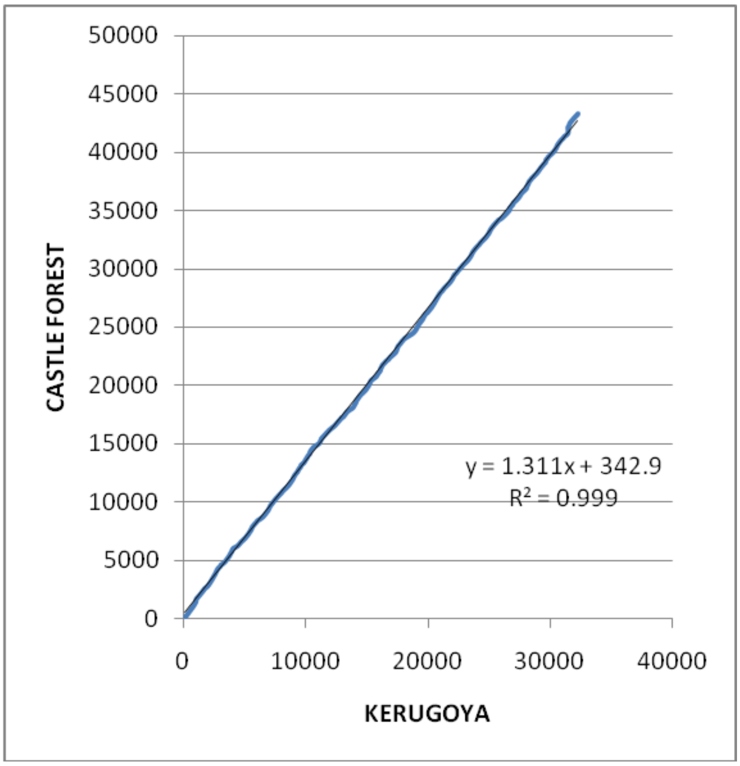
2008	6	32	81	21
2008	7	73	151	56
2008	8	45	110	21
2008	9	25	80	8
2008	10	245	323	224
2008	11	80	89	100
2008	12	0	0	2
2009	1	50	33	117
2009	2	0	18	10
2009	3	66	74	85
2009	4	197	202	199
2009	5	159	222	163
2009	6	35	27	14
2009	7	11	25	4
2009	8	50	94	16
2009	9	14	29	9
2009	10	315	403	239
2009	11	113	119	188
2009	12	48	145	43
2010	1	28	129	19
2010	2	88	59	118
2010	3	80	153	188
2010	4	431	433	224
2010	5	194	286	223
2010	6	65	144	20
2010	7	65	141	29
2010	8	53	99	49
2010	9	18	39	5
2010	10	0	0	102
2010	11	151	167	114
2010	12	0	0	23
2011	1	2	13	12

2011	2	0	0	18
2011	3	62	81	45
2011	4	281	276	266
2011	5	0	472	203
2011	6	35	68	8
2011	7	14	30	7
2011	8	60	106	26
2011	9	64	188	101
2011	10	337	444	263
2011	11	0	0	224
2011	12	114	131	68

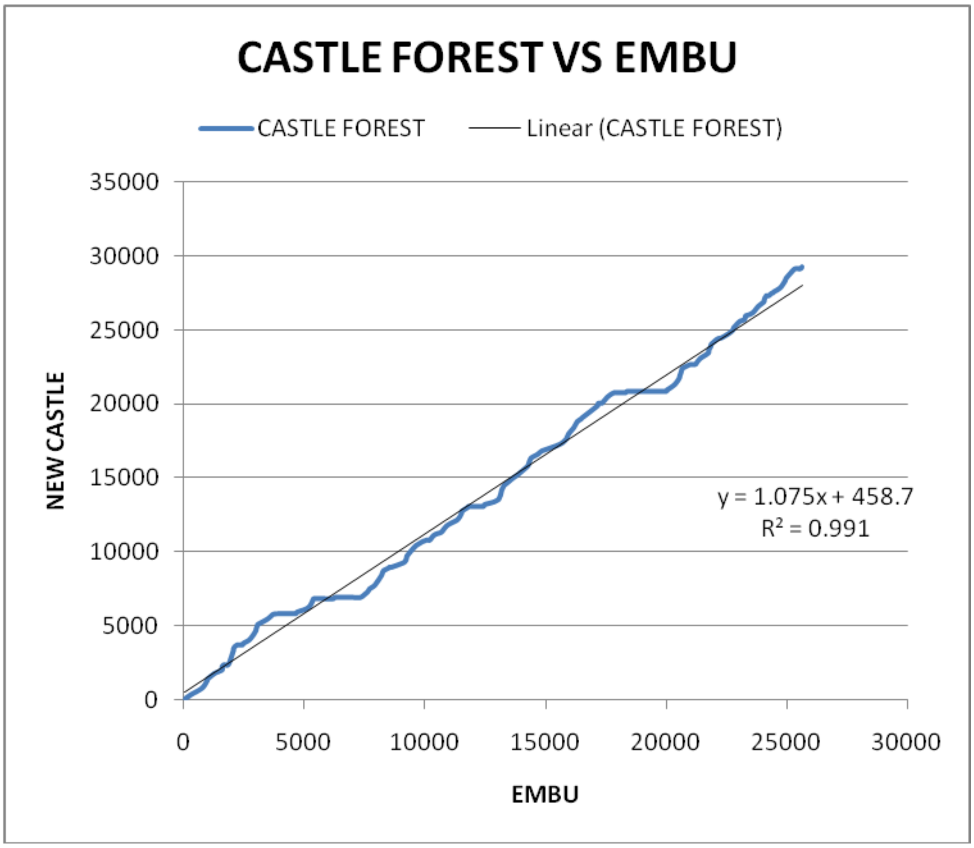
Appendix F : Double Mass Curve Analysis

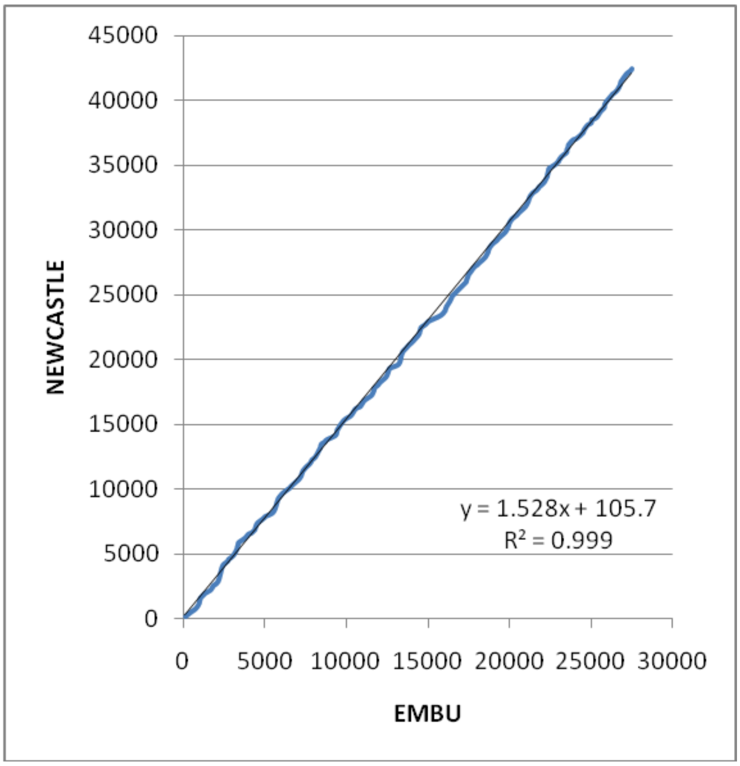
CASTLE FOREST VERSES KERUGOYA BEFORE AND AFTER VALIDATION





CASTLE FOREST VS EMBU BEFORE AND AFTER VALIDATION





Appendix G: Significance Of Spearman's Rank Correlation Table

Work out the 'degrees of freedom' you need to use. This is the number of pairs in your sample minus 2 (n-2).

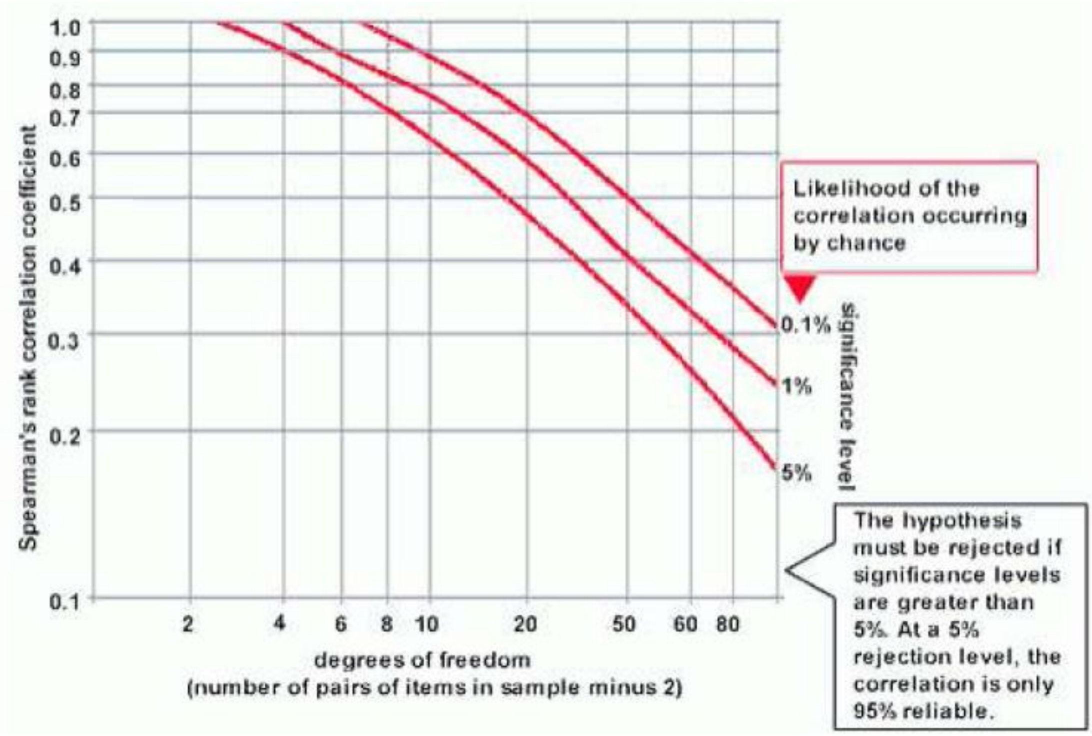
Plot the Rsp result on the table.

If it is below the line marked 5%, then it is possible your result was the product of chance and you must reject the hypothesis.

If it is above the 0.1% significance level, then we can be 99.9% confident the correlation has not occurred by chance.

If it is above 1%, but below 0.1%, you can say you are 99% confident.

If it is above 5%, but below 1%, you can say you are 95% confident (i.e. statistically there is a 5% likelihood the result occurred by chance.



Appendix H: Landsat Image Used For Producing 1984 Land Cover Data