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Msc Thesis

THE IMPACT OF MEGA INFRASTRUCTURE ON THE HYDROLOGY OF RUIRU AND KAMITI RIVERS

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A Thesis submitted in partial fulfilment for the award of a Degree of Master of Science in Civil Engineering (Water Resources Engineering) of the Department of Civil Engineering of University of Nairobi

August 2023

DECLARATION AND APPROVAL

I, Jeremiah Thuku Ngondo, hereby declare that this Msc thesis is my original work. To the best of my knowledge, the work presented here has not been presented for examination in any other university.

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DEDICATION

I dedicate this thesis to my lovely wife Nancy Adhiambo Thuku, my children Arnold, Shawn, and Mila, who have been a gift of God to me and the primary focus of the hard work and dedication I've put into completing this research.

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ABSTRACT

Like many other developing nations in Africa, Kenya has seen a significant rise in urbanization. Numerous cities and towns have seen population growth as well as spatial expansion, resulting in enormous metropolitan areas. Metropolitan areas have provided tremendous prospects for growth. Numerous issues and difficulties have been brought on by the fast urbanization in the economic, social, and environmental spheres. One such metropolis in Kenya is Ruiru.

Therefore, the goal of this research was to examine how mega infrastructure has affected the hydrology of the Ruiru and Kamiti rivers. Four catchment regions were included in the study area, and they were chosen based on the availability of hydrological data from Water Resources Authority, which was acquired from their offices in Nairobi and Kiambu. On the basis of the Shuttle Radar Topography Mission void filled Digital Elevation Model, the catchment extent was subsequently defined by river gauging station 3BB12 on River Kamiti and delimited using the river gauging station as the catchment outlet.

Data sets utilized in the study were Landsat images, google earth images, river flow data, river abstraction records, water production data and rainfall data. Various GIS methods employed to analyze the data included normalized difference built up index, hydrological characterization using the threshold method, change detection, and GIS software.

The study period's rainfall data revealed a very slight trend over time. Rainfall did not modify the river flow regime, as evidenced by comparisons to flows that decreased over time.

For the time period under research, the supervised classification built up index for the study area increased from 2.8% to 51.8%. However, average flows over this time decreased from 2.2 m3/s to 0.53 m3/s. This demonstrated that altering land use had a discernible impact on river flow regime. It would not have been accurate to draw the conclusion that mega projects had a different impact from "regular" urban growth. This is due to the flow duration curves for the several eras (1958–1987, 1988–2000, 2005–2010, and 2011–2016) displaying a pattern that was consistent throughout, with no aberrant alterations noted in the 10–15 years prior (period of mega projects).

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ABBREVIATIONS

AWWDA	-	Athi Water Works Development Agency
CBS	-	Central Bureau of Statistics
DEM	-	Digital Elevation Models
DONMED	-	Department of Nairobi Metropolitan Development
EIA	-	Environmental Impact Assessment
FDC	-	Flow duration curves
GIS	-	Geographic Information System
GRASS	-	Geographic Resources Analysis Support System
ILWIS	-	Integrated Land and Water Information System
LULC	-	Land Use Land Change
MOWSI	-	Ministry of Water & Sanitation and Irrigation
NDBI	-	Normalized Difference Built-up Index
NDVI	-	Normalized Difference Vegetation Index
NEMA	-	National Environmental Management Authority
RGS	-	River Gauging Station
RUJWASCO	-	Ruiru-Juja Water and Sewerage Company
SRTM	-	Shuttle Radar Topography Mission
THIWASCO	-	Thika Water and Sewerage Company
TRMM	-	Tropical Rainfall Measuring Mission
USD	-	United States Dollar
WASREB	-	Water Services Regulatory Board
WRA	-	Water Resources Authority

CHAPTER ONE: INTRODUCTION

1.1Study Background

In many parts of the world, water resources management has become a critical aspect with population and economies growing, which increases the demand for water (Global Water Partnership, 2005). This culminated in the need for allocation and conflict resolution for water resources, causing concerns for long term sustainability and human life observed in the participating countries.

Population expansion in Kenya is closely associated with a massive increase in demand for land, which is related to urban growth and increased agricultural activities. Kenya is classified as one of the water-scarce countries in the world (Global Water Partnership, 2015), and land use implications on water systems have been shown to cause far-reaching consequences, both ecologically and economically. The demand for land in the region is largely fueled by agriculture and settlement. The high population expansion and intense land utilization in the catchment are attributed to increased land degradation, leading to degradation of water resources, one of the critical ecosystem services.

Urban areas in Kenya mainly expand in a radial direction around an urban center or in a linear way along infrastructures such as roads or railway lines (Mundia and Aniya 2005). The Study area, which are Kiambu-Ruiru Sub-counties borders Kenyas's capital Nairobi, and thus it has a significant land use and land cover changes due to the expansion of the city over some time. This change in land use has impacted river flow conditions of Ruiru and Kamiti rivers in some way.

Rivers are largely susceptible to land use change and ubiquitous exploitation (Withers and Jarvie, 2008; Vörösmarty *et al.*, 2010). Deterioration of rivers as a result of unsustainable human activities has become a major concern for governments the world over (Chen and Lu, 2014), which are directly reflected in land use and land cover characteristics (Kang, *et al.*, 2010).

Bork *et al.* (1998) investigated land-use change and its environmental effects north of the Alps based on palynological and pedological data and demonstrated its strong imprint. Around 650 CE, 93% of the total area was covered by woods (697,500 km^2 out of a total of 750, 000 km^2). By 1310, the proportion of woods had diminished to 15% only (i.e., 112,500 km^2) mostly in favor of arable land and grassland. At present, forests cover about one third, arable land 38%, and grassland about 24%. Other land-use types were always of minor importance. At present, total annual surface runoff is assumed to be around 220 mm. Although Bork *et al*. (1998) did not specifically investigate the effects of altered surface runoff on river discharge, they concluded that changed evapotranspiration and interception had an effect.

Mega projects are mainly categorized as Irrigation, Power generation projects (Dams), and Infrastructure development such as housing and Industrial development. Alaa Elzawahry and Hesham Bekhit, 2016, researched on the impacts on the water resources of Egypt in different but interrelated dimensions. They discovered the main impact was the shortage of water reaching the most arid zone on the Nile in Egypt. Such shortage of water created a chain reaction influencing at large all the environmental activities in Egypt (total environmental impact). The impacts included crop and fish production and farmers income, present and future reclaimed land (other developments), salt water intrusion, soil salinity, supply intakes and intakes for water treatment plants, main canals and rayahs, ecological imbalance, tourism industry, health risks, generation of hydropower, Dam failure impacts, and socio-economic impacts.

This study therefore seeks to determine how much control and what effects infrastructure projects and other major operations have had on the hydrology of Ruiru and Kamiti rivers over a period of thirty (30) years using of geographic information system (GIS) technology.

1.2Problem Statement

Over the past few decades, the area of Ruiru has become an increasingly urban society with major on-going development projects. The changes in land use associated with development affect hydrology of rivers in many ways. Removing vegetation and soil, grading the land surface, and constructing drainage networks increase runoff to streams from rainfall. As a result, the peak discharge, volume, and frequency of floods increase in nearby streams. Changes to stream channels during construction of development projects can limit their capacity to convey floodwaters.

Ruiru town is located about 20 Km North of Nairobi. According to the Kenya National Bureau of Statistics, 2019, Ruiru is placed 5th in terms of population size after Nairobi, Mombasa, Kisumu, and Nakuru, (Table 1.1).

Table 1.1: Population brief of Urban areas

Urban Center	County	Male Population	Female Population	Total Population
Nairobi	Nairobi	2,192,452	2,204,376	4,397,073
Mombasa	Mombasa	610,257	598,046	1,208,333
Kisumu	Kisumu	560,942	594,609	1,155,574
Nakuru	Nakuru	317,326	327,874	645,235
Ruiru	Kiambu	180,947	190,144	371,111
Juja	Kiambu	148,446	152,480	300,948
Turbo/Eldoret	Uasin Gishu	133,579	133,682	267,273
Thika West	Kiambu	120,698	125,104	245,820
Kabete	Kiambu	97,794	101,845	187,122
Kikuyu	Kiambu	90,919	96,198	178,795
Ongata Rongai	Kajiado	87,871	90,916	167,501
Naivasha Central	Nakuru	84,336	83,146	166,906
Kisii Central	Kisii	81,330	85,573	166,357
Malindi	Kilifi	81,190	85,163	159,314
Limuru	Kiambu	79,632	79,682	140,338
Nyeri Central/Municipality	Nyeri	69,955	70,380	137,282
Dadaab	Garissa	72,091	65,186	135,399
Garissa(central)	Garissa	68,021	67,373	119,653

Urban Center	County	Male Population	Female Population	Total Population
Kiambu (Municipality)	Kiambu	56,503	62,671	115,855
Kakamega Municipality	Kakamega	53,075	53,202	106,277

(Source: Kenya National Bureau of Statistics, 2019)

The town currently has 490,120 residents, and the population is projected to increase to 970,000 by 2030, according to the 2019 census report. Due to Ruiru's role as one of the residences for Nairobi's expanding population, the town's close proximity to Nairobi adds to its rapid population increase. Additionally, Ruiru also gain from a better transportation system thanks to the Thika superhighway, the eastern and northern bypasses, and other roads that run through the town. In and around the town, construction is already accelerating quickly.

As new development occurs, roads and structures built in locations where it is susceptible to flooding are subjected to inundation dangers, such as flooding and attrition. Societies may mitigate against flooding by studying more on streamflow and impacts on land use. By using GIS technology, this study seeks to investigate any hydrological effects of mega infrastructure on the hydrology of the Ruiru and Kamiti rivers.

1.3Objectives of the Study

1.3.1 Overall Objective

The aim of this research is to establish what effects the on-going infrastructure projects and other land use operations have on the hydrology of Kamiti and Ruiru rivers by use of GIS technology.

1.3.2 Specific Objectives

The specific objectives of this research were to determine.

i. Land use and land cover trends within the study catchment defined by River gauging station 3BB12 on River Kamiti.

ii. Hydrological effect on Ruiru and Kamiti rivers by the increase in built up area from the year 1987 to the year 2018.

1.4Justification for the Study

As Kenya positions seeks to become a middle-income economy as entrenched in its Vision 2030, there is need to put in place sustainability indicators to show the state of human and economic conditions. This will not only help to investigate the trend of shifts in these attributes but will also perform a key role in achieving maintainable development. These indicators will also provide a framework under which crucial decisions to national and international policy will be made.

With the human population growing rapidly globally, the planet's land cover has changed tremendously, especially in low- and middle-income countries. Kiambu County has experienced a steady human population growth, making it the third most populous county in Kenya (KNBS, 2016). As such, issues such as infrastructure development, pollution control, change in the environment and other similar matters of man-environment contact have been a key fear by the scientific society and policy makers (Codjoe, 2007).

It has been impossible to analyze, control, and reinstate Kenya's inadequate water sources because of a lack of fundamental understanding about the landscape-level characteristics of river flow regimes and their effects on settlement and production downstream. Therefore, for policy creators in watershed development and for a healthier consideration of the connections between population economic and environmental settings as well as population growth, timely & accurate estimation of the effects of land use to variation in river flow regimes is of significant importance. (Geofrey Mwangi, 2008)

Notwithstanding the urgent requirement to observe change in land use over time, the hydrology of the watershed of Kamiti and Ruiru Rivers, especially areas of Mega projects like TATU city and ruiru & Juja wastewater treatment plant, have not been entirely addressed.

Tatu City is a development of Strategic National status. It is a flagship Vision 2030 private sector development and is gazetted as a Special Planning Area. Located on 5,000-acres. Tatu City comprises of residentials, commercial, and industrial development that is meant to cater to both local and international clients and visitors.

TATU city water supply is from the nearby Ruiru river whose intake and pumping station is located at Jacaranda near sasini coffee plantation. The designed capacity of the intake and pumping works is 13,000m^3/day and is currently abstracting an average of 17,000m^3/day, where it is treated before distribution.

The Ruiru and Juja wastewater treatment plant, situated at the convergence of Kamiti and Ruiru rivers, is a kshs 4.94Billion project funded by the World bank that was commissioned in April 2020. The project covers areas of Juja, Mugutha, Kenyatta Road, Toll and Kimbo areas. The amount of treated wastewater discharged to Ruiru and Kamiti rivers is 21,000m^3/day.

This study therefore seeks to find out the effect of abstracting 17,000m^3/day of water for supply to TATU city as well as the effect of discharging 21,000m^3/day of treated effluent from Ruiru-Juja wastewater treatment plant on the hydrology of Ruiru and Kamiti rivers catchment area.

It is necessary to use a method that can track these changes and analyze them for decision-makers. The standard methods for gathering data have severe limitations when it comes to identifying, tracking, and assessing changes. In order to gather data, identify changes, and analyze how the two megaprojects will affect the hydrology of the Kamiti and Ruiru rivers, remote sensing and GIS tools are crucial.

1.5Scope of Work

This study is limited to Ruiru sub-county, Kiambu County. Four catchment regions, which were chosen centered on the obtainability of hydrological data from WRA also collected from their offices in Nairobi and Kiambu, are the sole subject of the study. On the basis of the SRTM void filled DEM, the catchment zone was subsequently defined by RGS 3BB12 on River Kamiti and delimited using the RGS as the catchment outlet (DEM). The catchment area, and subsequently the study area, developed was approximately 283km^2

Remotely sensed satellite image acquisition was done. To identify changes in LULC, pictures of an identical region were collected at various periods and matched while taking into account temporal phenomena including vegetation, farmland, built-up areas, and waterbodies.

Drought and flood events were detected using the threshold method, with the flow duration curve as the most appropriate tool for the determination of streamflow thresholds. Rainfall patterns within the catchment over the study period were analyzed to estimate the additional water in the catchment basin that would be available for runoff.

CHAPTER TWO: LITERATURE REVIEW

2.1Preamble

The examination of pertinent information related to trends in land use change, factors causing land use & land change, and use of remote sensing and GIS tools inorder to study land use changes vis a vis land use planning are all included in this chapter.

2.2Theoretical Literature

2.2.1 Land use change concepts

Towards investigating ideas related to land practice and transformation, there are three basic points of view (LUCC, 1999). These are the systems approach, agent-based approach, and narrative approach. By establishing an empirical and interpretative baseline from which the veracity of other viewpoints can be assessed, the narrative perspective aims to provide a comprehensive description of the LULC story through historical detail and interpretation. This strategy is useful for locating stochastic and random events that expressly influence changes in land use/cover but might be overlooked in approaches using more constrained time horizons or temporal selection techniques.

The agent-based approach aims to simplify the fundamental characteristics and principles that guide each agent's behavior as they make decisions on a regular basis. There are several types of these distillations, and they include household, gender, and class among others, as well as the typical actor's rational decision-making in neo-classical economics. This viewpoint places a lot of emphasis on the role that human agents play in influencing decisions regarding land use.

The systems/structures perspective, on the other hand, aims to comprehend the social structures and institutions that set up the opportunities and limitations for decision-making (Ostrom 1990). According to Morán, Ostrom, and Randolph (1998), these structures interact at various spatial and temporal dimensions, linking local conditions to global processes and vice versa. Systems or structures might show up in unexpected or unintended ways.

This study integrates all the three approaches as recommended by LUCC (1999), where the described epistemological traditions are incorporated. First, observations and descriptions to understand land use change are adopted (i.e., inductive approach). Secondly, the use of a model to understand mega-projects impacts on water resources (i.e., deductive approach) is used. Thirdly, a critical evaluation of land practice modification aspects performed in-order to understand the drivers of land use transformation (i.e. dialectic approach) (LUCC 1999)

2.2.2 The river range model

Rivers are commonly understood as complex, living systems (Cosgrove and Petts, 1990; Gregory, 2006) that are heterogeneous and dynamic across compound scales of space and time. One of the concepts that attempts to describe rivers' functions across a landscape is the River Continuum Concept (RCC) (Vannote *et al.*, 1980). RCC makes an effort to explain how different river characteristics, such as fluvial geomorphic processes, the physical structure, and the hydrologic cycle, relate to patterns of community structure and function and organic matter loading, transport, utilization, and storage along a river's length (Vannote et al., 1980). This model proposes that stream order is influenced by riparian vegetation, trophic status, capacity, movement, and the comparative significance of useful feeding groups and is associated through appearance of the material constituent of the river. However, stream order is rarely used to describe the physical environment and should only be used to determine the comparative location of a river range within the whole moving water regime.

A river basin system, according to Lee (1995), is made up of a variety of components, such as precipitation, floodplains, lakes, and swamps. Due to the interdependence of these components, fractional tackling of river catchment urban expansion and administration have frequently fallen short of maximizing management outcomes, leading to inefficient utilization of river and terrestrial reserves, financial losses, & environmental deterioration. Water is also stated to be a specific resource to run due to the fact that most of all life aspects depend on it, the economy is dependent on it, human beings have their life being from it with the hydrological cycle of use and recharge, and both are interdependent (Global Water Partnership, 2000). Between water used for survival and water used as a resource, there is a delicate balance (Global Water Partnership, 2000). The aforementioned scenario is typical of the Ruiru and Kamiti basins, where the need for water is fueled by a variety of purposes (domestic, agricultural and industrial). It will be possible to gain insight into the effects of water resources status on the economy, the interaction between human activities and water resources, the mechanisms needed to manage water resources sustainably, and the hydrological processes that may be affected by knowing how these needs compare to the water resources that are currently available in the Ruiru and Kamiti watersheds.

Hydrologic connectivity (Pringle, 2003) includes greater hydrologic links, outside the watershed, on local and universal scales, as opposed towards riverine connectivity. In theory, the hydrologic cycle and riverine connectivity are combined to form the term "hydrologic connectedness," which denotes the aquatic-facilitated transfer of substance, power, and 18 creatures between rudiments of the water cycle (Pringle, 2001). Ecological integrity is described as an ecosystem's undiminished capacity to carry out its ordinary course of progress, its regular change over a period, and its staged recapture from interruption. Hydrological connectivity is crucial for preserving ecological integrity of ecosystems (Geofrey Wambugu, 2018). Water connection as well controls movement of invasive genera, nutrients from human activity, and hazardous wastes throughout the landscape. Due to the intrinsic difficulty of aquatic transport inside and outside of the stratosphere, ground, and underground spheres, as well as the sea, and also the scope and intensity of human modifications, the concept of "hydrologic connectedness" at vast scales is intimidating (Winter et al., 1998). (Pringle and Triska, 2000).

2.3 Experiential Literature

2.3.1 Population Effects on Water resources

Finite land and water resources are experiencing increasing human population for food production, urban expansion and the need for infrastructure facilities, giving rise to fears on sustainability due to conflicting demands. Additionally, the organic evolution of land use modifications frequently leads to a variety of geomorphic and hydrologic modifications. The ecological health of a river is crucial because it reflects the state of the land around it and provides insight into how practices within the watershed (especially in upper watershed management regions) may affect it (Ferreyra and Beard, 2007). These include modifications to flood peaks' geographical and temporal characteristics as well as to the degree and kind of soil erosion (Magilligan and Stamp, 2004).

Human well-being is impacted by land usage both directly and indirectly. As the main cause of earth, aquatic, and terrestrial deprivation, it has an impact on vegetation and animals, adds to national, continental, and worldwide climatic variations, and degrades our environment. Converting forest land to an urban environment, for example, may result in loss of biodiversity and changes in climatic patterns at the local and regional scales. Alternatively, mining and industrial activities that emit greenhouse gases may contribute to climate change at the global level. The capability of organic schemes to meet social requirements is disrupted by changes to ecosystem services, which include the necessities humans receive from ecologies (such as nutrition and fluids), variable services (such as kill-eat interactions, overflow and ailment control), social amenities (such as religious and leisure aids), and provision services (such as fertilization, nutrient reuse, output. Variations cause extensive soil degradation, which alters the biology of ailments that affect people's well-being and increases the body's susceptibility to infections (Collins, 2001).

In developing countries, urbanization presents a key dimension of economic, social and physical change (UNCHS, 2001). Cities inhabitants within the continent is anticipated to multiply two-fold by 2025 (Hall and Pfeifer, 2000), thereby pushing the need for built-up areas for settlement and additional urban usages. The outcome of this demand is likely to extend to the rural-urban fringe. With the growth of the city, the rural-urban fringe presents challenges and opportunities while dealing with the byproducts of land use changes. Urbanization of fringe areas provide a number of opportunities, including employment, better housing, and ready markets for agricultural products. Nevertheless, a human population influx exerts enormous pressure on ordinary possessions, current community amenities and public services (Rees and Wackernagel, 1994).

Transformation in ground cover might negatively impact heavily on aquatic assets (Stonestrom et al., 2009). Changes occur due to quick socioeconomic growth. These changes can affect different land use classes, such as when agriculture is converted to an urban area as a result of urbanization, and different land development classes itself. Land use changes could worsen the living circumstances in countries with limited water supplies by increasing the water scarcity (DeFries and Eshleman 2004). A varied choice of ecological and ground characteristics, together with the acceptable condition of aquatic, terrestrial, as well as air sources, and also ecological methods and actions, are impacted by modifications in terrestrial cover due to urban development. (Lambin *et al.,* 2006).

Waterways in a catchment contribute in adjusting or discharging runoff from agricultural landscapes, as well as municipal and industrial wastewater. When investigating catchment impacts to river hydrology, landscape heterogeneity has to be considered. This is important because spatial heterogeneity of catchment characteristics results into an increased number of environmental influences, for example human activity within the catchment has the potential to significantly alter runoff characteristics throughout time and space (Meybeck, 2004). This study employs a technique that records these hydro trends in order to get insight into the catchment-wide influences on stream water chemistry and to conceive catchment understanding at the mesoscale.

2.3.2 Land use change mapping

Decision-makers need to consider temporal and spatial land use. Ground change mapping has evolved from a community level to a universal level (Giri, 2012). Development in airborne and interstellar based radars for GIS and remote sensing techniques which can combine data from several sources and time periods has changed how land usage is mapped compared to earlier mapping techniques.

Synoptic views of the landscape are now possible at all scales, from the national to the international. Satellites equipped with remote sensing equipment have the capacity to record electromagnetic radiation well beyond the visible spectrum. Because the earth's surface reflects light differently, the electromagnetic spectrum may be divided into several spectral bands, which is essential for demonstrating the earth's surface's variability (Lillesand *et al*, 2004)

In comparison to ground-based observation, remote sensing can provide far more extensive observation. Multispectral scanner, RADAR, and LiDAR sensors installed on a robust airborne or spaceborne platform allow remote sensors to cover a wider area. Photographs, satellite pictures, RADAR, and LiDAR datasets are produced as a result. Roy P.S and Roy Arijit (2010) mentioned high resolution, regional, and low-resolution datasets can all be obtained by remote sensing.

Mapping modifications in built up cover requires the capacity to distinguish amongst distinct ground changes. Remote sensing data sets are utlized to build maps showing changes in ground cover that reflect variability on the exterior of the earth. The spatial dynamics and temporal kinetics of land cover change might be visible. It is possible to reflect on different land cover at various times to spot transformation, that may subsequently be investigated to learn the extent, nature, and position of such modifications and the powers behind them (Harold *et al.*, 2003).

A computerized system with the ability to capture and work with geographic data is referred to as a GIS. Organize, handle, examine, adjust, obtain, and present the results of the query or the processed data (Musa and Odera, 2014). The Global Positioning System and GIS are used to monitor modifications in ground cover. GIS offers a user-friendly environment for analyzing data from remote sensors. By using remote sensing, GIS is guaranteed to have current ecological numbers (Ashbindu *et al.*, 2001).

The tools of GIS and remote sensing combined allow for the analysis of both spatial and temporal phenomena as well as the monitoring of changes. Making decisions is made easier because of the representation of various geographic data in various GIS forms.

The hydrological regimes of urban and peri-urban streams are typically altered as a result of urban growth. In most cases, the change is brought on by a rise in the total impermeable surface, which causes higher surface runoff and decreased percolation. which will cause a rise in flooding incidents and a fall in base flows. Urbanization ultimately raised water demand, which in turn increased water abstraction and waste-water introduction into waterways.

Other studies (Gitau *2016*, Wambugu *2018*) have also shown how the growth of urban areas has altered regional climate. This is mostly occurring as a result of the growth of heat islands, which can influence the water cycle by, for instance, altering the features of rainfall, such as its intensity, which then affects stream flow.

A number of aspects need to be considered in order to determine how mega projects would affect the hydrological characteristics of urban streams and peri-urban streams because the change could be caused by a variety of different factors. It's crucial to ascertain the following.

- The degree of urbanization
- A change in the river regime
- A shift in the frequency of catastrophic floods and droughts

2.3.3 Hydrologic Modelling

Even while catchment scale research and watershed management have grown in importance in defining effects of social doings on the acceptable condition of the water inside and outside of the catchment as well as in the collecting rivers, many uncertainties remain. For instance, if all other parameters remain constant, there is ongoing debate over whether the riparian zone's land use or that of the overall watershed is of a greater effect on the river condition (Osborne and Wiley, 1988).

These uncertainties persist in part because different catchments have distinct combinations of variables that affect water quality, and in part because in-depth watershed-scale investigations are time- and resource-intensive and thus scarce (Geoffrey Mwangi, 2018).

Impacts of LULC variations on hydrological processes have been studied using a variety of techniques, including the matching catchments technique, trends investigation (a numerical technique), and hydrometric simulation (Li et al., 2009). Hydrological modeling is one of these strategies that has seen widespread use around the globe because it uses fewer resources and offers more flexibility for simulating and comparing watershed processes in real-world versus ideal circumstances (Li et al., 2009). To avoid the complex interactions of multiple factors, Fohrer et al. (2001) analysed the simulation’s working for varying LULC in a mock water-catchment with one produce at a time and one inherent soil kind. They assessed the aqueous reaction to Land use land cover changes in four catchments in Germany with varied land use land cover division.

Between 1960 and 1990, watershed models were created. These include the Hydrologic Simulation Program in Fortran (HSPF), created in the 1960s (Bicknell et al., 1993), the Topography-based Hydrological MODEL (TOPMODEL), created in 1974, and the Soil and Water Assessment Tool SWAT, developed in 1967 at the Hydrologic Engineering Center in Davis, California (USACE 1981). (Arnold et al., 1998). Improvements in data management and use through the integration of graphical user interfaces (GUIs) with geographic information systems (GIS) and the use of remotely sensed data preceded the publication of these models (Edsel et al., 2010). (Borah and Bera, 2004).

The use of GUIs allows for visualization of watershed processes, while GIS enables acquisition, storage, retrieval, analysis and manipulation of hydrological information in a spatial setup. The change in water-catchment simulation has been prompted by improvements in GIS and remote sensing practices (Edsel *et al.,* 2010). These include remote sensing methods that collect geographic data on soil type and land use at predictable grid intervals with repeating coverage, such as radar and satellite imaging. Hydrologists now have more possibilities thanks to GIS technology, including faster processing of massive databases describing variability in land surface properties and better model results visualization (Jain et al., 2004).

Early GIS software packages were standalone applications with restricted capability, primitive client interaction with software, and slow speeds. The motivation came about from rather rigid computer technology that were difficult to alter and had little flexibility (Edsel et al., 2010). The development of hydrological modeling in the GIS platform has been facilitated by advancements in GIS software in conjunction with the accessibility of better hardware. Additionally, customers have a large selection of models to pick from thanks to the availability of both paid and free software resources. However, the models' complex technical requirements for operation limit the range of users who can apply them to hydrological processes in an efficient manner.

2.3.4 Hydrological Characterization through the threshold method and Flow Duration Curves

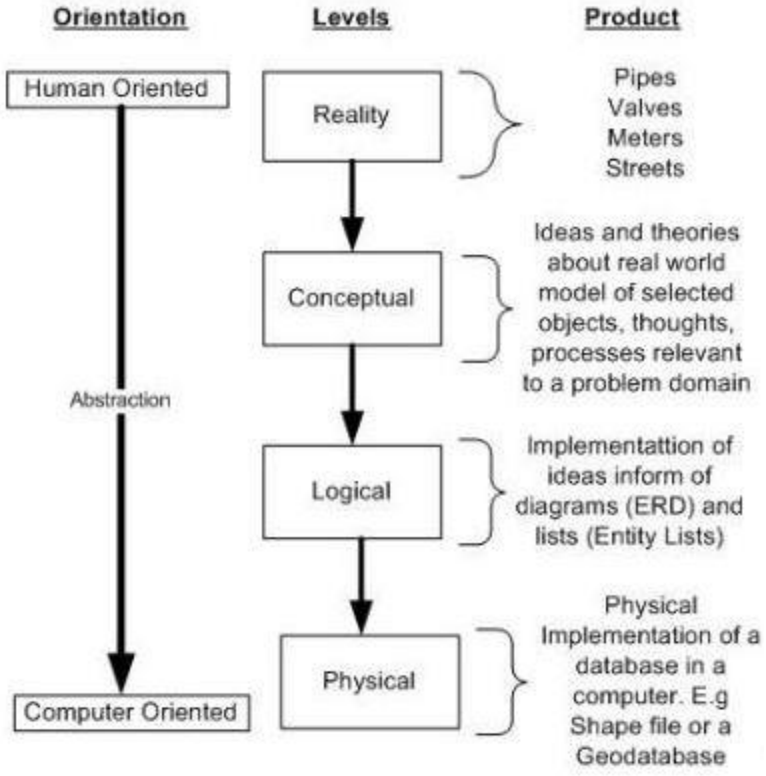
An approach that allows comparison across all hydrological levels is the threshold level method. This benefit is employed particularly in research on the spread of drought and flooding. For this strategy, there are several computation processes and instruments. The Flow Duration Curve is the best method for determining streamflow thresholds (FDC). FDC, which is an increasing incidence arch which shows the percentages specified discharges were matched or surpassed at a particular time, reflects a natural behavior of streamflow categories. The use of this aspect is well contemplated in many publications. (IEK publication Vol iii, Sri Lanka, 2020). There are applications related to waterpower engineering, water supply, locating of industrial plants, pollution studies, climate change impacts and human activities etc., that have utilized flow thresholds linked to flow duration curves.

Flow duration curves which can either be a plot of streamflow versus the time of exceedance or streamflow versus the exceedance probability, portrait the characteristics of a watershed with respect to its streamflow. Research documenting the advantages of FDC opt to use the exceedance probability plots. (Wijesekara *et al*, 2012). FDCs also differ with the temporal resolution of data. Use of daily and monthly data is quite common. Even though monthly or annual FDC are valuable for water resources evaluations, they do not permit evaluation of flow variability in streams because there are significant differences in the behavior of daily and monthly FDC types. Therefore, the selection of temporal resolution depends on the desired objective of an application. FDC used for hydrological evaluations also vary with the selected data duration. A “Period of Record” or “Steady State” FDC represents the likelihood of streamflow over a long planning horizon, annual FDC reflects the inter-annual flow variations, while the “Median Annual FDC

(MA FDC)" is minimally affected by the abnormally wet or dry periods. Accordingly, the Period of Record (PoR) FDC which has a higher potential to capture the long-term streamflow responses, together with the probability of exceedance option, were utilized in the present work for the evaluations at monthly and daily temporal resolutions.

2.4 Data Sets

A data modeling procedure like the one shown in Figure 2.1 will result in a GIS database. Since data is the engine that powers GIS, its performance will suffer if there is a lack of data or if data with impurities is present. Without data, none of the other elements would exist. The catalog unit register, their unit interaction illustration catalog, and a tangible catalog in a computer are the major outcomes of this process.



2.5Technology and Landsat Images

2.5.1 Hardware and Software

The two primary components of GIS technology are software and hardware. Hardware for this project will include Windows-based computers and the Trible Juno GPS. However, to map database objects with accompanying images, custom GIS software is typically used for database management and the creation of map layouts (model maps).

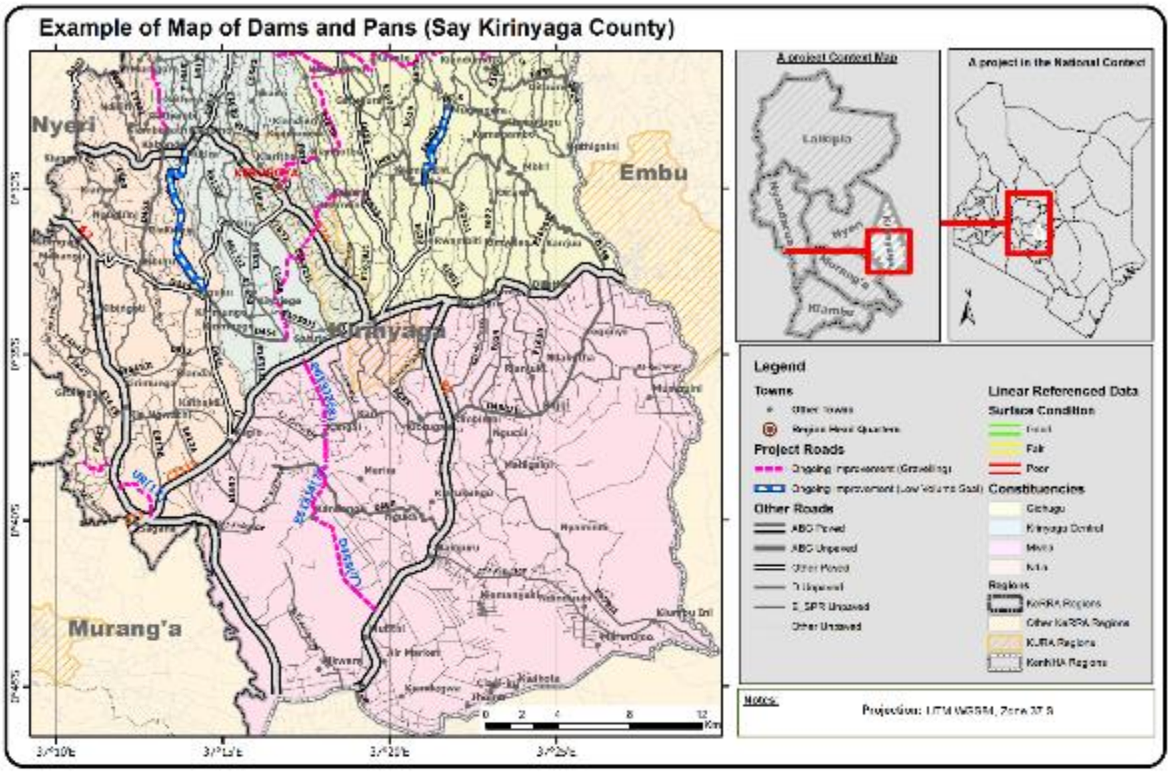


Figure 2.1: Model Maps

2.5.2 Landsat Images

Landsat is the lengthiest successively, frequently obtained group of reasonable-resolution land remote sensing data. Forty years of pictures offer a special database for people working in the sectors of geology, engineering, academia, map development, forestry, planning, infrastructure development, and agriculture. They are also crucial for crisis response and triage assistance.

The Landsat Project, a collaborative project of National space agency and the United States geological survey, provides information to the military, civilian, commercial, industrial, and educational sectors in the United States and around the world.

With the launch of Landsat 1 in July 1972, the Landsat program has continued through Landsat 8. The main dataset for the detection of urban expansion will be made up of Landsat pictures.

2.6 GIS and its application in Studying of River Flow Patterns: Case Studies

It was demonstrated by Wine M. (2012) in his PhD publication, Water-limited Landscapes Undergoing Transformative LULC Change, where historical as well as real-time streamflow data may be accessed online. Levels through river positions and instrument or gauging stations are included in a GIS. Additionally, wireless and telemetry data can be connected in a Global information system. The Meteorological department has data configured to communicate scale height and quantities of flow in cubic meters/hour, both historical and current. Real-time data can be accessed directly from a GIS over the Internet. The two government authorities namely WRA and NEMA are other data sources for flood information and water quality. These data may all be analyzed using GIS, giving a geographic representation to information that would otherwise be in a table-like format.

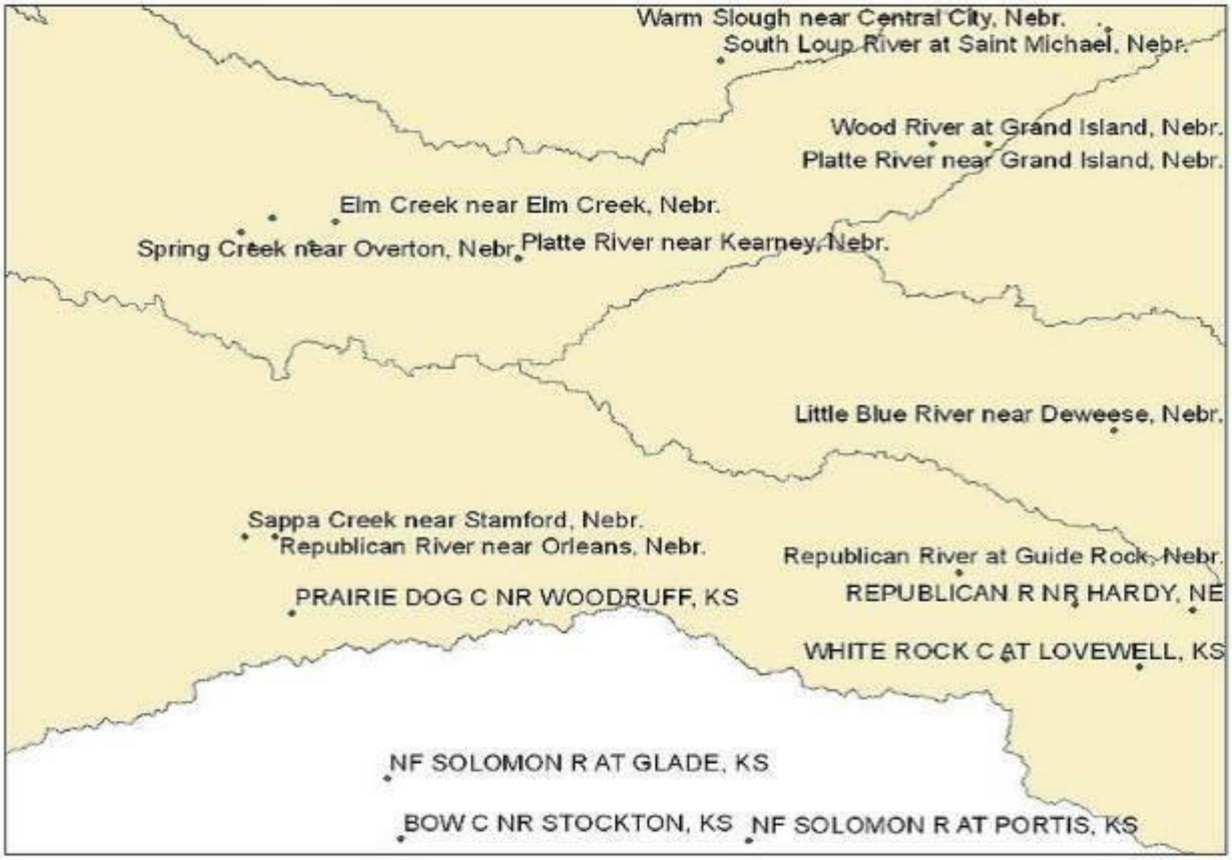


Figure 2.2: United States Geological service measured positions using GIS

Locally, most studies employing GIS and remote sensing platforms have concentrated on how land use practices affect hydrological processes. One of the model's first uses in Kenya was in research by Jayakrishnan. *et al*. (2005), where a simulation towards investigating the effects of land transformation related to cattle rearing on stream flow and residue movement in the basin of river sondu, having a drainage area of approximately 3100kms^2 in the Nyanza region. The periodic modelled quantities of present built up indices measured up favorably to the detected figure, according to the study. The research highlighted the necessity for stronger simulated entered figures sets to be generated as these are necessary for comprehensive evaluations of hydraulic features because this performance was linked to insufficient input information (Nash *et al.,* 1970).

Githui *et al*. (2009) employed soil and water assessment tool in western Kenya, to study effects on origin flow and river flow in present built-up transformation patterns, such as the conversion of forests to peasant crop production, and reforestation. The results indicated a high risk of flooding would rise if present ground transformation tendencies persisted. The outcome of the research showed a substantial association linking the hydrological course of Nzoia River basin and the effects of changing land use, particularly growing agricultural land use. SWAT simulations revealed an increase in runoff of around 119 percent between 1970 and 1985 in the Nzoia watershed, which was linked to a rise in use of land for crop production and a deforestation from 1973 to 2001. (Githui *et al.,* 2009).

In a separate research, Mango et al. (2011) showed it is feasible to tackle water sources issues through modeling techniques in data-scarce regions like Kenya. They did this by using GIS in conjunction with landsat centered projected precipitation to aid hydrological assets conservation attempts in the basin of river mara (Mango et al., 2002). Although the study stressed that managing sustainable water resources can be a difficult task in areas with little access to data, it also showed that GIS modelling can produce reliable results that can be used to investigate the effects of terrestrial utilization and guide water catchment improvements. The research, though, issued a warning saying these simulations could be hampered by unknowns, also with processes that the simulator was unaware of, processes that the model did not account for, and processes that the modeler had simplified (Abbaspour et al., 2007). According to the study, any additional forest conversion would exacerbate peak flows and lower dry-season flows in the watershed, escalating existing substantial issues with water shortage in parched seasons and mountain attrition during rainy periods.

In order to determine the geographical and transient nature of the size and course of terrestrial utilization in Njoro River water catchment, Baker and Miller employed GIS modeling. It showed in what way variations in land utilization in the River Njoro Watershed changed the amount of surface overflow in the highlands while reducing subterranean revitalization. As shown by the research, increased erosion and sedimentation brought on by flashier floods and higher streamflow were to blame for the destruction of the Mau Forest. This study brought attention to the need of a healthy watershed since upstream circumstances directly affect downstream ecology (for instance, the Njoro river drains into Lake Nakuru, a significant park in Kenya and a recognized site for various species with a variety of bird and mammal populations). The study discovered a possible rise in water resource conflict, particularly between pastoral and agricultural groups inside of the water catchment. (Baker and Miller., 2013).

Concerning the Nzoia watershed in Kenya, Odira et al. (2010) utilized the SWAT model to simulate streamflow fluctuations caused by variations in land utilization and overlay and reported higher release in the course of the rainy periods and a fall during arid times.

D Melesse (2012) used a GIS program to simulate extended period precipitation and overflow in the River Basin of Mara near the Tanzanian-Kenyan boundary. The Mara River Basin faces numerous water catchment point concerns, that comprises of overgrazing, cultivation, desertification, urban settlement, erosion and sedimentation, like the majority of watersheds in Kenya. In order to comprehend how normal practices and people actions interact within, this study used the SWAT model. The study showed when there is a lack of data on rainfall, alternate bases of information can be obtained by means of GIS, and can be used to run simulations and provide good findings, despite limitations in the amount of observed data. Prior investigation within the aforementioned basin used soil and water assessment tool on two branches of river Mara and indicated that simulation done using projected data actually achieved more favourable results when compared to data sourced from the meteorological department and WRA. Use of alternate data sources like RFEs is further justified by the authors' suggestion saying accuracy of the meteorological and WRA data might have influenced the results that were obtained. (Le and Pricope, 2017).

In the US, groundwater supplies provide about one-fourth of the water used for irrigation, business/industrial purposes, and personal use. The need for groundwater is projected to rise as surface water resources are subjected to greater pressures. This resource has already been heavily used and even improperly managed in certain places. Here, the over abstraction of underground water in Nebraska decreased the amount of runoff obtainable for downstream movement and use in Kansas, leading to that state's filing of a lawsuit against Nebraska. Another illustration is the decline in quantity of rivers in the River watercatchment of Kansas and Nebraska. Under ground water may as well be represented in a Geographic information system and examined by researchers, despite not being as obvious as surface water flow.

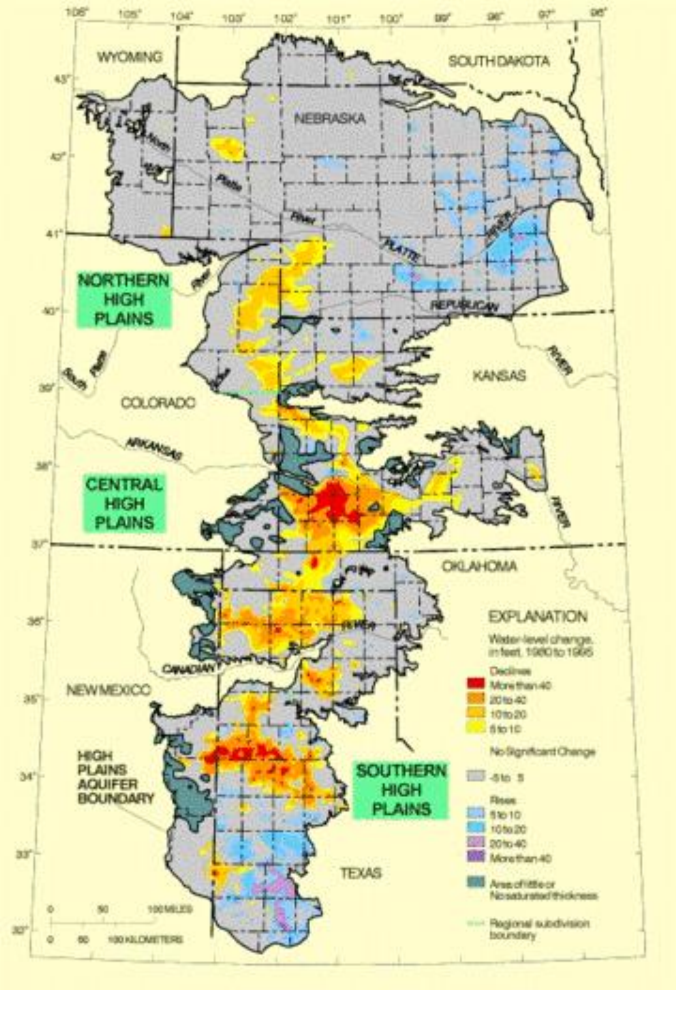


Figure 2.3: Underground water quantity variation of the highland aquifa

One could argue that illustrating groundwater is a more difficult undertaking than illustrating surface water. The hydrologic cycle places a premium on understanding about location on replenishing of groundwater by surface water and vice versa, so the two resources are by no means unrelated. GIS is particularly well adapted to hydrogeology. Groundwater flows in three dimensions and travels more gradual when compared to water movement at ground level, at a slower than 100 centimeters daily to probably point one of a kilometer daily. Surface water, on the other hand, moves much more quickly and is more two-dimensional.

2.7 Economic activities within the Study area

The majority of the county's residents rely on this subsector for their livelihoods, with agriculture serving as the area's primary economic activity in the areas of tea, coffee, dairy, poultry, and horticulture cultivation. Mining activities include the extraction of building stones, ballast, hardcore, gravel, murram, and natural gas by Carbacid Company Limited in Lari and Gatundu constituencies.

The main industrial centers of the study areas are located in Juja and Ruiru constituencies. Brookside dairies, Chandaria industries, Cooper K brands, Davis & Shirtliff, Stecol, TWIGA foods, FFK, Cooper K brands, KWAL, Cold solutions, Tianlong, Africa logistics properties, Kim Fay, Dormans, Clay works, are some of the companies.

Some of the tourist attractions within the study region include; Fourteen falls, Kereita forest, Chania falls, Kilimambogo, Paradise lost, Evergreen park, and other sites and locations within the greater Kiambu area

With its dense forest, Kinare Forest offers opportunities for wildlife tourism. The forest is home to many different bird species including weavers, guinea fowl and sparrows, as well as wild animals such as monkeys and elephants.

3.1Description of Study Area

3.1.1 Geographical location

The Ruiru and Kamiti basins are in Kiambu County, in the former Central Province of Kenya. The area of study was chosen on the basis of identified mega projects occasioned by the proximity to Kenya's capital, Nairobi, which makes it experience rapid land use changes and pressure on available surface water resources.

There are 671,646 people living in the 484.515 km^2 watershed of the River Ruiru. It is located between latitude 1°20'S and 0°.50'S, longitude 36°40'E and 37°00'E. Ruiru river that separates Lari and Githunguri sub-counties flows from the Kikuyu escarpment. Administratively, the Ruiru River watershed is located entirely in Kiambu County, passing through the sub-counties of Ruiru, Githunguri, and Lari. (Figure 3.1)

The river Kamiti drains the lower sides of the project area with a distance of 32.6 km as well as a drainage basin of around 283 km2. It springs in the Kikuyu escarpment forest near Githiga. The Kamiti River's principal tributaries include the Riara, Kiu, Kianjibbe, Kibereti, Mutropi, and Chigeroti streams. The Nairobi River is where it empties. More eucalyptus may be found in the catchment's riparian zone, where vegetation covers roughly 60% of the area.

The catchment location of Ruiru-Kamiti watershed is shown in **Figure 3.1** below;

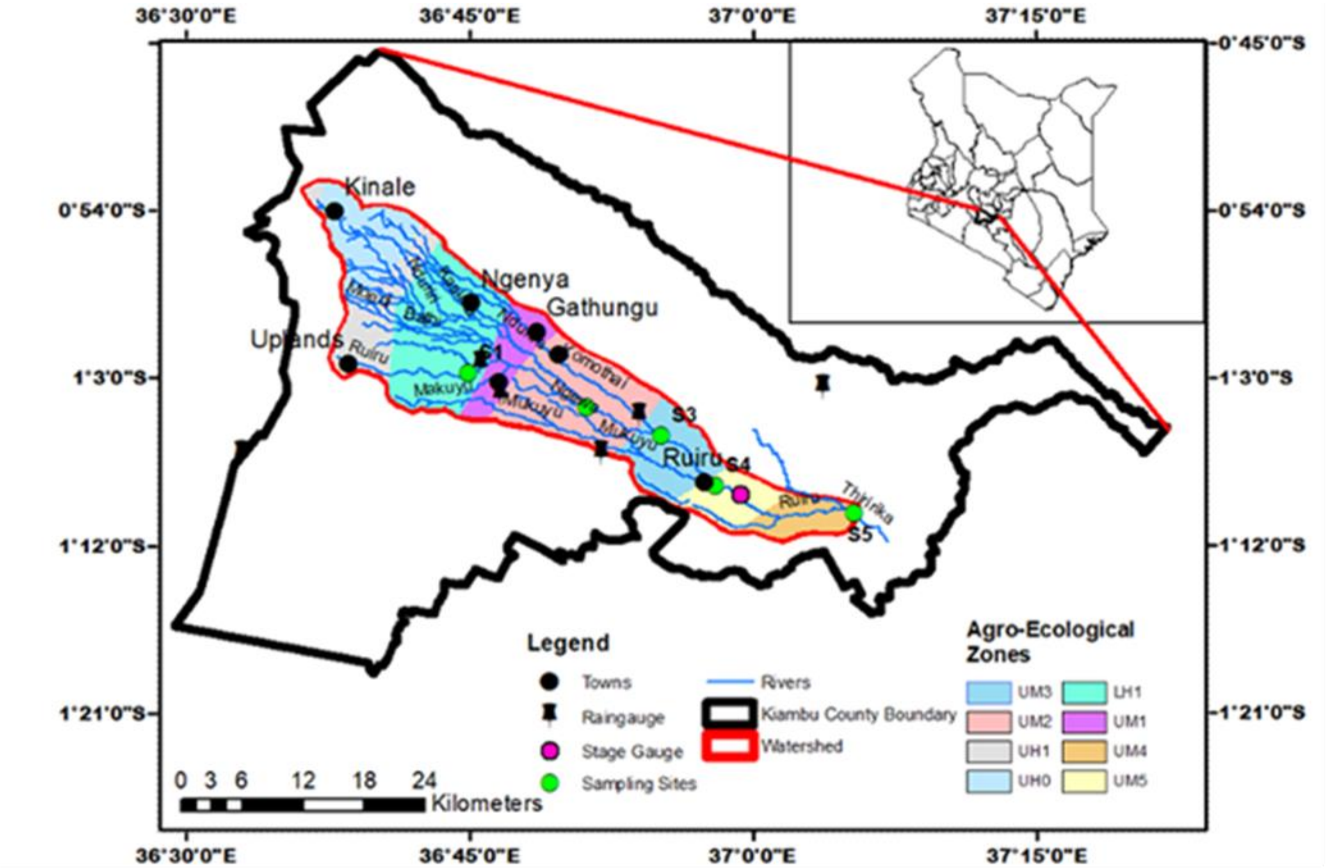


Figure 3.1: Ruiru-Kamiti Watershed

Four catchment regions, as shown in Figure 3.2, were chosen in lieu of the study area in accordance with the availability of hydrological information from WRA. River gauging stations linked to the catchment region have data up to the year 2010 from the official WRA water database in Nairobi. From past experience, the majority of RGS with data up to 2010 are probably currently being actively observed.

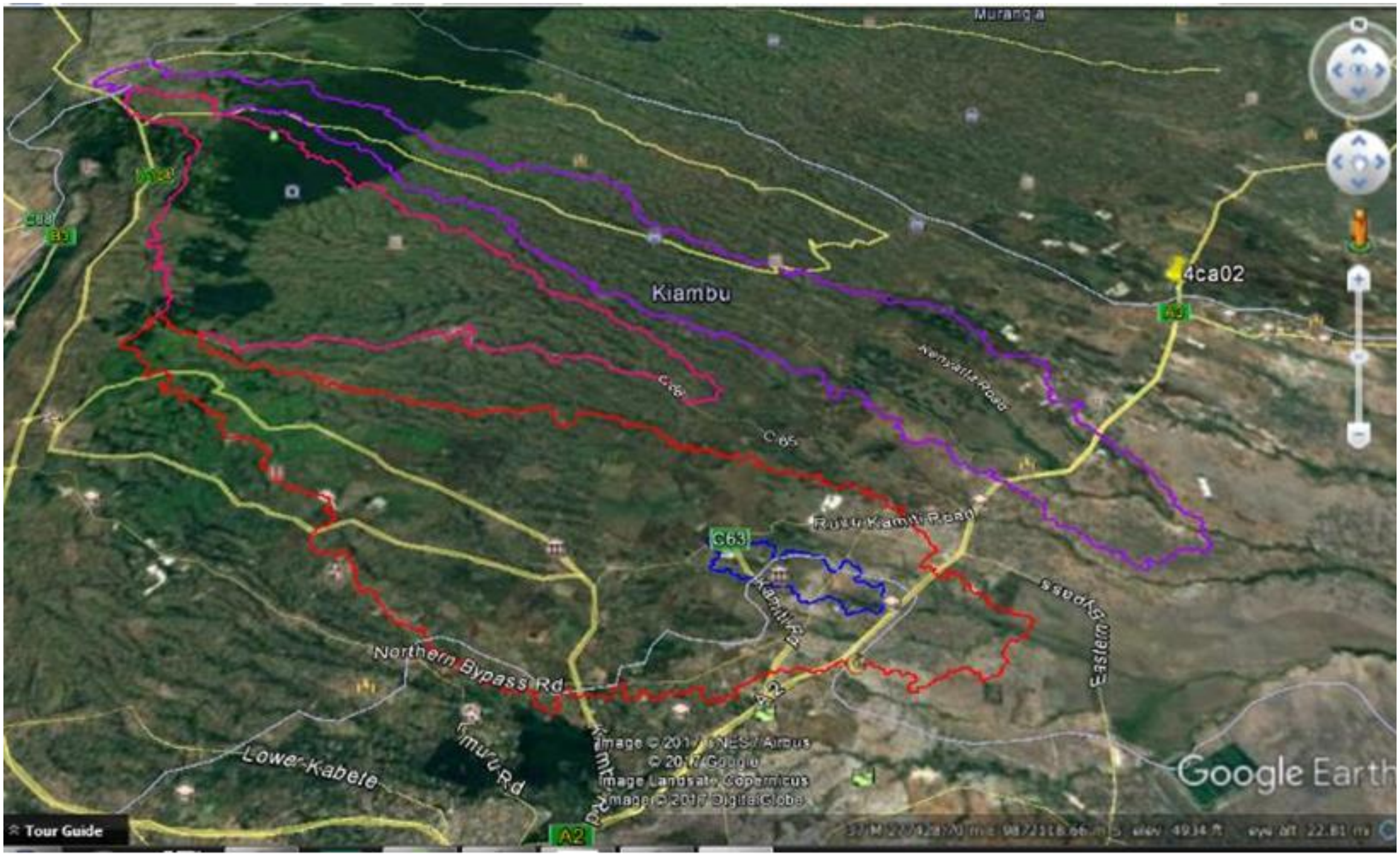


Figure 3.2: The study area comprising of four catchment areas

The catchment area was further defined by RGS 3BB12 on River Kamiti. Based on the SRTM void filled Digital Elevation Model, the catchment region was defined using the RGS as the catchment outlet (DEM.

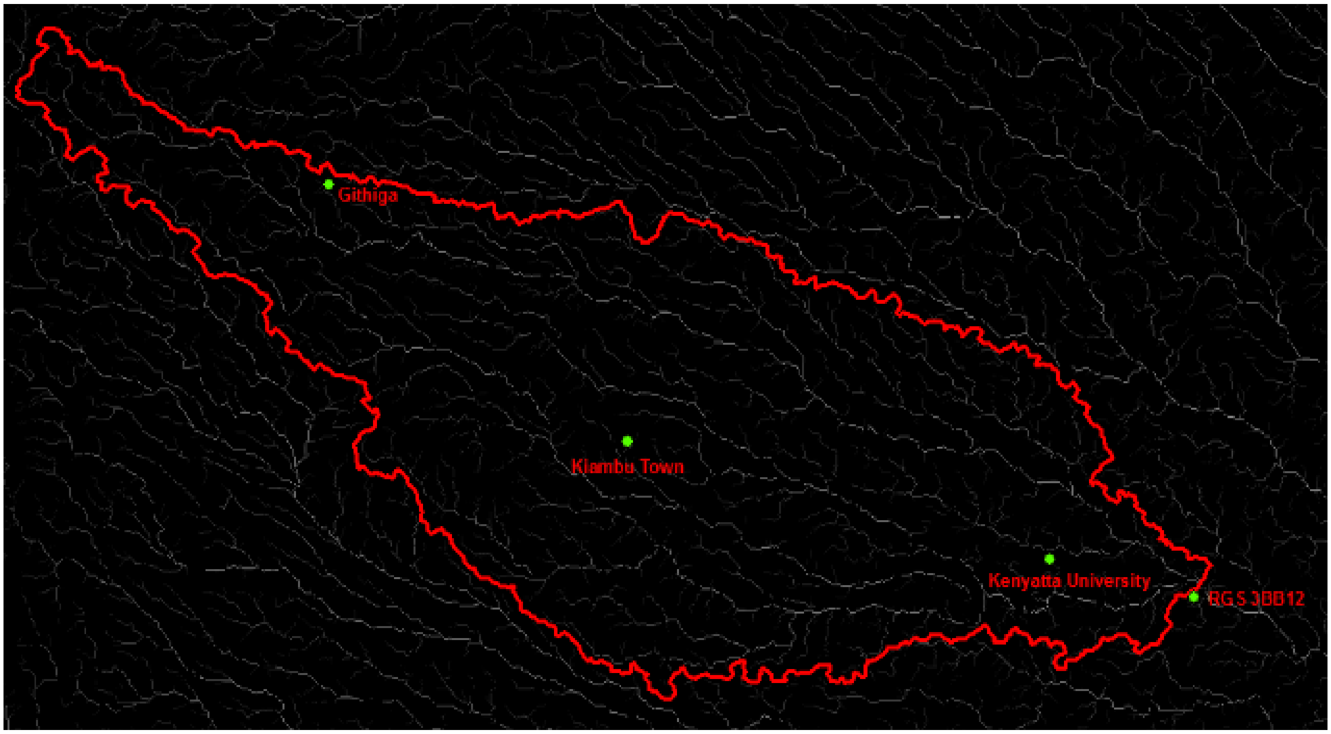


Figure 3.3: Study Catchment area as delineated by RGS 3BB12 on river Kamiti/Ruiru Confluence

3.1.2 Geology and Soils

Most of the rocks in the research region are volcanic and range in age. They vary from Pleistocene to Miocene volcanics, primarily in the ranges of the Aberdare, to the southwest of Ruiru town. The Aberdare ranges, which are predominately composed of intermediate and basic lavas, are where the Sattima series is found. The middle trachytes, which are made up of the Kabete, Karura, Tigoni, and Ruiru Dam trachytes, are grouped with the upper trachytes, which contain the Kinari tuffs and Limuru trachytes. The Kinari tuffs and Limuru trachytes are part of the upper trachyte division. The Karura, Tigoni, Kabete, and Ruiru Dam trachytes make up the Middle trachytes. Simbara basalts make up the study area's central and southern regions. Tertiary volcanics, primarily trachytic tuffs and agglomerates on the plateau surface, make up the majority of the Kamiti and Kahawa. The main valleys expose the Simbara basalts and agglomerates as well as the Kapiti phonolites.

To the northwest of the study area, the landscape rises into the Aberdare Mountains. This mountainous region's geomorphology is characterized by lengthy slopes that descend into small valleys with sporadic crags and rocky hills. The mountainous environment changes in the direction of Kinale to low interfluves and flat-bottomed valleys beginning from the top of the Rift Valley Escarpment to the foot slopes of the Aberdare Ranges. Further northeast of Ruiru town towards Kikuyu, the topography shifts to extensive, tapered hills that are roughly parallel to one another and are divided by small, meandering valleys of varied widths and nearby streams. A large incline with wide, extensive corrugations, mild falls, and intermittently twisting, sharp-sided, level-bottomed gorges characterizes the scenery to the North of Ruiru town. The area to the south- east of the study area is characterized by low plains with occasional low hills rising from the landscape. The geology and geomorphology of the study area has an influence on LULC characteristics, with the upper, higher elevation areas characterized by areas under montane forest, tea plantations and pineapple farms. The mid elevations are characterized by small-scale coffee growing, maize, beans, cabbages, potatoes among others. The lower elevations are mainly grassland previously occupied by coffee and sisal plantations in some areas.

The study area's soil distribution is highly correlated to its geomorphology, with Ironstone soils, Lithosols, and Vertisols predominating in the lower portions of the plains (Sombroek *et al.,* 1980). The toe slopes of the volcanic foot ridges are consisted of Eutric Nitisols and Nito-chromic Cambisols, while the upper ridge crests mainly consist of deep, well-drained, heavily weathered, brownish crumbly clayey soils characterize the environment (Shitakha, 1983). The soils have an acidic pH range of 5.1 to 6.6 in the B-horizons and 6.0 to 6.6 in the topsoil. The topsoil's cationic exchange capacity ranges from 9.0 to 34 cmol/kg, while the B-horizons' ranges from 10 to 28 cmol/kg.

Most of the loams in the project region are dominated by Nitisols, which are usually soils with an argic B-horizon, with clay dissemination, and does not display a comparative reduction from its extreme in excess than 20% within 150 cm of the soil top (FAO, 1977)

The soils in the landscape influence the land use types that develop in different areas, which in turn influence the erodibility of the soil, the infiltration capacity and ultimately the hydrology of the landscape. Areas under forest cover are expected to have lower erosion rates compared to areas under agriculture and urban/settlement land use.

3.1.3 Topography

Both the greater and lower highlands and midland zones are the four primary topographical regions of the study area and Kiambu County in general. The Aberdare ranges extend into the Upper Highland Zone, that's situated to the north-west of the terrain. This area is located between 1800 and 2550 meters a.s.l. The region is primarily located in the Lari division and is characterized by steep, heavily dissected hills. Limuru, as well as portions of Kiambaa, Kikuyu, Githunguri, Gatundu, Kabete, Limuru, and Lari situated on the lower highland zone. There are hills, plateaus, and high-elevation plains in this region, which is located between 1500 and 1800 meters above sea level. With some horticultural, maize, and sheep farming also being performed, the region is mostly a tea and dairy zone. Between 1300 and 1500 meters above sea level, the upper midland zone encompasses the majority of Juja. It consists of igneous mid-point moorlands, while the bottom moorland area partially encompasses Limuru, Kikuyu, and Thika Town (Gatuanyaga) (Jaetzold and Schmidt, 1983).

3.1.4 Climate and Hydrology

With altitude being the main determinant of rainfall, the average yearly precipitation varies from approximately 600 mm round around Thika to 2000 mm in upper regions. A bimodal rainfall system includes long showers that occur in April and May. A chill dry period between June to August then follows, and from October through December there are only sporadic showers. The average extreme temperatures vary from approximately 25°C to 29°C in the easterly and southerly parts and approximately 17°C to 21°C in the mid northerly-westerly parts, while the average lowest temperatures range from approximately 7° to 15°C in the northern and eastern areas respectively. The coolest months are July and August, while January through April are the warmest. In the dry months, the mean comparative humidity is approximately 55% while in the rainy periods the humidity is approximately 250%.

The agro-ecological zones are determined by the climate, soils, and rainfall (Jaetzold and Schmidt, 1983). These have the relevant codes UM1, LH1, UH1, and UH2. The Upper Humid Zone is referred to as UH, and the Lower Humid Zone as LH. The Upper Moist Zone is UM, and the Lower Moist Zone is LM. Moist Zones are less wet than humid Zones. The various LULC systems, for instance forested areas, grasslands, & agricultural, are determined by the agroecological zones (tea, coffee and subsistence crops). The moist zones are less moist than the humid zones.

Livestock, sorghum (Sorghum vulgare), sunflowers (Helianthus annuus), and corn (Zea mays) are characteristics of the drier southeastern regions. The research area's major portions are located in the main and marginal coffee zones, respectively.

The hydrology of the study area consists of both on ground and under-ground water, that consists of approximately 85% of the aquatic assets. Kiambu County has four sub-basins. These are: Kamiti and Ruiru Rivers sub-basin containing the Riara, Kiu, Kamiti, Makuyu, Ruiru, Bathi, Gatamaiyu and Komothai rivers; Nairobi River sub-basin, which occupies the southern part of the county, with the main rivers being the Nairobi, Gitaru, Gitahuru, Karura, Ruirwaka, and Gatharaini; the river Chania and its tributaries, consisting of the rivers Thika and Kariminu, which rise from the slopes of Mount Kinangop in the Aberdares chain; the Ewaso Kedong sub-basin, which runs in a north-south direction and occupies the western part of the county with many different streams forming swamps;The Aberdare Plateau, which supports the sub-basins of the Thiririka and Ndarugu rivers, mainly has the Mugutha, Theta, Thiririka, Ruabora, Ndarugu and Komu streams flowing from the Nairobi, Kamiti, Ruiru, Thiririka and Ndarugu sub-basins around the sub-basin of the river Athi.

The land use and land cover systems in Kiambu County are expected to lead to effects on the hydrological conditions of both surface and sub-surface streams. The bio-chemical water condition of the rivers, including Ruiru and Ndarugu, could be altered by changing land use patterns.

3.1.5 Population

Kiambu County population was estimated at 2,417,735 out of which 1,187,146 were male, 1,230,454 females, and 135 intersex. Ruiru Sub- County urban population was estimated at 371,111 out of which 180,947 were male and 190,144 Female (KNBS vol.1, 2019)

3.2 Data Sources, Tools, and Methods

Remotely sensed satellite image acquisition was done to realize the objectives of this investigation. To identify changes in LULC, pictures of an identical region were collected at various periods and matched while taking into account temporal phenomena including vegetation, farmland, built-up areas, and waterbodies.

3.2.1 Data Sources and Tools

3.2.1.1 Landsat Satellite images

Imagery from the Landsat program were obtained since they had favorable spatial and radiometric clarity, but only a moderate geographical resolution (Lillesand et al., 2004). Five multispectral photos were obtained from the United States geological survey website for 1987, 2000, 2005, 2010, and 2018. Built-up areas were mapped and processed utilizing automation and the Normalized Difference Built-up Index (NDBI). It capitalizes on the distinct spectral response of urban regions and different land covers. Numerical operation manipulation of re-encrypted Normalized Difference Vegetation Index (NDVI) and NDBI imagery produced out of Thematic mapper imagery effectively maps constructed regions. GRASS GIS and ILWIS softwares were utilized to process Landsat pictures and create all of the necessary mapping.

3.2.1.2 Google earth images

Google Earth images had been available in high quality for some years and were thus utilized to validate the urban expansion indicated by Landsat image processing.

3.2.1.3 River flow data

The WRA provided discharge data for each watershed exit point, which was utilized to characterize the catchment hydrology.

3.2.1.4 River abstraction records

WRA maintains a registry of water licenses, which was utilized to assess if there was a significant change in volume/quantities of water abstracted from the rivers from persons/companies authorized to do so.

3.2.1.5 Water production data

Water service provider data was utilized to quantify variations in water consumption over time.

3.2.1.6 Rainfall data

Amounts of precipitation were acquired out of two primary sources namely Kenya Meteorological department and Tropical Rainfall Measuring Mission (TRMM), which estimates rainfall at 1000 x 1000 m grid resolution. It was used to monitor changes in rainfall patterns.

3.2.2 Methods

3.2.2.1 Normalized Difference Built-up Index (NDBI)

During this study, a new approach in regard to the Normalized Difference Built-up Index (NDBI) was used to computerize the development of mapping constructed regions. It employs differential imagery reaction of constructed areas and different ground covers. Numerical operation manipulation of re-encrypted Normalized Difference Vegetation Index (NDVI) and NDBI imagery produced out of Thematic mapper imagery effectively maps constructed regions.

$$NDBI = \frac{(TM5 - TM4)}{(TM5 + TM4)}$$

3.2.2.2 Hydrological Characterization

Drought and flood events were detected using the threshold method, with the flow duration curve as the most appropriate tool for the determination of streamflow thresholds. The threshold method is a method that allows for comparison between hydrological levels (Heudorfer B. et al., 2017). The base flow index was used to quantify base flows, which were then supported by changes in water abstraction.

3.2.2.3 Change Detection

The change in constructed area was assessed and associated with changes in hydrological features. Changes in rainfall parameters were assessed and associated with changes in accumulation areas.

3.2.2.4 Integrated Land and Water Information System (ILWIS)

The Integrated Land and Water Information System (ILWIS) was used as GIS as well as a remote sensing computer application, combining imagery, thematic and vector data into a single, comprehensive desktop application. ILWIS offered a vast array of functions, inter alia data export/import, digitization, refinishing, testing and presentation, and high-quality map creation. Known for its functionality, ease of use and cost effective, ILWIS software has built a large user base through time. It is popular with researchers in hydrology and GIS applications.

3.2.2.5 Geographic Resources Analysis Support System (GRASS) GIS

GRASSGIS was used to process Landsat imagery & produce all the necessary mapping. GRASS GIS is an unrestricted, software libre GIS package aimed at geographic information handling and investigation, imagery handling, illustrations and map development, spatial modeling, and visualization. GRASS GIS is utilized in academia and business environment worldwide, together with numerous institutions and organizations.

3.3Information Extraction from the Images

3.3.1 Image Classification

Image classification is a method for spontaneously classifying an imagery in a terrain towards different ground cover groups. The method comprises searching all bytes in a picture and classifying them into a handful of different classes as per their Digital number values. Categorization is a regular approach employed in remote sensing aspect removal. It includes classifying layers from similar characteristics, which helps distinguish between different aspects in an imagery. Numerical categorization attempts by classifying specific image digital information on the basis of spectral data.

The Multivariate toolbox comprises of both supervised and unsupervised classification capabilities through the ArcGIS Spatial Analyst allowance. The imagery categorization toolbar makes it easy to create training samples and signature files for supervised classification. The basic classification method is the maximum likelihood classification tool. This utility requires a signature file that identifies the classes and their associated statistics. The signature file for the supervised classification is created using training samples from the Image Classification toolbar. The signature file for unsupervised classification is generated by running a clustering tool. Spatial Analyst includes additional post-categorization manipulation capabilities, including screening and borderline purging.

Figure 3.4 shows a detailed processes of the image classification workflow.

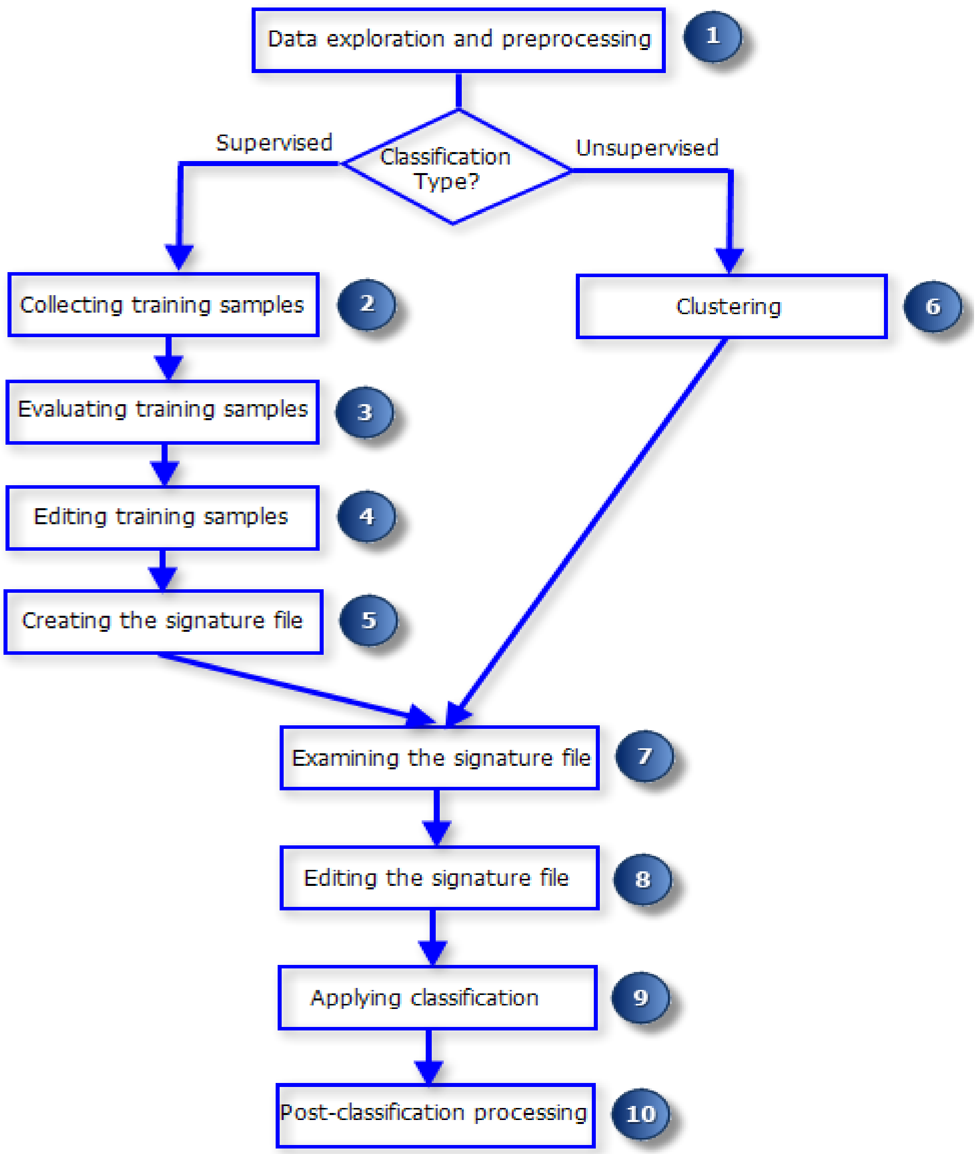
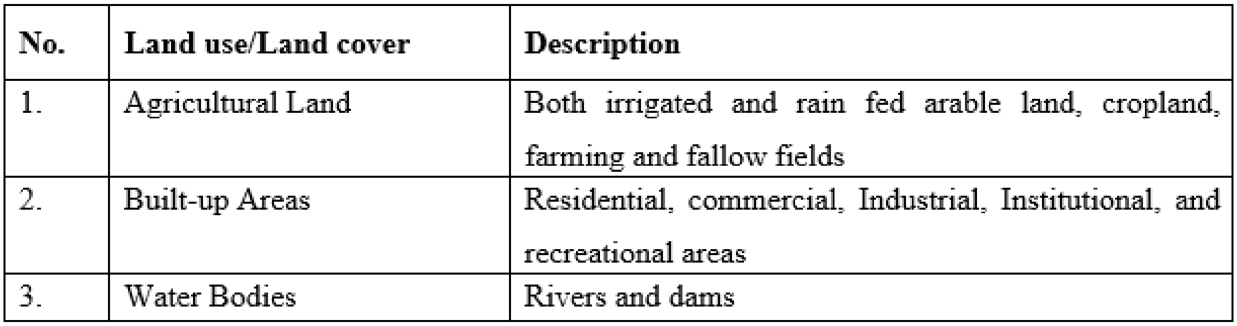


Figure 3.4: Image classification workflow

To classify images in this study, the supervised classification technique was applied. Supervised categorization necessitated the establishment of preparation locations that served as a benchmark for categorization. The categorization divided the pixels in the info sets towards groups that agreed on the preparation locations.

This study discovered and defined three LULC classes for classification purposes, as shown in Table 3.1.

Table 3.1: Land use and Land cover image classification



No.	Land use/Land cover	Description
1.	Agricultural Land	Both irrigated and rain fed arable land, cropland, farming and fallow fields
2.	Built-up Areas	Residential, commercial, Industrial, Institutional, and recreational areas
3.	Water Bodies	Rivers and dams

Ground truth information, maps, and overhead photographs were utilized to outline training spots. The maximum likelihood algorithms were exercised to carry out this classification.

3.3.2 Post Classification

After classification, post classification filtering was performed to generalize the dataset and create better and consistent classes. The process involved eliminating isolated pixels within the imagery and polishing group limits or cutting off a few areas of the categories to allow for considerable consistency. It occurred as a result of execution issues in the course of imagery improvement and categorization. The categorized image was substantially cleaner after the filtering and smoothing operation.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Preamble

A number of aspects needed to be considered in order to determine how mega projects would affect the hydrological characteristics of urban streams and peri-urban streams because the change could be caused by a variety of different factors. It was crucial to ascertain the following.

- The degree of urbanization
- A change in the river regime
- A shift in the frequency of catastrophic floods and droughts

This chapter comprises the results and discussions of results obtained from Landsat images, river gauging station flow data for Kamiti river at RGS 3BB12, and rainfall data over the period under study.

4.2 Land use Land cover

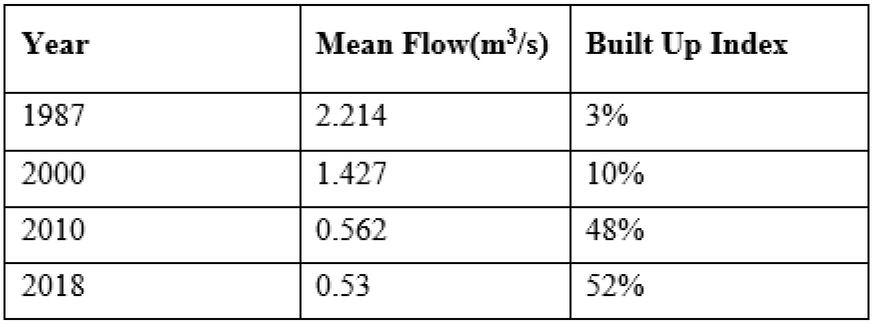
The analysis made use of data from the Landsat program. The global land survey data set was specifically utilised. The Landsat dataset is provided in the form of a number of bands that can be combined in a variety of ways to generate the needed information.

The Landsat bands images were processed before analysis to convert digital numbers (DN) to reflectance. After atmospheric adjustment, the DN was converted to surface reflectance using grass GIS software. For easy viewing, the surface reflectance bands were blended into a composite raster with the RGB color set to natural color.

Using supervised classification, each composite raster's land use was determined. This was done because it was discovered that the built up index approach was heavily influenced by recently cultivated fields or places with very little vegetation. Other non-built up areas were joined to non-built up land use classification, resulting in the creation of a catchment map displaying both constructed and non-built land use.

Having converted the raster images to vector and using the attribute table tool in ArcGIS, the built-up areas were calculated as shown in Table 4.1 and Table 4.2

Table 4.1: Supervised Classification Built up Index



Year	Mean Flow(m^3/s)	Built Up Index
1987	2.214	3%
2000	1.427	10%
2010	0.562	48%
2018	0.53	52%

Table 4.2: Land use Land cover changes from 1987 to 2018

Land use /year	***1987***		***2000***		***2005***		***2010***		***2018***	
	DN	**Area (%)**	**DN**	**Area (%)**	**DN**	**Area (%)**	**DN**	**Area (%)**	**DN**	**Area (%)**
Built Up Areas	8881	**2.8%**	32809	**10.5%**	84882	**27.1%**	149605	**47.7%**	162379	**51.8%**
Farmland (Vegetation)	250938	**80%**	172249	**54.9%**	152606	**48.7%**	94199	**30%**	28704	**9.2%**
Bare	53869	**17.2%**	108630	**34.6%**	76200	**24.2%**	69884	**22.3%**	122605	**39%**
	313688	100%	313688	100%	313688	100%	313688	100%	313688	100%

4.2.1 Land use Land cover distribution in 1987

Arable areas, which includes both rain fed and irrigated arable land, lasting crop land, and cultivation, represents approximately 80% of the area in the study region. This significant proportion is because huge tracts of the land have been taken up by coffee and tea companies for production of the cash crop for the local and international market.

The built-up area covered 2.8 percent of the whole study area. Domestic households, businesses, and Manufacturing areas are examples of land cover in this context. This poor coverage is due to increasing agricultural techniques during the period as well as the lack of development of the areas (Mundia and Aniya, 2005). According to the National Development Plan (2000), moderate economic growth between 1985 and 1995 led to low levels of urbanization and thus poor supply of built-up areas.

Bare land covered 17.2% of the land area. It is important to note that GRASS GIS software uses color for classification. The main disadvantage with this is that during dry periods where grass is brown may be interpreted as bare ground with no vegetation. This arises where the color infra-red composite detects scorched grass as bare ground. Supervised classification, however, was done to mitigate against this misrepresentation.

The Built up area dispersion is as indicated in Figure 4.1

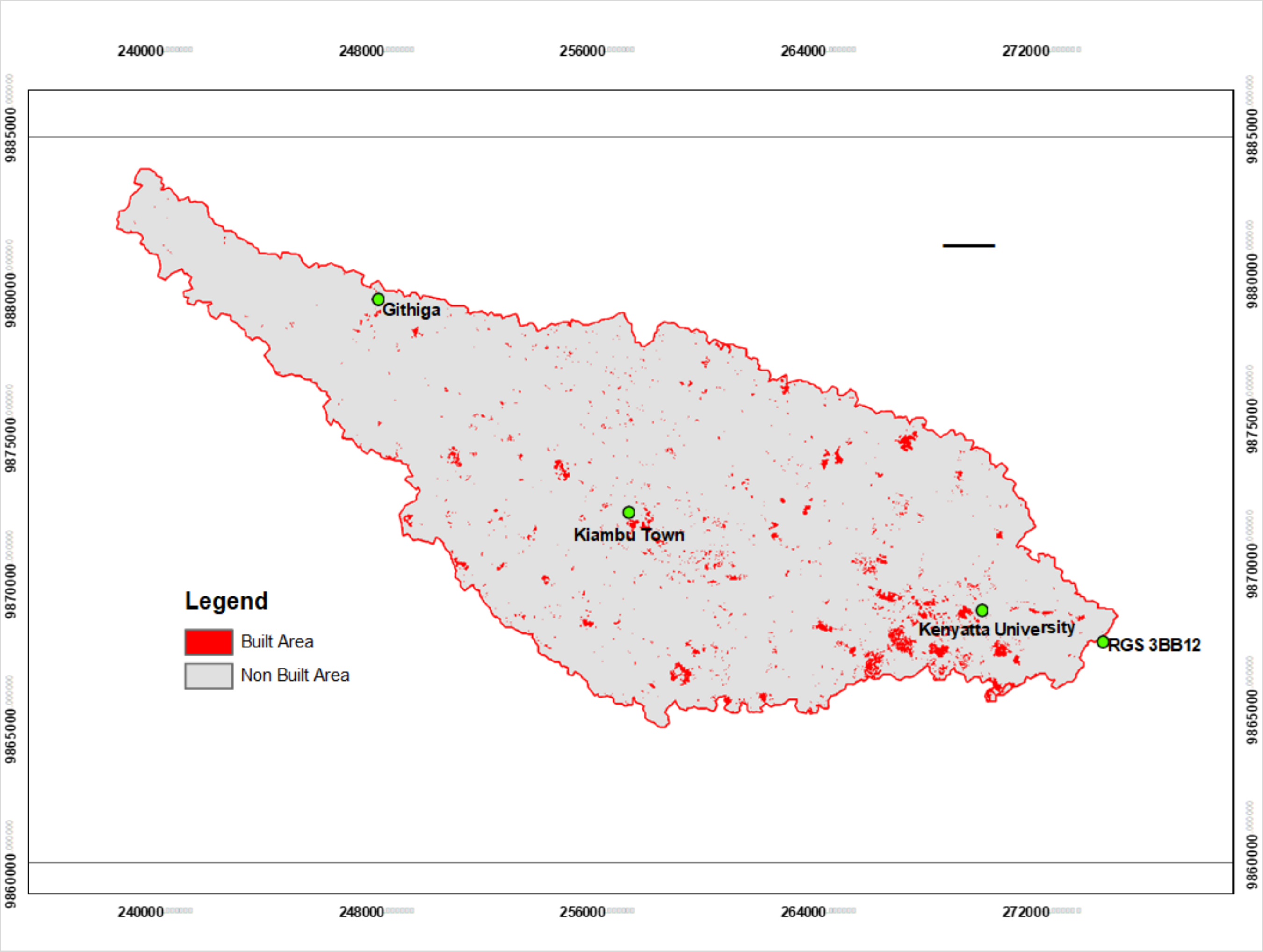


Figure 4.1: Built up area cover in 1987

4.2.2 Land use Land cover distribution in 2000

Farmland, which includes both rain fed and irrigated arable land, lasting crop land, and cultivation, represents approximately 54.9% of the area in the study region. This shows there was a decline in Farmland from 80% in 1987 to 54.9% in 2000. Bare land covered 34.6% of the land area. But as mentioned in the preceding section, misinterpretation of bare land by the software might have occurred if the images were taken during the dry season.

The built up areas expanded from 2.8% in 1987 to 10.5% in 2000. The Built up area distribution is as indicated in Figure 4.2

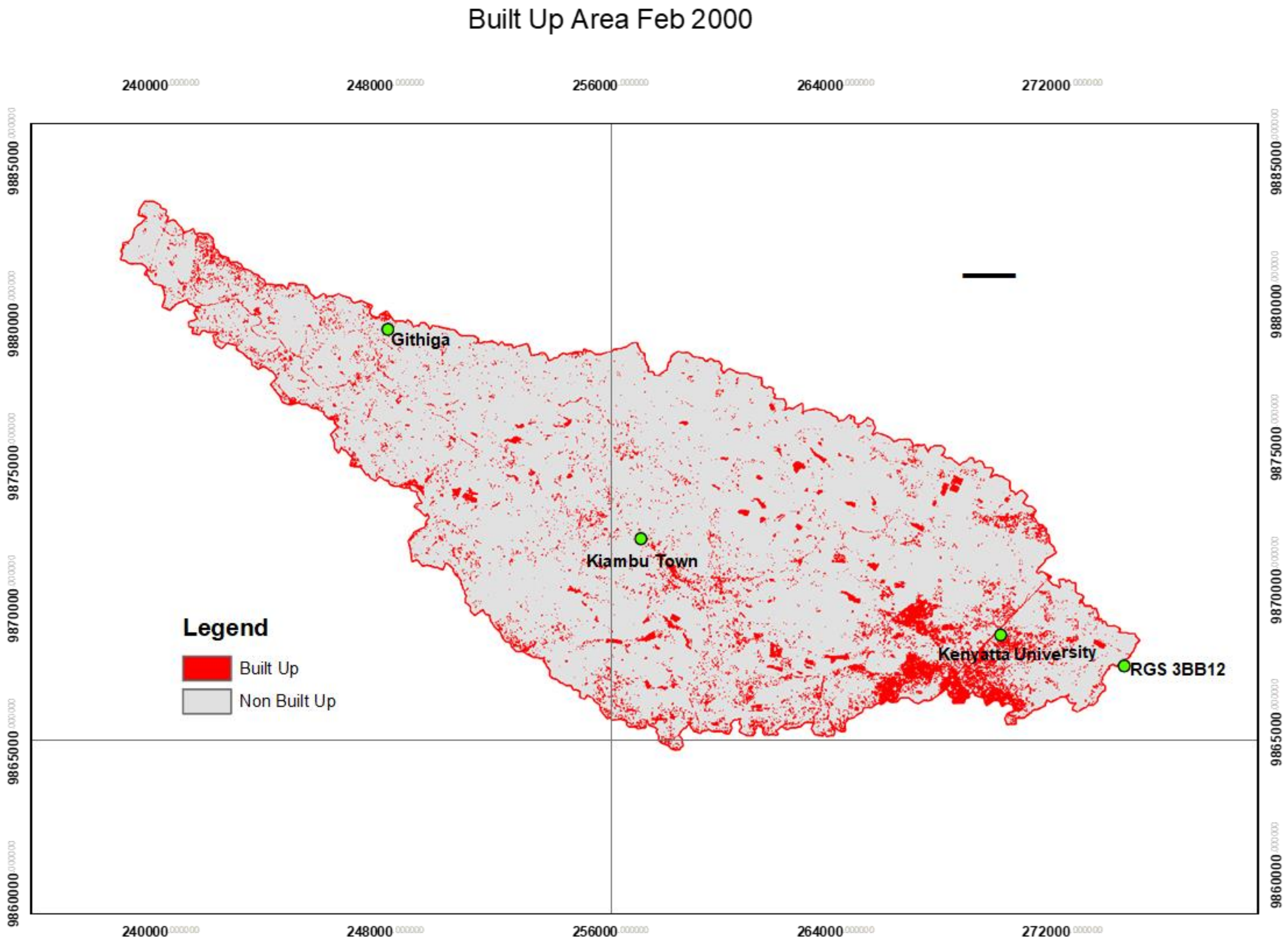


Figure 4.2: Built up area cover in 2000.

4.2.3 Land use Land cover distribution in 2005

Arable areas maintained a downward trend by decreasing from 54.9% in 2000 to 48.7% in 2005. However, the developed land increased from 10.5% in 2000 to 27.1% in 2005. Fallow land covered 24.2% of the land area. The distribution of the built-up area is as indicated in Figure 4.3

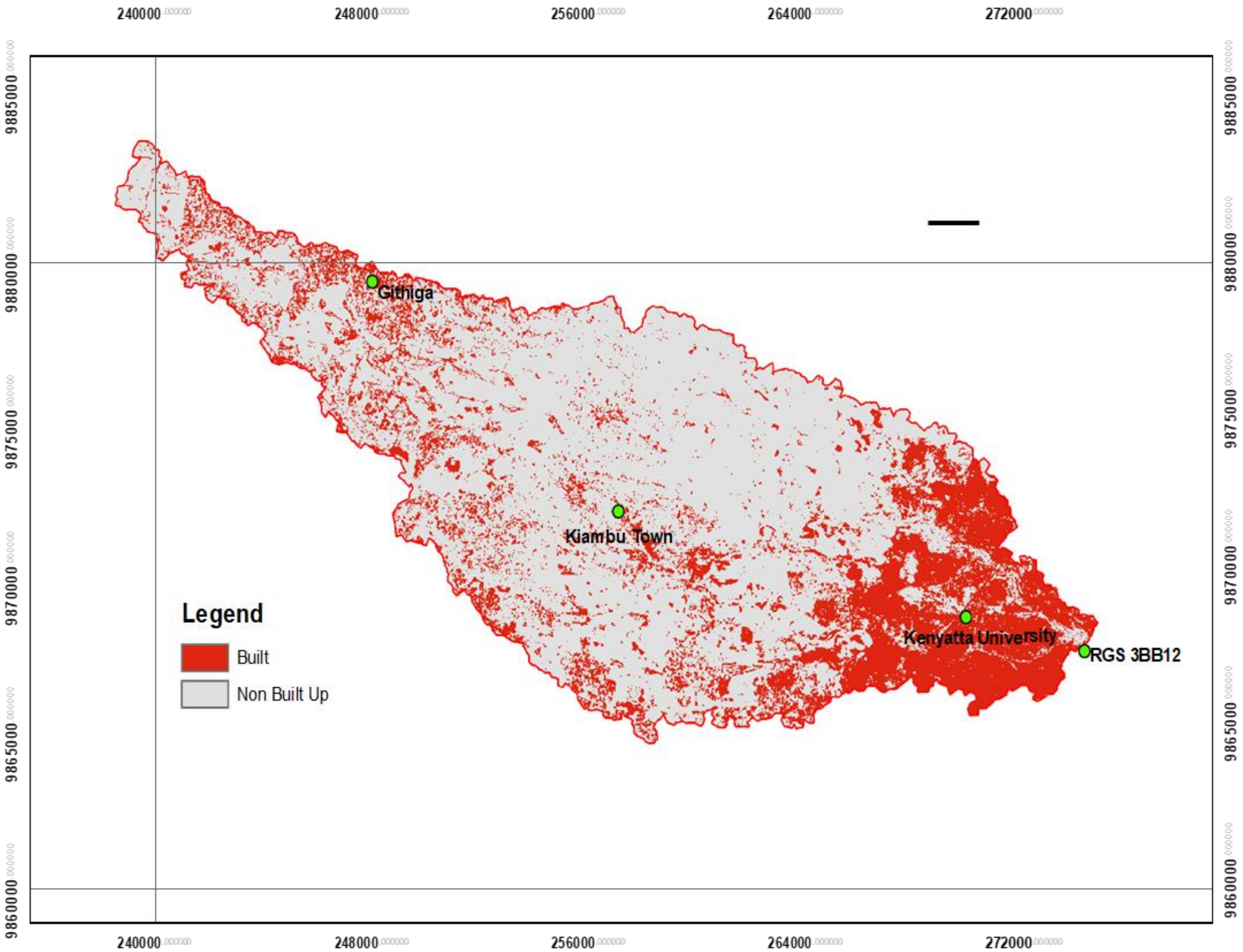


Figure 4.3: Built up area cover in 2005

4.2.4 Land use Land cover distribution in 2010

Farmland comprising crop land declined from 48.7% in 2005 to 30% in 2010. The built up areas nonetheless increased from 27.1% in 2005 to 47.7% in 2010. Bare land covered 22.3% of the land area. But as mentioned in the preceding section, misinterpretation of bare land by the software might have occurred if the images were taken during the dry season.

The Built up area distribution is as indicated in Figure 4.4

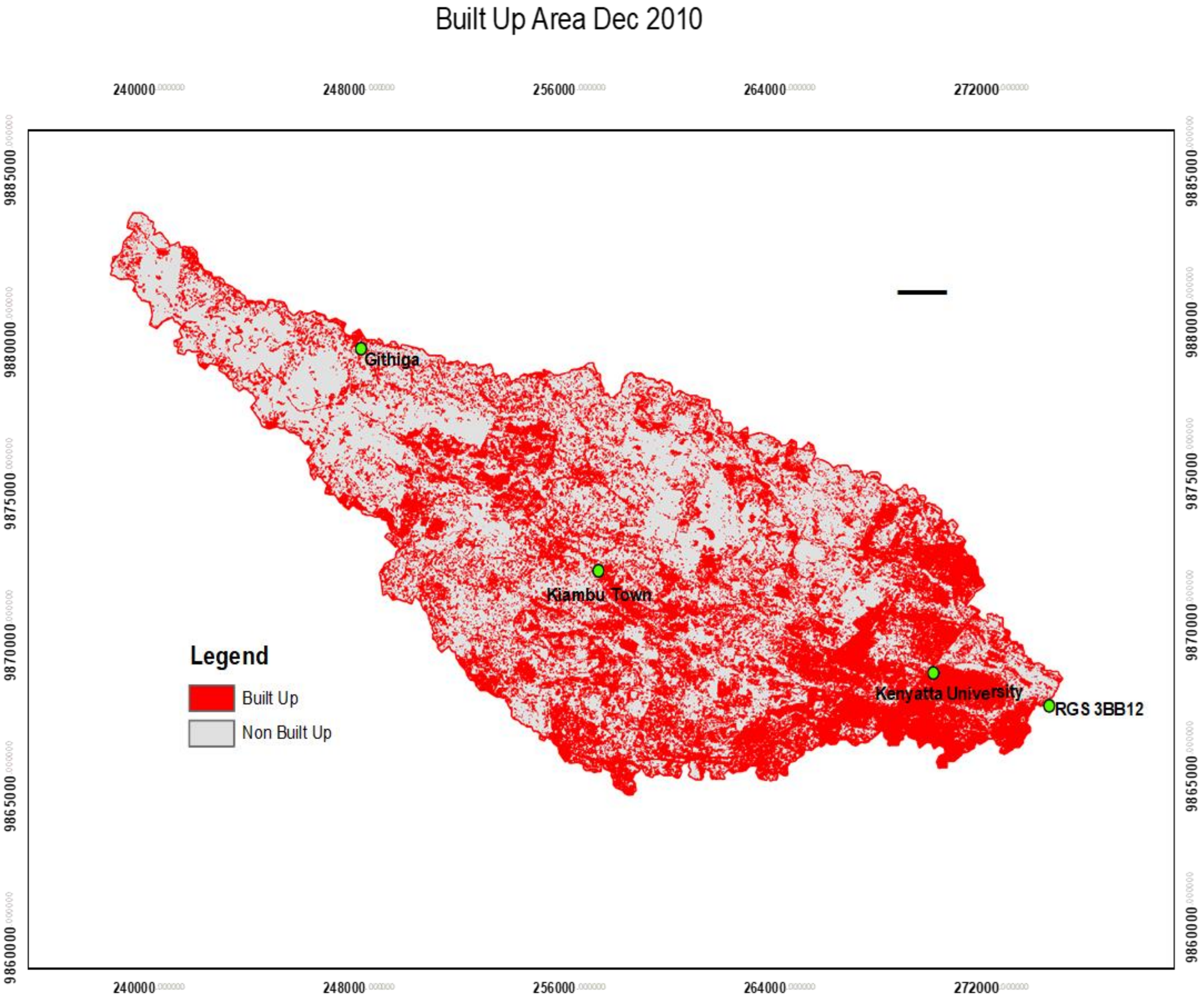


Figure 4.4: Built up area cover in 2010

4.2.5 Land use Land cover distribution in 2018

Farmland area decreased from 30% in 2010 to 9.2% in 2018. The built up areas increased from 47.7% in 2010 to 51.8% in 2018. Bare land covered 39% of the land area. It is important to note that GRASS GIS software uses color for classification. The main disadvantage with this is that during dry periods where grass is brown may be interpreted as bare ground with no vegetation.

This arises where the color infra-red composite detects scorched grass as bare ground. Supervised classification, however, was done to mitigate against this misrepresentation.

The Built up area apportionment is as shown in Figure 4.5

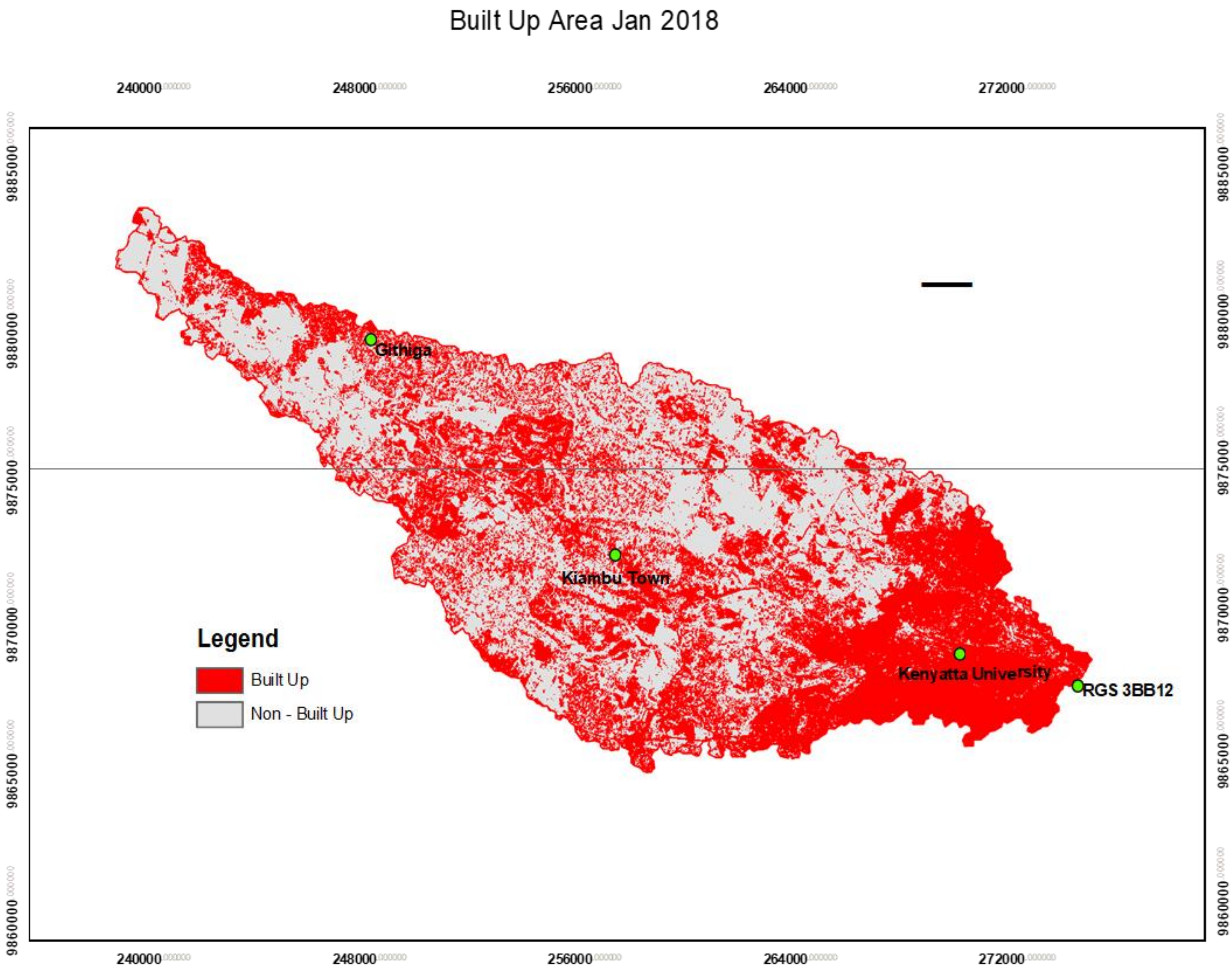


Figure 4.5: Built up area cover in 2018

4.3Validation analysis of Landsat Images through Google Earth

Validation of urban growth detected by Landsat image analysis was performed using Google Earth imagery.

Google Earth is a computer application, that creates a three-dimensional image of the globe established mainly on satellite imagery. The software represents both the land and ocean by overlaying satellite imagery, GIS data, and aerial photography, on a 3 dimensional sphere, enabling operators to identify various towns and ground features from different perspectives.

Google launched Historical Imagery in version 5.0, allowing users to browse older imagery. When you click the period icon in the toolbar, a period marker appears, marking the period of accessible imagery from before. This application enables for the tracking of variations in a region in the course of time. When using the time-lapse feature, you can view a zoomable video dating back 32 years.

4.3.1 Land use Land cover distribution validation in 1987

The natural color composite was developed for the year 1987 through google earth. It compares favorably with the Landsat image of the same year with visible urban development around Kenyatta University, Kiambu town, and Githiga on both images.

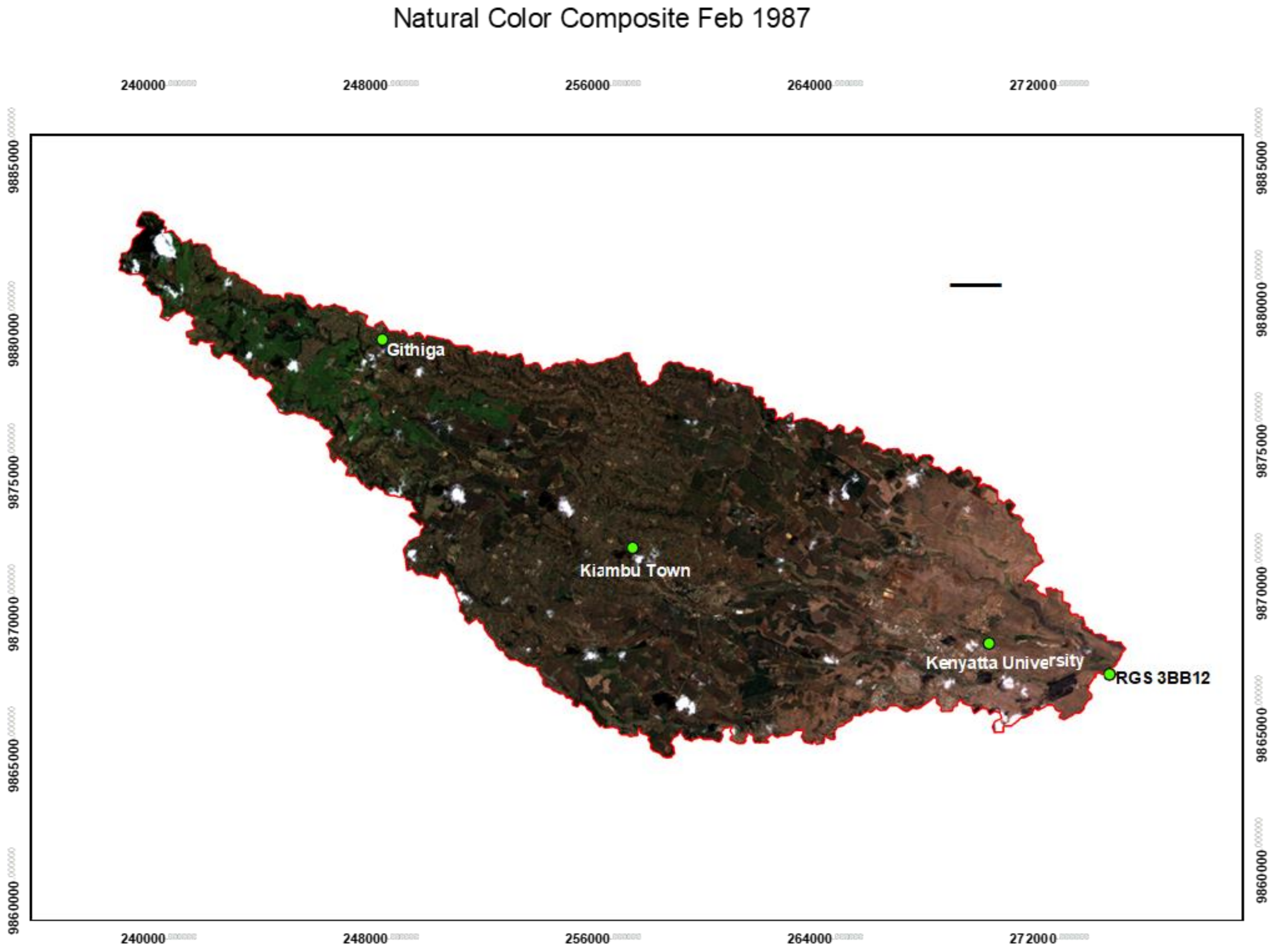


Figure 4.6: Google earth image of the study area in the year 1987

4.3.2 Land use Land cover distribution validation in 2000

The urban development distribution indicated from the natural color composite for the year 2000 was consistent with the Landsat image of the same year. More settlement was observed to have developed around Kiambu town and Kenyatta University, which was comparable to data given by Kenya National Bureau of Statistics (2015) of rate of population growth of 4.7 for the County.

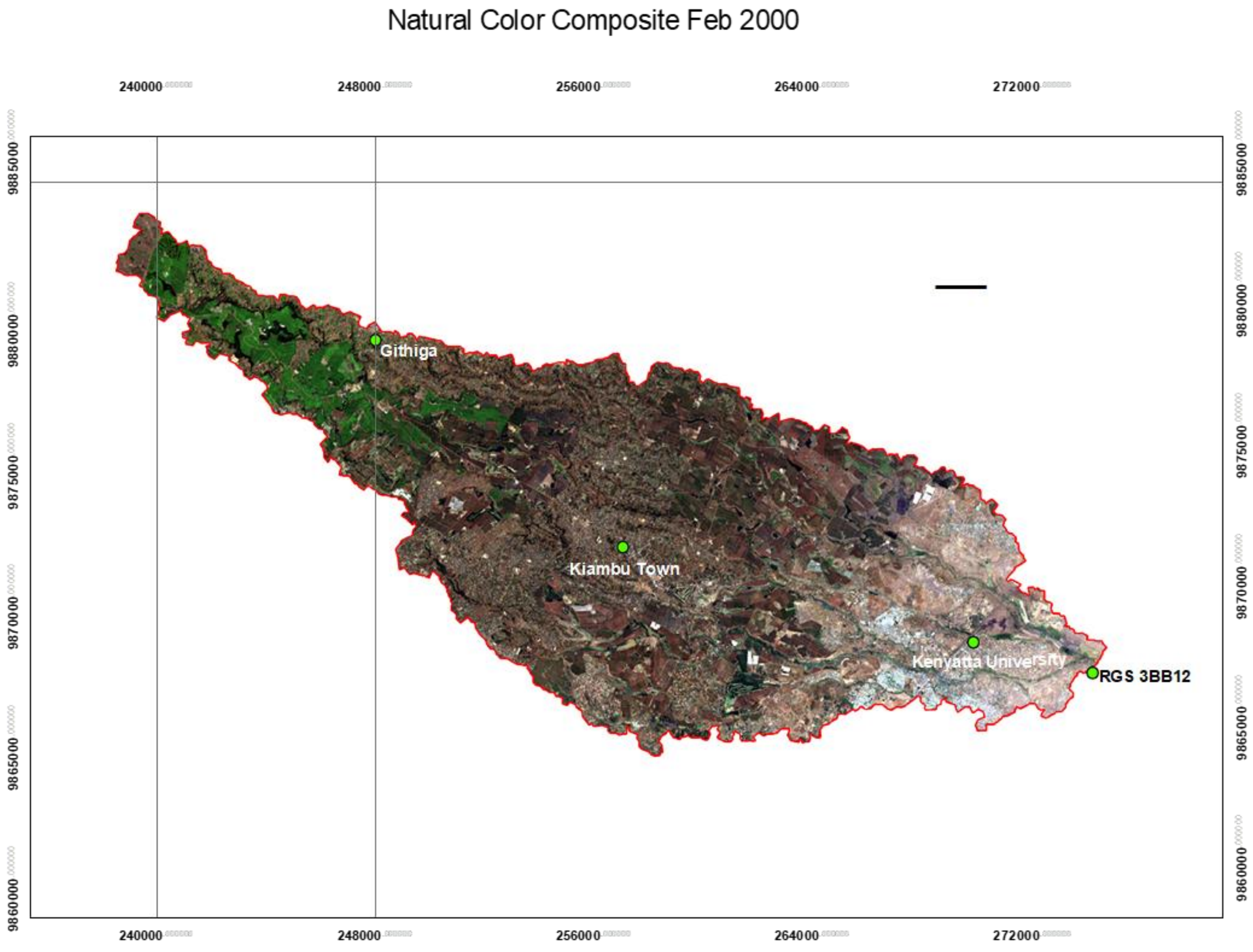


Figure 4.7: Google earth image of the study area in the year 2000

4.3.3 Land use Land cover distribution validation in 2005

Similar to the year 2000, google earth image for the year 2005 showed an increase in urban development around the three urban areas of Kenyatta University, Githiga, and Kiambu town. Urban development density distribution from the Landsat Image for the year 2005 was consistent with the natural colour composite of the same year as indicated in Figure 4.8.

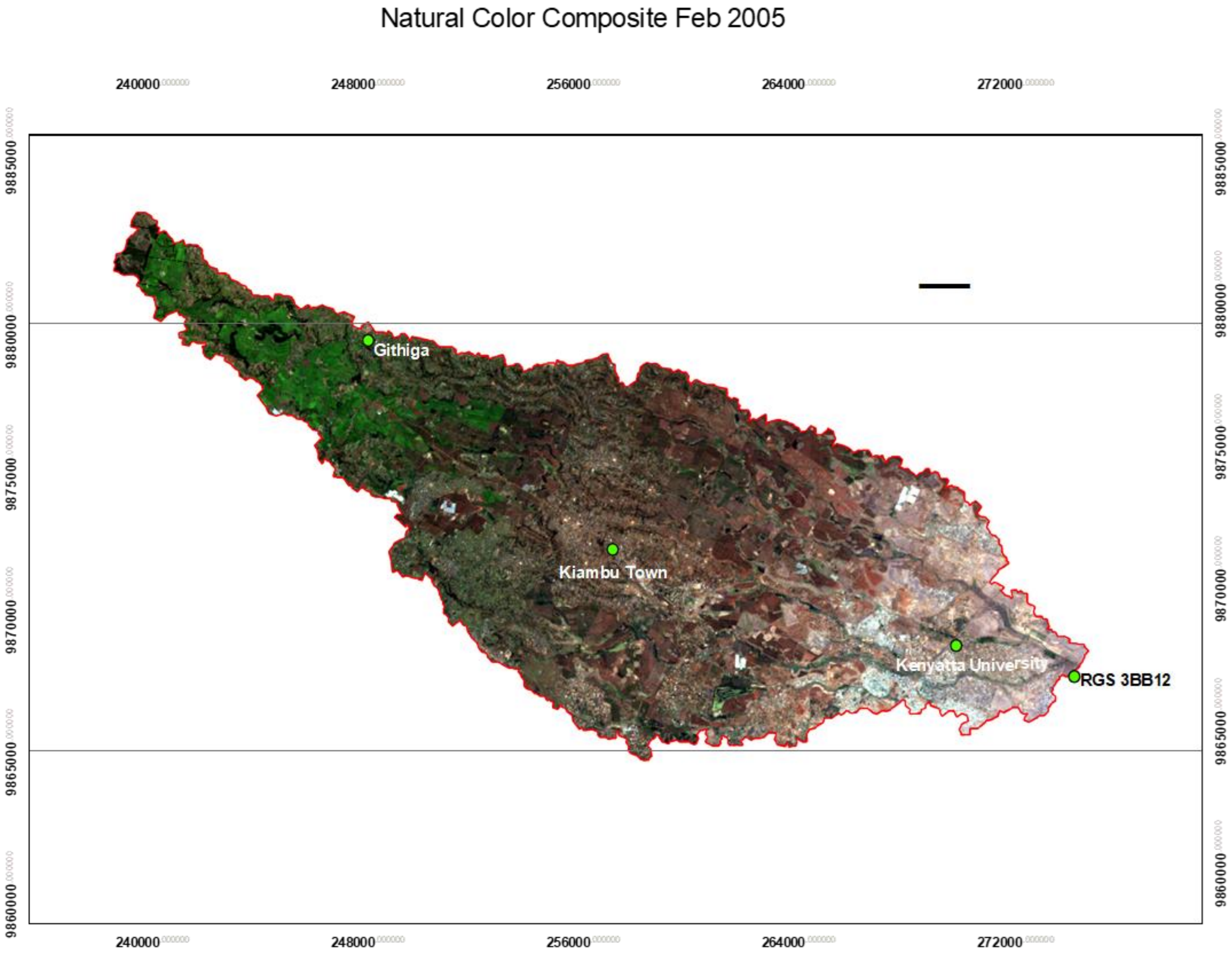


Figure 4.8: Google earth image of the study area in the year 2005

4.3.4 Land use Land cover distribution validation in 2010

The natural composite image for 2010 had few variations to the one for 2005, but when comparison was done using the Landsat images for both years a visible increase in urban development was observed. This therefore showed the limitation of google earth as a tool for change detection during a short time, and Landsat images for a better means of assessing LULC change over relatively short periods time.

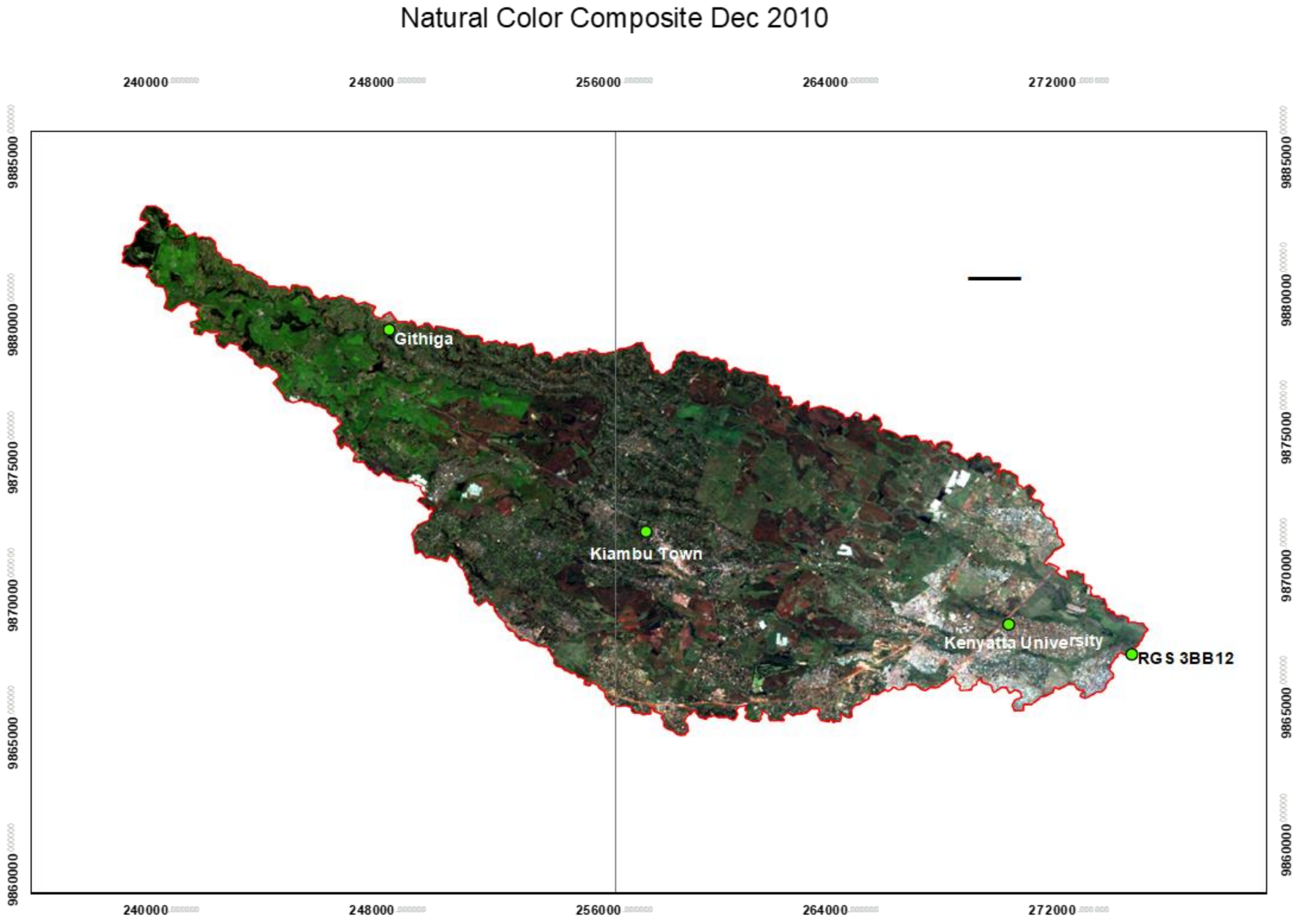


Figure 4.9: Google earth image of the study area in the year 2010

4.3.5 Land use Land cover distribution validation in 2018

Due to improvements by google in 2013 by using Landsat 8 to provide imagery in a higher quality and with greater frequency, the google earth imagery for the year 2018 was clearer with urban development distribution visible and distinct. This compared favorably with the Landsat image of the same year shown in figure 4.9.

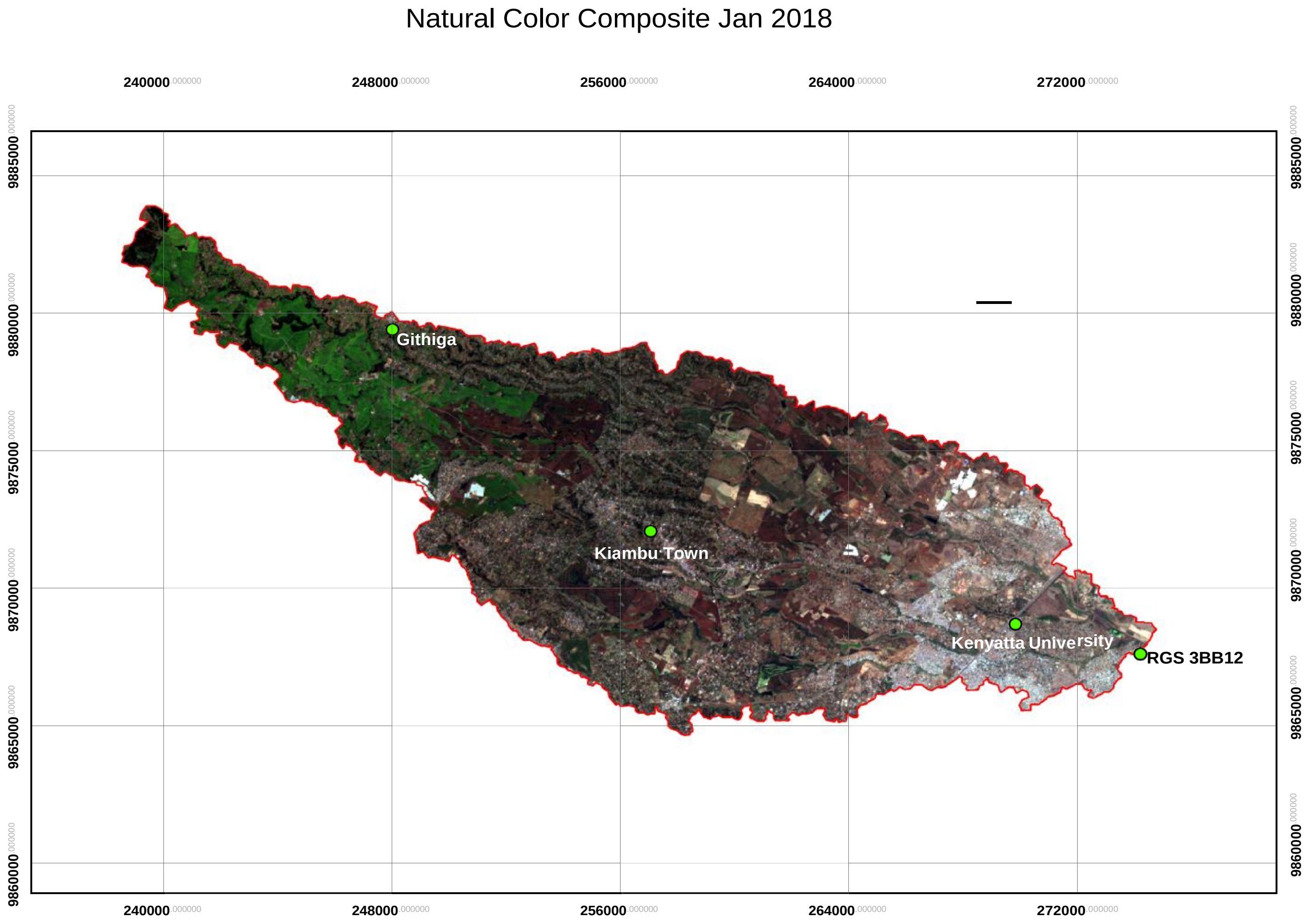


Figure 4.10: Google earth image of the study area in the year 2018

4.4Analysis of River Discharge Data

Monthly river discharge data were obtained from two measuring stations RGS 3BB12 and 3BB11 along Kamiti river as shown in Figure 4.10. The available discharge data for River gauging station 3BB12 ran from the year 1951 to 2016, while River Gauging station 3BB11 ran from the year 1951 to 2014.

Given the relatively minimal extent of the River gauging station 3BB11 watershed and the unreliability of the collected data, study of the RGS 3BB11 data was abandoned, and the RGS 3BB12 catchment was studied instead.

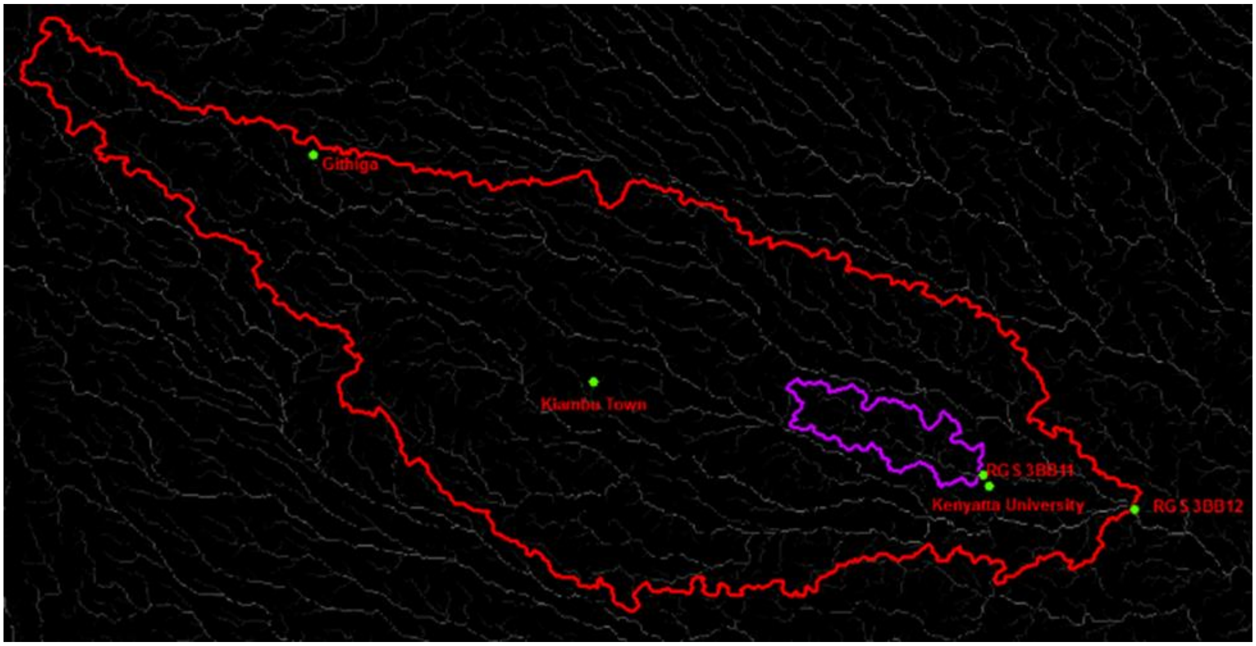


Figure 4.11: Map of catchment area showing two gauging stations RGS 3BB1 and RGS 3BB12

The monthly data for River gauging station 3BB12 were used to generate daily mean flows and annual daily average flows using the time-steps specified by the Landast pictures used in the built-up area analysis. Figures 4.12 and 4.13 depict the years 1958-1987, 1988-2000, 2005-2010, 2011-2016.

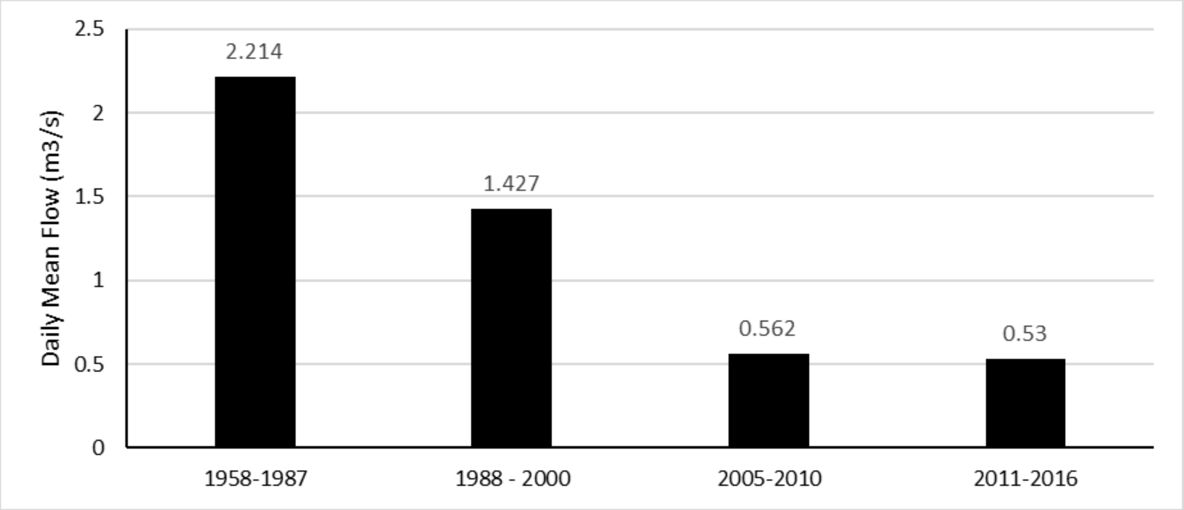


Figure 4.12: Daily mean flows for RGS 3BB12 from the year 1958 - 2016

There was no data for the RGS under examination between 2001 and 2004. This was due to a lack of coordination in data transmission between the Ministry of Water and Sanitation and the WRA during the water sector reforms. However, the data acquired for the remainder of the research period was able to fill in the gaps and informed assumptions made during analysis.

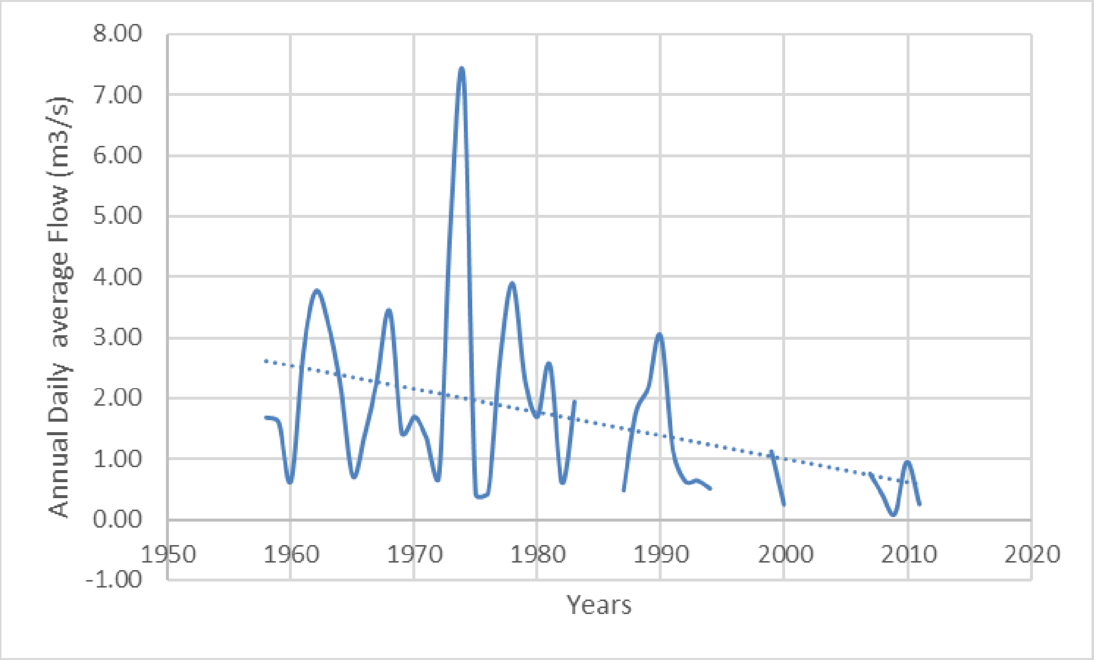


Figure 4.13: Annual Daily Average Flow RGS 3BB12

4.5Time-series Charts Analysis

Figure 4-13 depicts a time series of river gauging station 3BB12 data sets from 1958 to 2016 (Table 7-1 in attachment 1), demonstrating a general reduction in average daily flow over the study period.

Figures 7-1 through 7.4 in Appendix 2 depict a time-series examination of the daily average flow. The Landsat photos used in the built-up area study established the time-steps.

The time series show how the flow regime shifted from a relatively high steady flow regime broken by continual high peaks to one dominated by very lows with occasional relatively high peak flows.

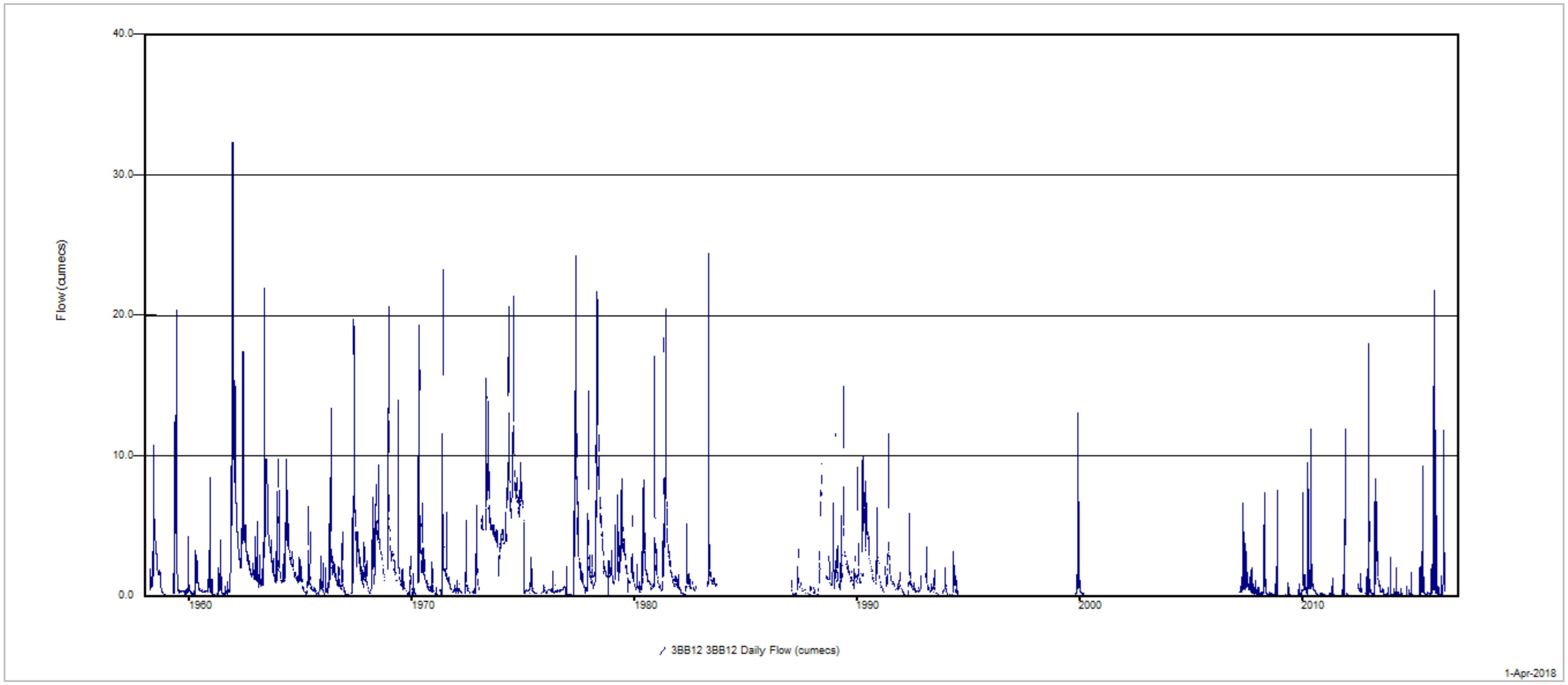


Figure 4.14: RGS 3BB12 timeseries 1958 - 2016

4.6Flow Duration Curves Analysis

The Flow Duration Curve (FDC) is the most appropriate tool for determining streamflow thresholds. The natural behavior of streamflow categories is reflected by FDC, which is a accumulative incidence arch that depicts the proportion of the particular discharges that were surpassed or matched within a certain duration.

With the time steps defined by the Landsat images used in the built-up area analysis, flow duration curves of plots of streamflow versus time of exceedance were created. Appendix 3 figures 7.6–7.10 show the graphs for the individual time periods.

Figure 4.15 compares flow duration curves for various time periods.

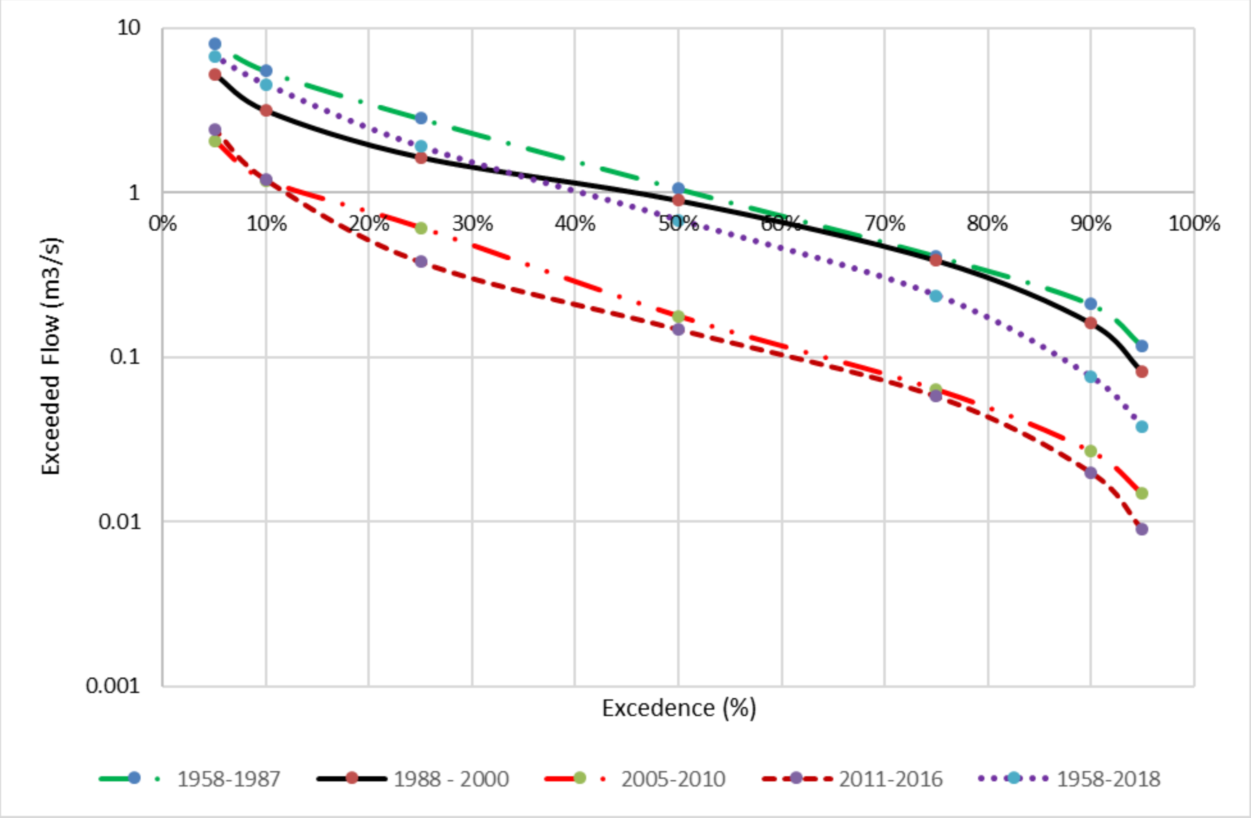


Figure 4.15: Flow duration curves comparisons for different time periods

The Flow duration curves were typical in that mean flows (Qmean) dropped within Q10 and Q70. Great flows occurred within Q0 and Q10, whereas low flows occurred within Q70 and Q100. Flows fell overall between 1958 and 2018, with the pattern of fall between the five curves being consistent.

4.7Climatic Data Analysis

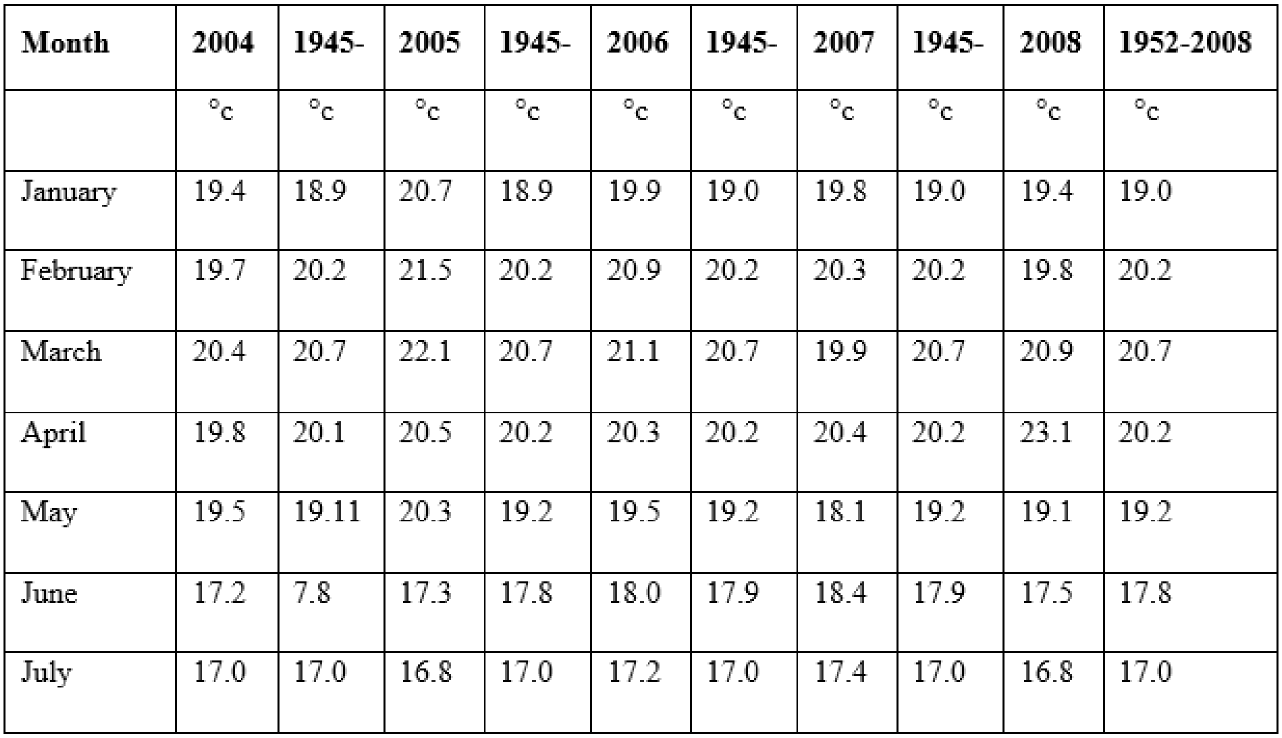
The numeric investigation of the collected atmospheric information was performed with the goal of demonstrating the general climatological characteristics of the study area, and that the three (3) key climatic parameters did not contribute significantly to shift in the flow regime of Kamiti river over time.

To do this, data on the three most important meteorological parameters (rainfall, evaporation, and temperature) were gathered. Using various hydrological data base tools, the acquired data was organized, processed, and analyzed.

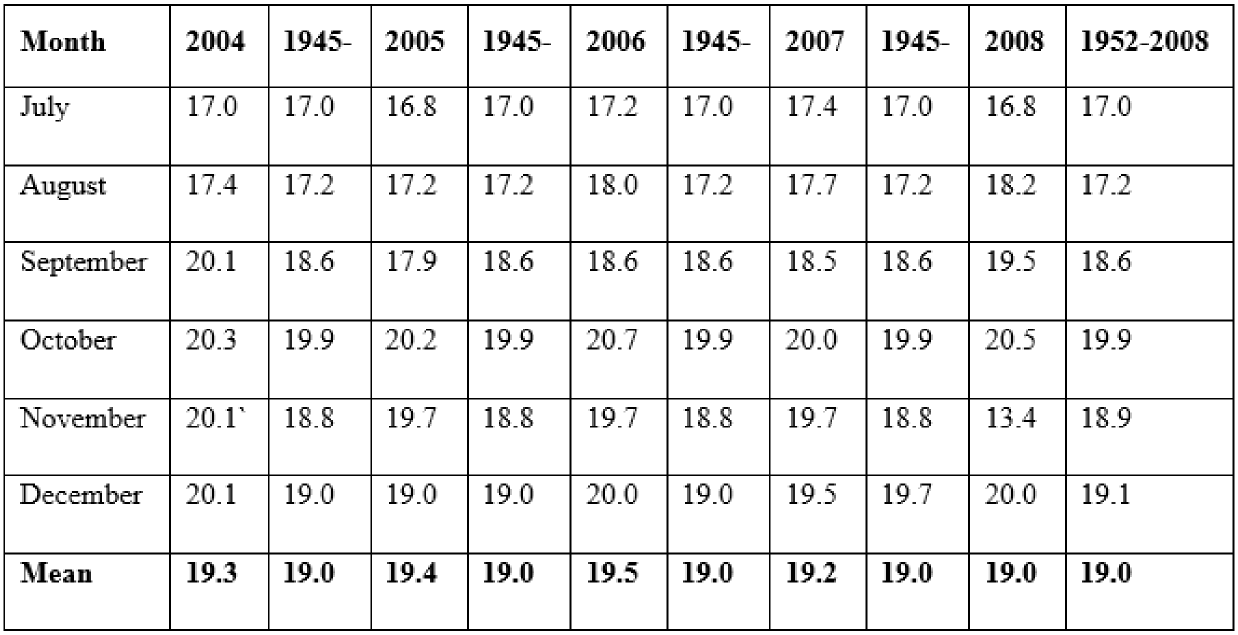
4.7.1 Temperature

Temperatures within the region of study were calculated through information from the Jacaranda station. Evaluation of the information period (1945-2008) in Table 4.3 revealed that mean temperatures varied through the months but were maximum (20.7°C) in February through April and minimum (17.0°C) in July. There was no abnormal discrepancy between the different time periods.

Table 4.3: Atmospheric temperature (°C) at Jacaranda coffee station



Month	2004	1945-	2005	1945-	2006	1945-	2007	1945-	2008	1952-2008
	°c	°c	°c	°c	°c	°c	°c	°c	°c	°c
January	19.4	18.9	20.7	18.9	19.9	19.0	19.8	19.0	19.4	19.0
February	19.7	20.2	21.5	20.2	20.9	20.2	20.3	20.2	19.8	20.2
March	20.4	20.7	22.1	20.7	21.1	20.7	19.9	20.7	20.9	20.7
April	19.8	20.1	20.5	20.2	20.3	20.2	20.4	20.2	23.1	20.2
May	19.5	19.11	20.3	19.2	19.5	19.2	18.1	19.2	19.1	19.2
June	17.2	7.8	17.3	17.8	18.0	17.9	18.4	17.9	17.5	17.8
July	17.0	17.0	16.8	17.0	17.2	17.0	17.4	17.0	16.8	17.0

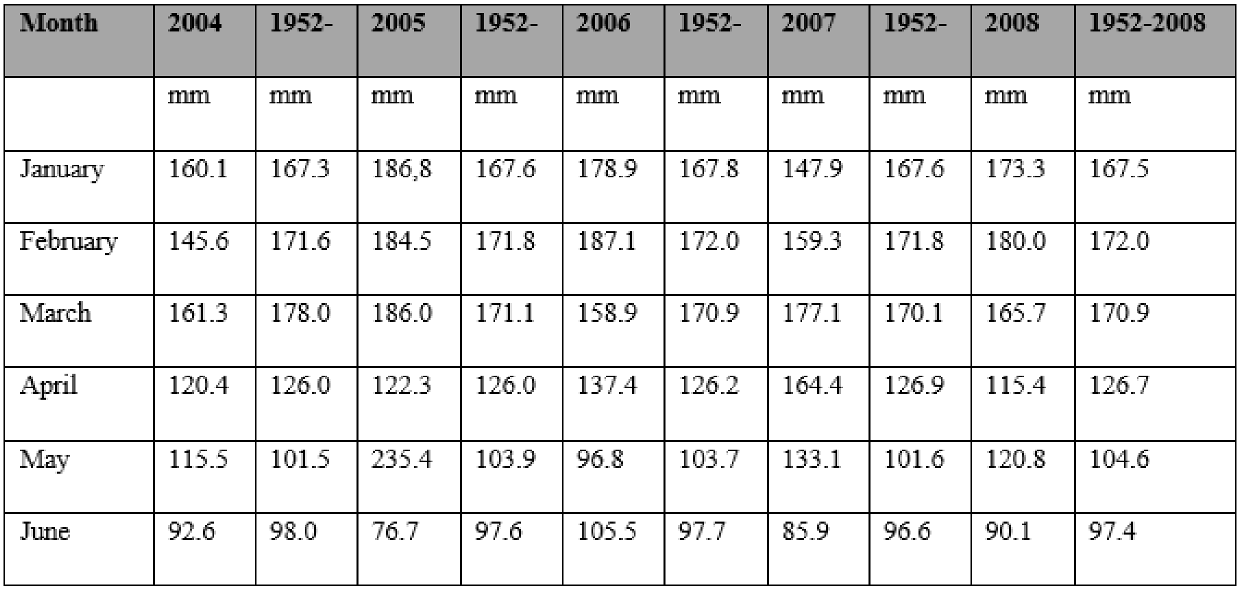


Month	2004	1945-	2005	1945-	2006	1945-	2007	1945-	2008	1952-2008
July	17.0	17.0	16.8	17.0	17.2	17.0	17.4	17.0	16.8	17.0
August	17.4	17.2	17.2	17.2	18.0	17.2	17.7	17.2	18.2	17.2
September	20.1	18.6	17.9	18.6	18.6	18.6	18.5	18.6	19.5	18.6
October	20.3	19.9	20.2	19.9	20.7	19.9	20.0	19.9	20.5	19.9
November	20.1`	18.8	19.7	18.8	19.7	18.8	19.7	18.8	13.4	18.9
December	20.1	19.0	19.0	19.0	20.0	19.0	19.5	19.7	20.0	19.1
Mean	**19.3**	**19.0**	**19.4**	**19.0**	**19.5**	**19.0**	**19.2**	**19.0**	**19.0**	**19.0**

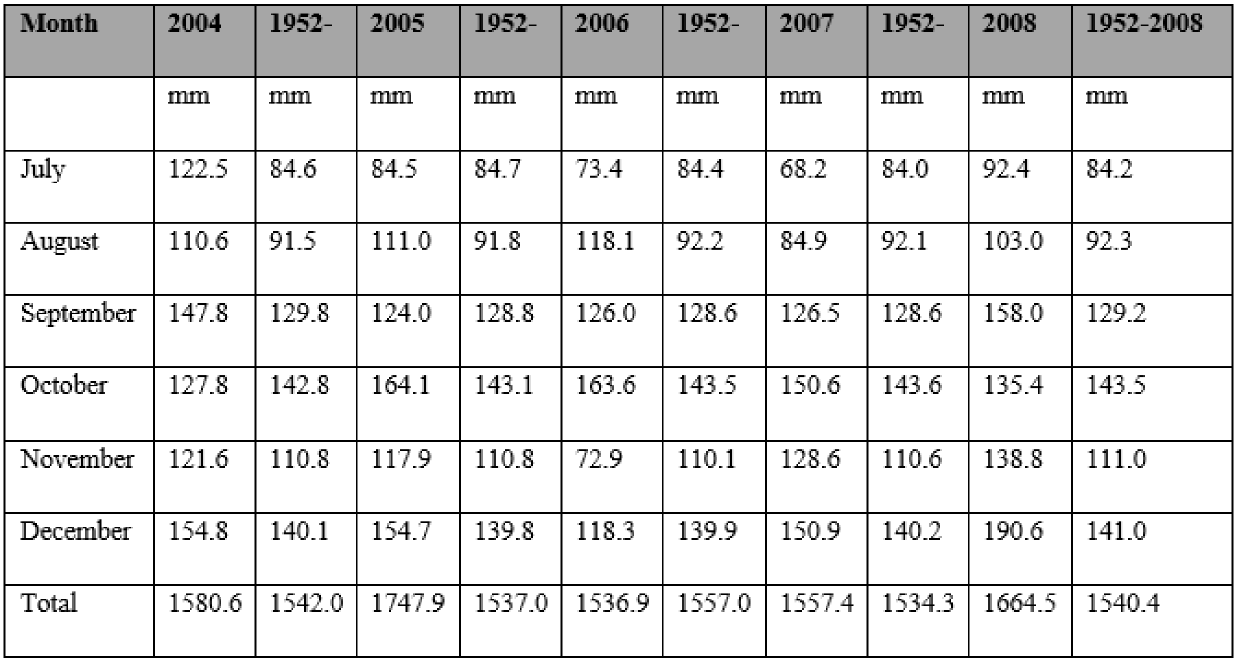
4.7.2 Evaporation rates (mm)

The quantity of precipitation obtainable for extraction as under-ground or surface water resources in rivers and reservoirs, is influenced by evaporation rates, which also affect transpiration rates from plants in catchments. Those from a pan "A" in the Jacaranda research station (1952–2008), which were identified as of greater reliability and consistent than information sourced at Nairobi meteorological station, hence utilized to estimate the subbasin evaporation rates. Table 4.4 shows the results.

Table 4.4: Evaporation ‘PAN A' (mm) at Jacaranda



Month	2004	1952-	2005	1952-	2006	1952-	2007	1952-	2008	1952-2008
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
January	160.1	167.3	186,8	167.6	178.9	167.8	147.9	167.6	173.3	167.5
February	145.6	171.6	184.5	171.8	187.1	172.0	159.3	171.8	180.0	172.0
March	161.3	178.0	186.0	171.1	158.9	170.9	177.1	170.1	165.7	170.9
April	120.4	126.0	122.3	126.0	137.4	126.2	164.4	126.9	115.4	126.7
May	115.5	101.5	235.4	103.9	96.8	103.7	133.1	101.6	120.8	104.6
June	92.6	98.0	76.7	97.6	105.5	97.7	85.9	96.6	90.1	97.4



Month	2004	1952-	2005	1952-	2006	1952-	2007	1952-	2008	1952-2008
	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
July	122.5	84.6	84.5	84.7	73.4	84.4	68.2	84.0	92.4	84.2
August	110.6	91.5	111.0	91.8	118.1	92.2	84.9	92.1	103.0	92.3
September	147.8	129.8	124.0	128.8	126.0	128.6	126.5	128.6	158.0	129.2
October	127.8	142.8	164.1	143.1	163.6	143.5	150.6	143.6	135.4	143.5
November	121.6	110.8	117.9	110.8	72.9	110.1	128.6	110.6	138.8	111.0
December	154.8	140.1	154.7	139.8	118.3	139.9	150.9	140.2	190.6	141.0
Total	1580.6	1542.0	1747.9	1537.0	1536.9	1557.0	1557.4	1534.3	1664.5	1540.4

According to Table 4.4, the month of February had the highest evaporation rate (172 mm), while the month of July had the lowest (84.2 mm). The yearly evaporation rate was 1540.4 mm.

4.7.3 Rainfall

The link between rainfall and runoff is driven by rainfall data, which is why rainfall analysis is important. Using rainfall data, it was possible to estimate the additional water in the catchment basin that would be available for runoff. It was essential in figuring out how much rain and water will fall in the catchment.

The research area's rainfall data were generally of high quality. Rainfall analysis was based on actual storms, despite the use of design storms.

Storms differ in a variety of ways that have a substantial impact on hydrological parameters. The most important criteria are intensity, duration, volume, and frequency, all of which are interconnected.

Rainfall data for Jacaranda station was analyzed using a hyetograph from 1970 to 2018, as shown in Figures 4.16, 4.17, 4.18, 4.19, and 4.20.

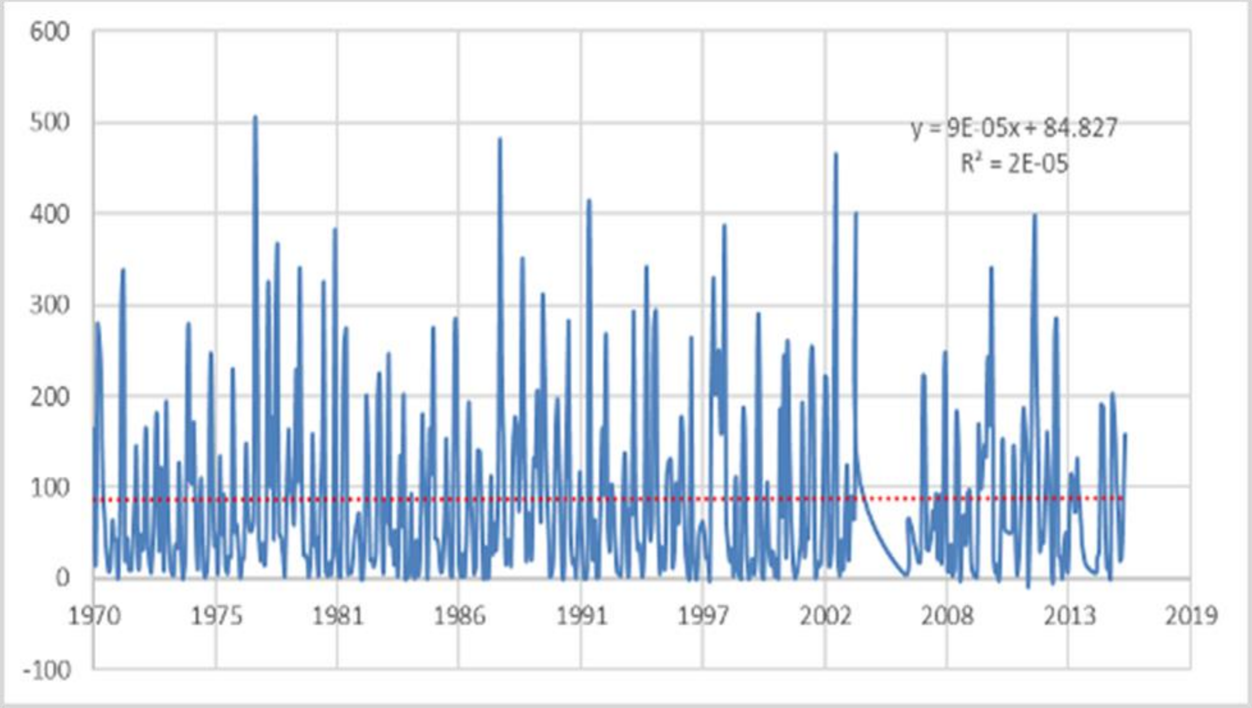


Figure 4.16: Rainfall hyetograph for Jacaranda gauging station between 1970-2016

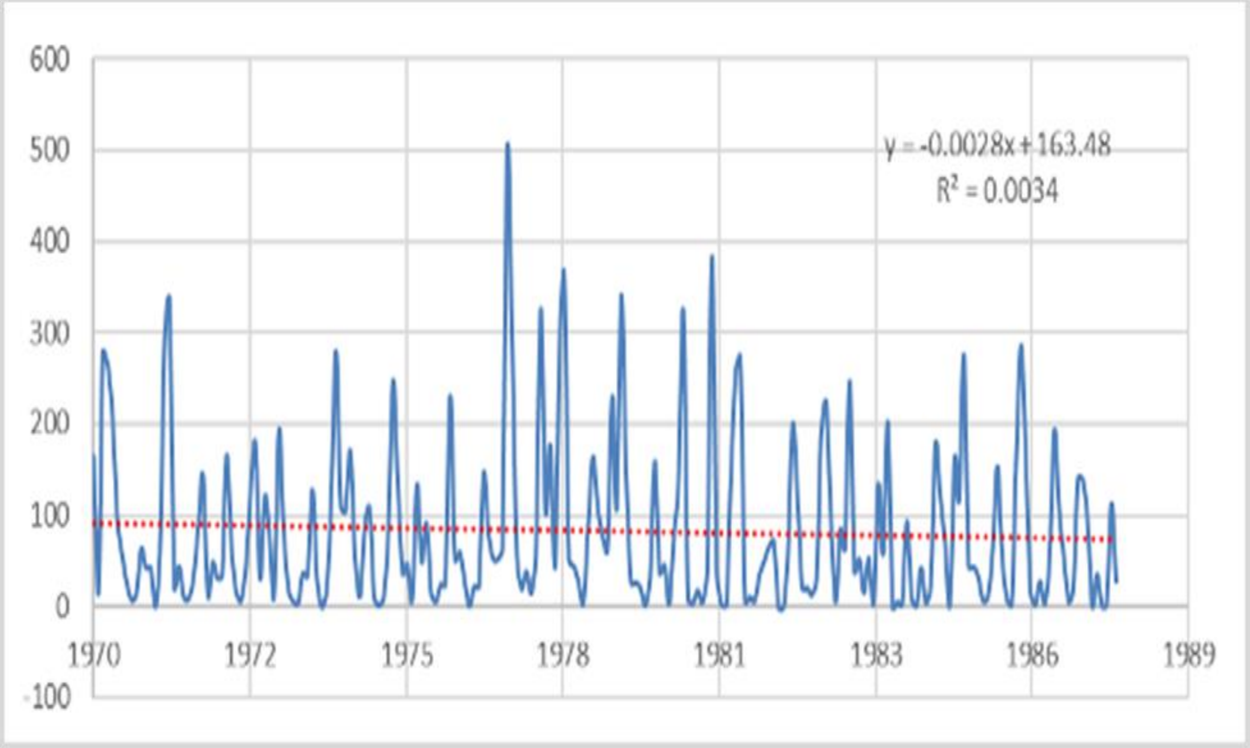


Figure 4.17: Rainfall hyetograph for Jacaranda gauging station between 1970-1987

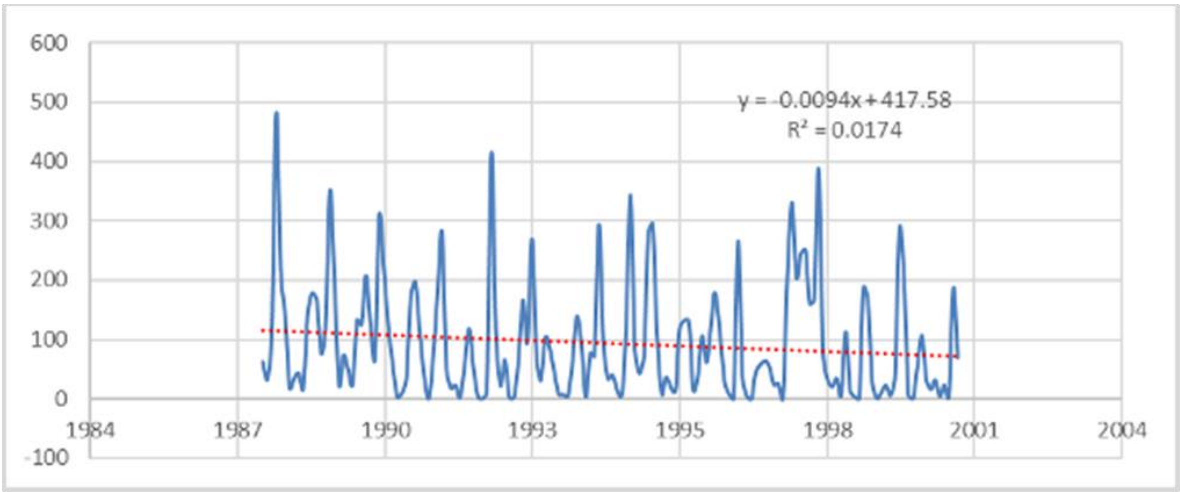


Figure 4.18: Rainfall hyetograph for Jacaranda gauging station between 1988-2000

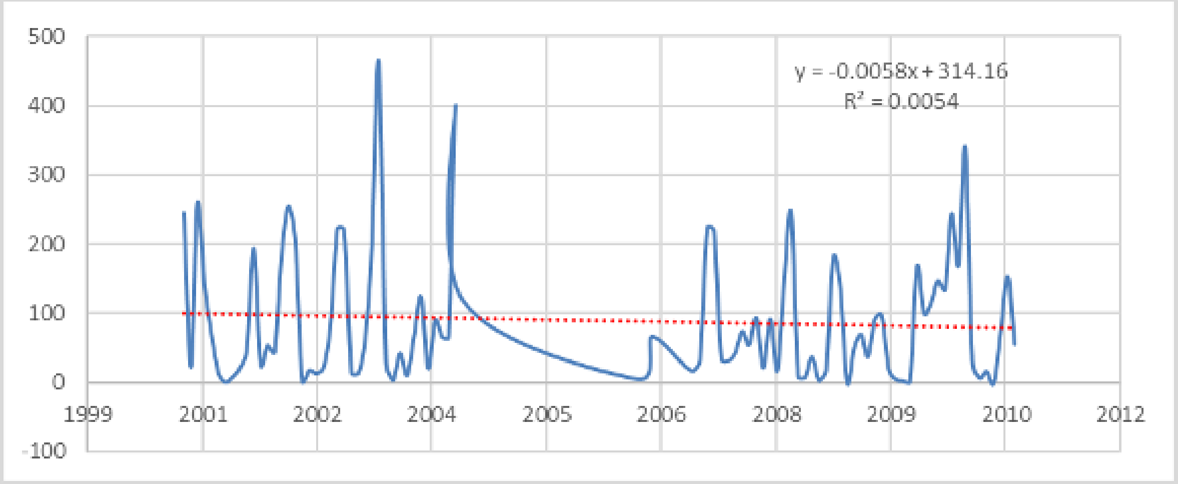


Figure 4.19: Rainfall hyetograph for Jacaranda gauging station between 2001-2010

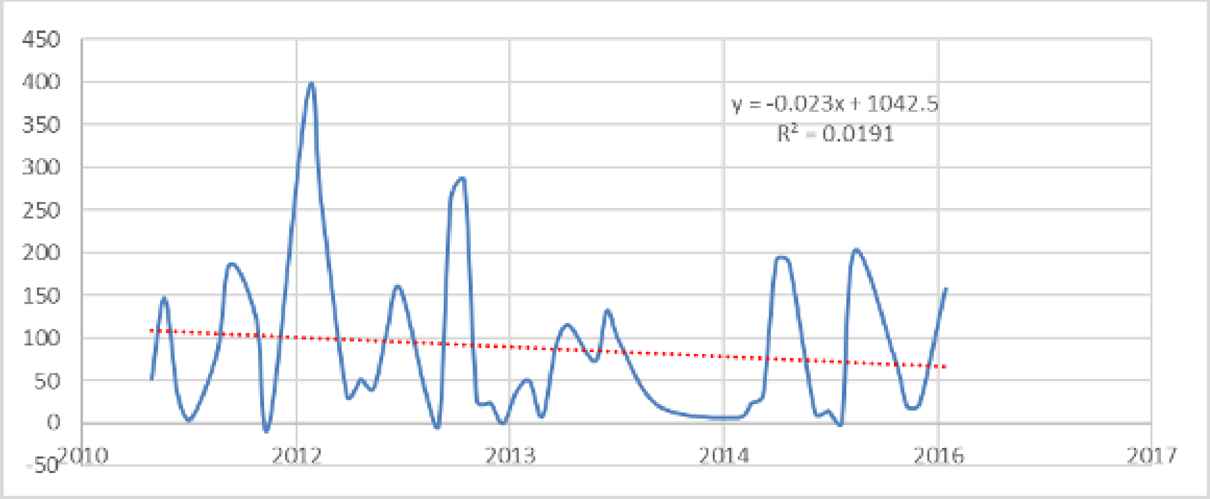


Figure 4.20: Rainfall hyetograph for Jacaranda gauging station between 2011-2016

The slope line's gradient depicts the trend over time (red line). In this situation, the slope y=9E^{-05} is very modest for the period 1970-2016 (figure 4.16), implying that there was no trend over time.

4.8 Discussion of the Results

4.8.1 Land use Land cover distribution

As can be seen from Table 4.2, there was significant increase in built up area from 2.8% in 1987 to 51.8% in 2018. It can be deduced that the increased need for development such as water treatment facilities, highways, and diverse necessities has resulted in an expansion in urban development with better infrastructure enticing additional businesses to establish and set up in this region. Two mega projects that developed because of improved infrastructure and a rise in populace is TATU city and Ruiru-Juja waste-water treatment project.

Area coverage of farmland and vegetation on the other hand reduced from a high of 80% in 1987 to 9.2% in 2018. This is consistent with ground truth information from the natural colour composites images which shows a corresponding increase of urban settlements over the same study period.

4.8.2 Hydrological effect of Kamiti river observed through river gauging station 3BB12

As demonstrated from the flow duration curves in Figure 4.15, flows were typical in that mean flows (Qmean) dropped within Q10 and Q70. Great flows occurred within Q0 and Q10, whereas low flows occurred within Q70 and Q100. Flows fell overall between 1958 and 2018, with the pattern of fall between the five curves being consistent. Research has shown the advantages of utilizing FDC in the preparation of exceedance probability plots. (Wijisekera N.T.S, 2020)

Mean flows decreased from 2.214m^3/s to 0.53m^3/ between 1958 to 2016., as indicated in Figure 4.12.

4.8.3 Effect of Mega-infrastructure on the hydrology of Kamiti and Ruiru rivers

The rise in built-up area index with a matching decline in discharge flows, as shown in Figure 4.21 below, suggests that there was a definite impact of LULC on Kamiti river flow patterns. However, to conclude that megaprojects had a distinct impact from 'regular' urban development is incorrect. Reason for this is that flow duration curves for the various periods showed an identical trend, with no significant shift observed between 2005 and 2018, when both TATU city and Ruiru-Juja waste water treatment plant were under implementation.

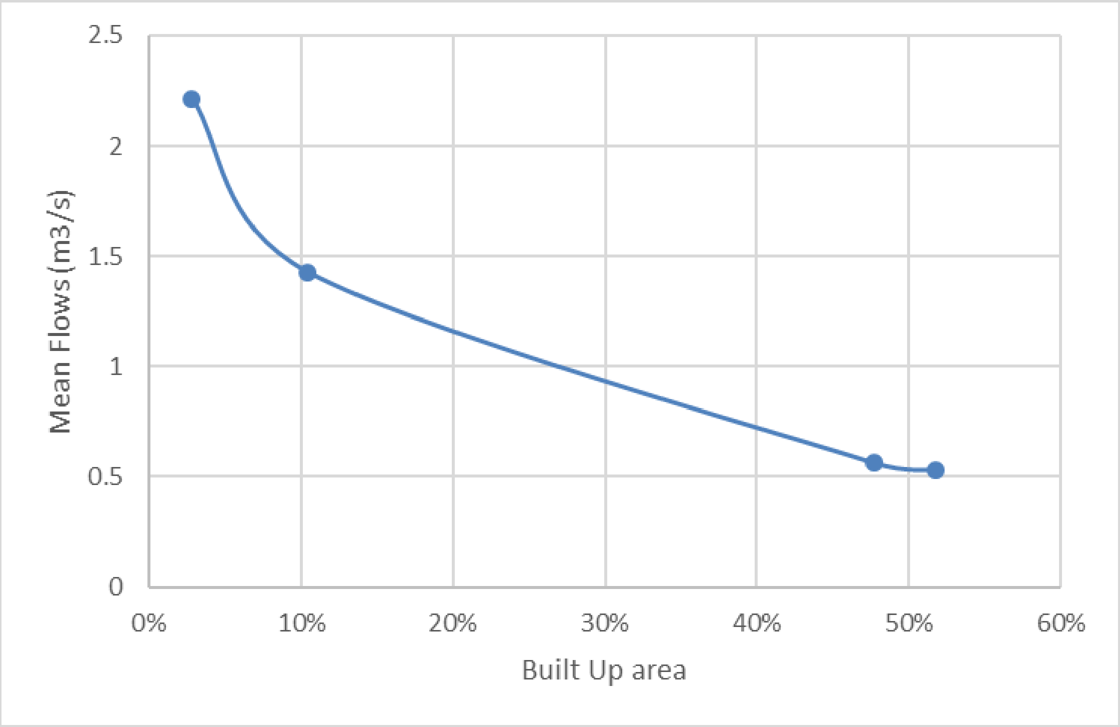


Figure 4.21: Change of Mean flows with Built up area

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Preamble

This Chapter draws conclusions and makes recommendations from the results obtained and observations carried out in the study.

5.2 Conclusion

This study involved the determination of how much control and what effects the on-going infrastructure projects and other major operations have on the hydrology of Kamiti and Ruiru rivers by use of GIS technology. The study is useful in obtaining information regarding Land use land cover changes, factors driving these changes, and the effect they have on Kamiti water shed. The results obtained provides useful insights to planners and policy makers for informed decision making.

The first objective was to map Land use Land cover trends within the study catchment from 1987 to 2018. The research revealed that Kamiti/Ruiru river watershed is increasingly becoming urbanized especially at the lower reaches where Thika highway is a major driver in this trend. This was clearly seen during supervised classification of built up area where built up area increased from 2.8% in 1987 to 51.8% in 2018.

The second objective was to determine any hydrological effect on Ruiru and Kamiti rivers by the increase in built up area from the year 1987 to the year 2018. This study revealed that there was a negative effect in river discharge volumes over a similar period, with discharge decreasing from a mean of 2.214m^3/s to 0.53m^3/s. While it is expected that increase in built up area will lead to an increase in river discharge due to increased run-off, it can be deduced that the high abstraction volumes upstream of Kamiti and Ruiru rivers for water supply has had a significant effect on discharge downstream.

To then conclude that mega projects had a separate effect to ‘normal’ urban development will not be correct. This is because the flow duration curves for the different periods (1958-1987, 1988-2000, 2005-2010, and 2011-2016) show a similar pattern with no abnormal changes seen in the period 2005 to 2016.

5.3 Recommendations

The recommendations are in accordance with data collected, analysis, and findings collected from this research and are secured on suitable Land use activities to offset the reduction in agricultural land and hydrological changes to Kamiti and Ruiru rivers flow regime.

This research therefore recommends the following;

a) Institutions mandated to handle water resources and climatic data for instance the Water Resources Authority and the meteorological department should improve the data collection protocol for long term flow volumes assessment in both Ruiru and Kamiti rivers. Existing data was seen to have gaps, and weaknesses related to data collection protocol, faulty equipment, timing and recording, which could compromise the overall quality of data. There are only two monitoring stations for the two rivers, which limits our knowledge on specific parts of the watersheds. There were also data inconsistencies for rainfall data for the period 2004 – 2006. There is therefore need for establishment of additional monitoring stations and improve the monitoring of water quality at monitoring stations. The significance of owning correct, comprehensive, and illustrative extents of databases is of utmost importance for use in management.

b) To strengthen the planning department of Kiambu County by introducing modern techniques of geo observations and mapping for land use changes in the county. Such techniques include mapping of land features by use of remote sensing & GIS applications platforms, drones, and other geospatial applications.

c) Developmental control. This will assist in mitigating the negative effects of transformation of land. The present regulating authorities require more autonomy and strength in order to execute their mandate. The zoning regulations form the ground for developmental management and should be enforced.

d) Institutional and legal framework harmonization Various authorities and institutions apply a variety of laws and policies in land use management. Such backdrop has proven contradictory in their implementation of land administration uses over the years. These disagreements have occurred regularly amongst building authorities and authorities dealing in architecture, surveying, and the environment.

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7.1APPENDIX 1: RGS 3BB11 and 3BB12 Monthly daily average Flow

Table 7.1: RGS 3BB11 and 3BB12 Monthly daily average flows

	RGS 3BB11 Monthly daily average flow (m3/s)											
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1958			0.81	1.21	4.89	3.55	2.02	1.64	0.63	0.22	0.09	
1959			0.79	3.56	7.56	0.95	0.35	0.38	0.38	0.25	0.82	0.84
1960	0.25	0.12	0.59	1.55	0.92	0.45	0.38	0.35	0.40	0.53	1.42	0.55
1961	0.11	0.08	0.10	0.81	1.31	0.23	0.18	0.36	0.48	1.86	16.25	11.20
1962	9.58	4.45	2.87	3.19	8.06	4.34	3.11	2.32	1.80	1.75	1.85	1.81
1963	1.66	1.27	0.96	3.37	7.68	7.75	4.22	3.07	2.01	1.37	1.68	3.76
1964	2.12	1.06	1.45	4.21	4.23	3.32	2.42	2.33	1.51	1.16	1.35	1.41
1965	0.99	0.39	0.23	1.42	1.47	0.59	0.47	0.41	0.20	0.35	1.23	0.76
1966	0.34	0.45	1.08	3.57	3.14	2.00	1.32	0.99	1.15	0.63	1.91	0.30
1967	0.05	0.08	0.04	1.66	10.04	4.58	3.37	2.20	1.42	1.53	1.76	1.09
1968	0.39	0.63	3.28	3.47	5.60	4.82	3.53	2.65	1.55	0.98	6.68	7.62
1969	2.95	2.78	1.82	1.17	3.38	0.95	0.95	0.69	0.45	0.25	1.07	0.66
1970	0.63	0.20	0.10	8.05	3.48	2.67	1.61	1.02	0.66	0.49	1.05	0.30
1971	0.21	0.07	0.21	1.31	7.79	1.86	1.63	1.05	0.66	0.44	0.43	0.40
1972	0.52	0.42	0.24		0.69	0.99	0.29		0.28	0.39	2.63	0.68
1973	5.15	5.03	4.75	6.85	7.88	6.00	5.01	4.71	4.19	4.38	2.71	3.91
1974	4.46	3.79	4.39	11.62	8.90	7.30	11.87	7.51	7.26	6.29	7.56	6.17
1975	0.32	0.41	0.45	0.85	0.63	0.34	0.26	0.28	0.25	0.25	0.48	0.43
1976	0.36	0.50	0.48	0.46	0.32	0.40	0.37	0.46	0.50	0.60	0.51	0.17
1977	0.11	0.08	0.09	8.25	9.56	3.16	1.86	1.34	0.73	0.44	4.80	1.99
1978	1.63	0.97	3.82	11.05	10.65	5.96	3.78	1.98	1.55	1.48	1.79	2.01
1979	1.03	2.16	2.52	2.38	4.91	3.92	3.01	1.89	1.06	0.97	2.54	1.01
1980	0.60	0.86	0.50	1.21	4.44	2.50	1.44	1.05	0.68	0.63	4.17	2.12
1981	1.00	0.60	1.03	6.56	8.60	4.77	2.64	1.72	1.14	0.90	0.89	0.78
1982	0.36	0.16	0.08	1.09	1.22	0.75	0.66	0.57	0.49			

	RGS 3BB11 Monthly daily average flow (m3/s)											
1983				4.76	2.10	1.04	1.00	0.79				
1984												
1985												
1986												
1987	0.49	0.16	0.15	0.65	1.37	0.81	0.46	0.42	0.24	0.17	0.36	0.43
1988	0.29	0.14	0.23	2.80	7.44			1.30	1.45	0.93	1.82	1.24
1989	3.39	1.46	1.02	2.08	6.27	2.73	2.21	1.63	1.26	1.03	1.66	1.31
1990	2.93	1.06	3.59	6.77	5.25	4.41	2.80	1.93	1.27	1.06	2.85	2.43
1991	0.82	0.51	0.40	1.19	4.11	1.96	1.07	0.95	0.61	0.54	0.84	0.60
1992	0.31	0.08	0.01	1.10	1.98	0.65	0.54	0.41	0.35	0.45	1.00	
1993	1.72	1.50	0.51	0.48	0.55	0.75	0.26	0.14	0.11	0.08	0.42	1.16
1994	0.17	0.10	0.10	1.15	1.12	0.37						
1995												
1996												
1997												
1998												
1999										0.27	0.84	2.25
2000	0.32	0.17										
2001												
2002												
2003												
2004												
2005												
2006												
2007			0.35	1.53	1.10	1.31	0.81	0.66	0.68	0.39	0.43	0.21
2008	0.18	0.10	0.52	1.97	0.36	0.10	0.14	0.09	0.07	0.57	0.74	0.04
2009	0.03	0.03	0.03	0.05	0.13	0.06	0.01	0.00	0.03	0.20	0.27	0.15
2010	1.53	0.85	1.16	1.92	3.97	0.90	0.43	0.19	0.08	0.08	0.13	0.09
2011	0.04	0.01	0.06	0.12	0.34	0.04	0.01	0.01	0.04	0.18	1.89	

	RGS 3BB12 Monthly Daily Average flow (m3/s)											
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Annual**
1951				1.86			2.65	2.49	0.60	0.34	1.02		1.49
1952	3.03	2.29	1.28	1.70					2.89	1.92	2.56	1.93	2.20
1953	0.71	0.11	0.24	0.80	1.19	0.48	0.21	0.53	0.35	0.94	1.07	0.44	0.59
1954	0.10					0.30	0.77	0.34		0.03	0.46	0.01	0.29
1955	0.01	0.85	0.00	0.29	1.68	0.82	0.28	0.17	0.12	0.49	0.58	0.00	0.44
1956	0.10	0.00	0.01	0.05	0.07	0.02	0.01	0.01	0.00	0.00	0.07	0.01	0.03
1957	0.00	0.06	0.01	0.27	1.04	0.58	0.30	0.23	0.14	0.09	0.15	0.16	0.25
1958	0.09	0.47	0.09	0.19	1.52	0.76	0.66	0.37	0.25	0.18	0.15	0.16	0.41
1959	0.08	0.04	0.06	0.07	0.20	0.04	0.03	0.02	0.02	0.01	0.20	0.20	0.08
1960	0.02	0.01	0.12	0.32	0.07	0.05	0.04	0.03	0.03	0.05	0.31	0.04	0.09
1961	0.01	0.01	0.02	0.07	0.20	0.01	0.01	0.02	0.05	0.22	1.61	1.76	0.33
1962	1.57	0.85	0.57	0.62	1.28	0.72	0.52	0.38	0.27	0.23	0.22	0.21	0.62
1963	0.22	0.15	0.12	0.37	1.66	1.45	0.97	0.66	0.43	0.29	0.38	0.72	0.62
1964	0.46	0.20	0.30	0.89	0.77	0.60	0.45	0.48	0.29	0.21	0.20	0.22	0.42
1965	0.14	0.07	0.04	0.35	0.29	0.11	0.09	0.06	0.03	0.05	0.15	0.08	0.12
1966	0.05	0.07	0.11	0.61	0.46	0.20	0.15	0.13	0.12	0.06	0.22	0.05	0.19
1967	0.01	0.01	0.01	0.16	1.30	0.65	0.47	0.33	0.23	0.31	0.35	0.18	0.33
1968	0.07	0.08	0.40	0.52	0.86	0.94	0.65	0.56	0.31	0.20	1.32	1.16	0.59
1969	0.55	0.46	0.39	0.20	0.56	0.17	0.13	0.11	0.09	0.06	0.09	0.05	0.24
1970	0.05	0.02	0.02	1.38	0.50	0.50	0.15	0.19	0.17	0.11	0.35	0.06	0.29
1971	0.04	0.01	0.00	0.40	0.90	0.43	0.35	0.18	0.10	0.06	0.06	0.13	0.22
1972	0.08	0.04	0.02	0.00	0.15	0.18	0.03	0.01	0.01	0.03	0.38	0.06	0.08
1973		0.01	0.00	0.08	0.04	0.01	0.00	0.00	0.00	0.00	0.02	0.00	0.02
1974	0.00	0.00	0.00	0.32	0.18	0.12	0.51	0.10	0.11	0.06	0.11	0.05	0.13
1975	0.00	0.01	0.02	0.24	0.10	0.01	0.01	0.01	0.01	0.02	0.08	0.04	0.05
1976	0.00	0.00	0.00	0.05	0.07	0.02	0.01	0.00	0.00		0.00	0.03	0.02
1977	0.00	0.04	0.01	2.28	2.48	1.28	0.73	0.51	0.28	0.40	1.26	1.11	0.86
1978	0.90	0.47	0.85	2.58	1.47	2.94	1.87	1.11	0.76	0.88	0.95	0.22	1.25
1979	0.52	0.25	0.52	2.81	6.32	1.29	11.47	2.29	1.13	0.81	0.44	0.14	2.33
1980	0.06	0.06	0.04	0.15	0.51	0.31	0.16	0.10	0.06	0.06	0.68	0.35	0.21
1981	0.11	0.04	0.15	1.13	1.18	0.64	0.44	0.30	0.19	0.28	0.27	0.26	0.42
1982	0.09	0.00	0.02	0.25	0.39	0.16	0.10	0.07	0.04				0.13

	RGS 3BB12 Monthly Daily Average flow (m3/s)												
1983				0.71	0.46	0.23	0.21	0.15					0.35
1984													
1985													
1986													
1987	0.07	0.00		0.07	0.24	0.15	0.04	0.00	0.00	0.01	0.02	0.01	0.05
1988	0.01	0.00	0.00	0.34	1.12			0.31	0.27	0.18	0.33	0.34	0.29
1989	0.45	0.24	0.23	0.41	0.94	0.55	0.58	0.41	0.35	0.28	0.41	0.36	0.43
1990	0.55	0.24	1.08	1.25	1.15	0.97	0.75	0.56	0.41	0.78	0.61	0.76	0.76
1991	0.30	0.14	0.05	0.35	0.89	0.56	0.34	0.20	0.10	0.05	0.28	0.15	0.29
1992	0.05	0.01		0.24	0.49	0.20	0.18	0.12	0.11	0.14	0.58		0.21
1993	0.41	0.28	0.14	0.15	0.19	0.26	0.11	0.07	0.04	0.05	0.10	0.22	0.17
1994	0.02	0.01	0.01	0.32	0.63	0.10	0.07	0.02	0.00	0.10	0.80	0.46	0.21
1995	0.10	0.04			0.75	0.36	0.29	0.17					0.28
1996	0.11	0.10	0.17	0.32	0.16	0.55	0.11	0.11	0.09	0.04	0.65	0.19	0.22
1997	0.08	0.04											0.06
1998													
1999												0.41	0.41
2000	0.08	0.03	0.04	0.08	0.06	0.06	0.05	0.03	0.03	0.03	0.06	0.08	0.05
2001	0.10	0.07	0.07	0.38	0.28	0.12	0.15	0.12	0.06	0.24	0.20	0.05	0.15
2002	0.06	0.01	0.08	0.30	0.88	0.25	0.10	0.05	0.03	0.13	0.48	0.37	0.23
2003	0.28	0.10	0.11	0.30	0.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14
2004	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.08	0.04	0.15	0.05	0.03
2006	0.02	0.03	0.12	1.08	0.95	0.40	0.40	0.00	0.00	0.00	0.81	0.79	0.38
2007	0.00	0.00	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
2008	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.05	1.34	1.50	0.78	0.39
2009	0.59	0.53	0.37	0.61	0.78	0.51	0.43	0.18	0.00	0.00	0.00	0.32	0.36
2010	0.39	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.04
2011													
2012													
2013													
2014							0.22	0.22	0.26	0.25	0.42	0.30	0.28

7.2APPENDIX 2: RGS 3BB12 Time-series Plots

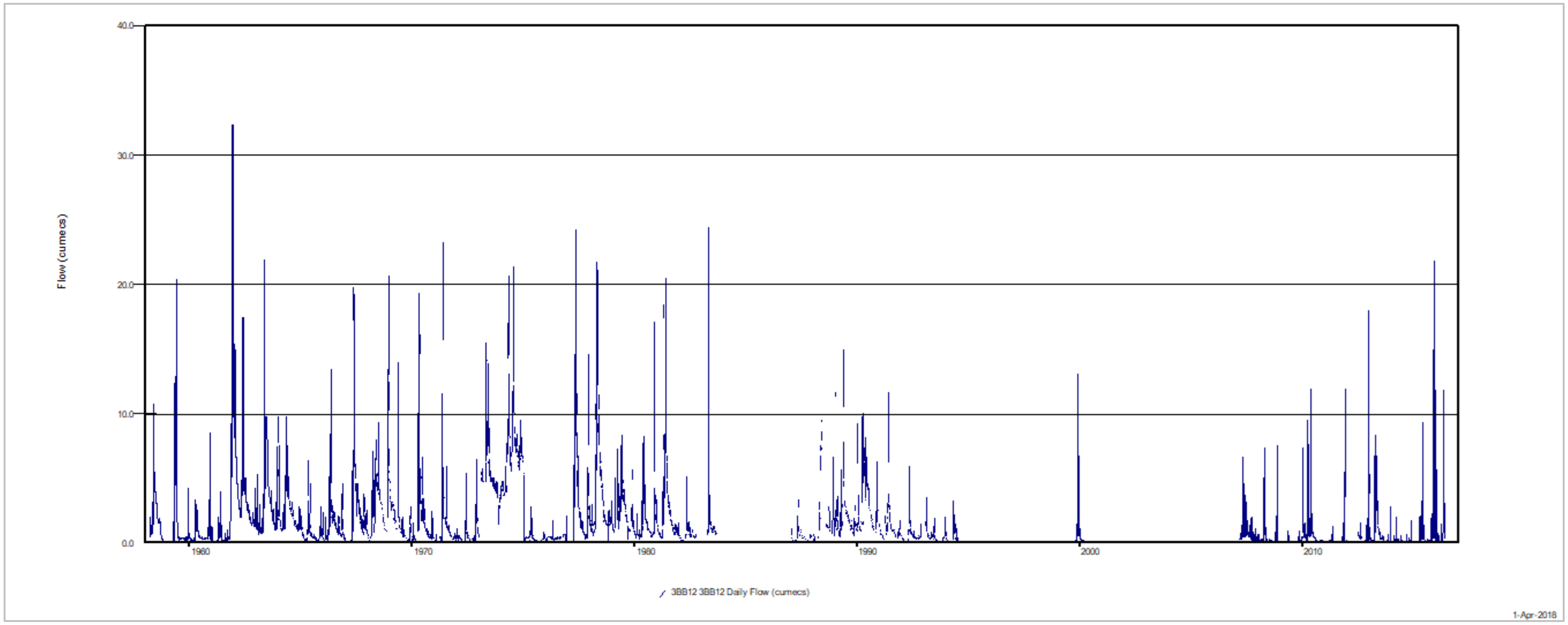


Figure 7.1: Time-series plot for RGS 3BB12 for the period 1954 - 2018

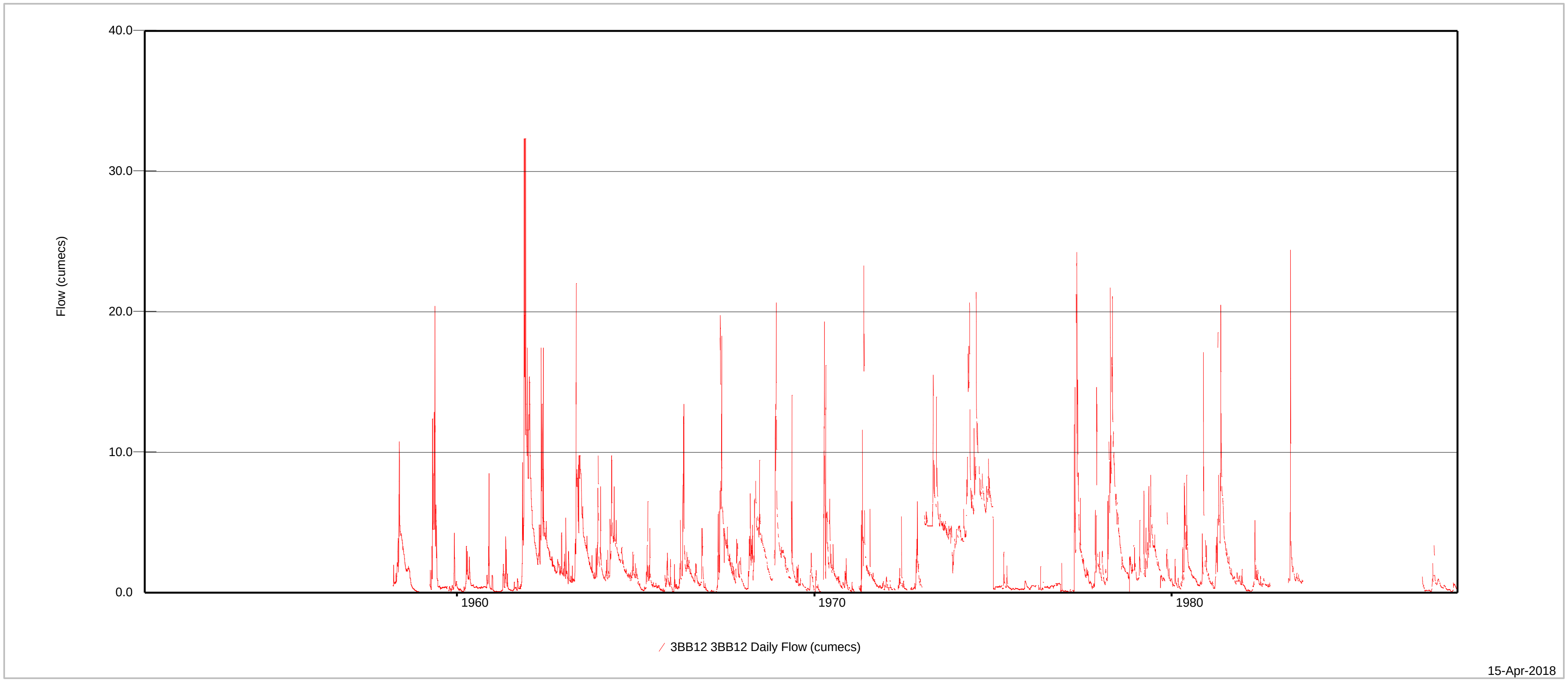


Figure 7.2: Time series plot for RGS 3BB12 for the period 1954 - 1987

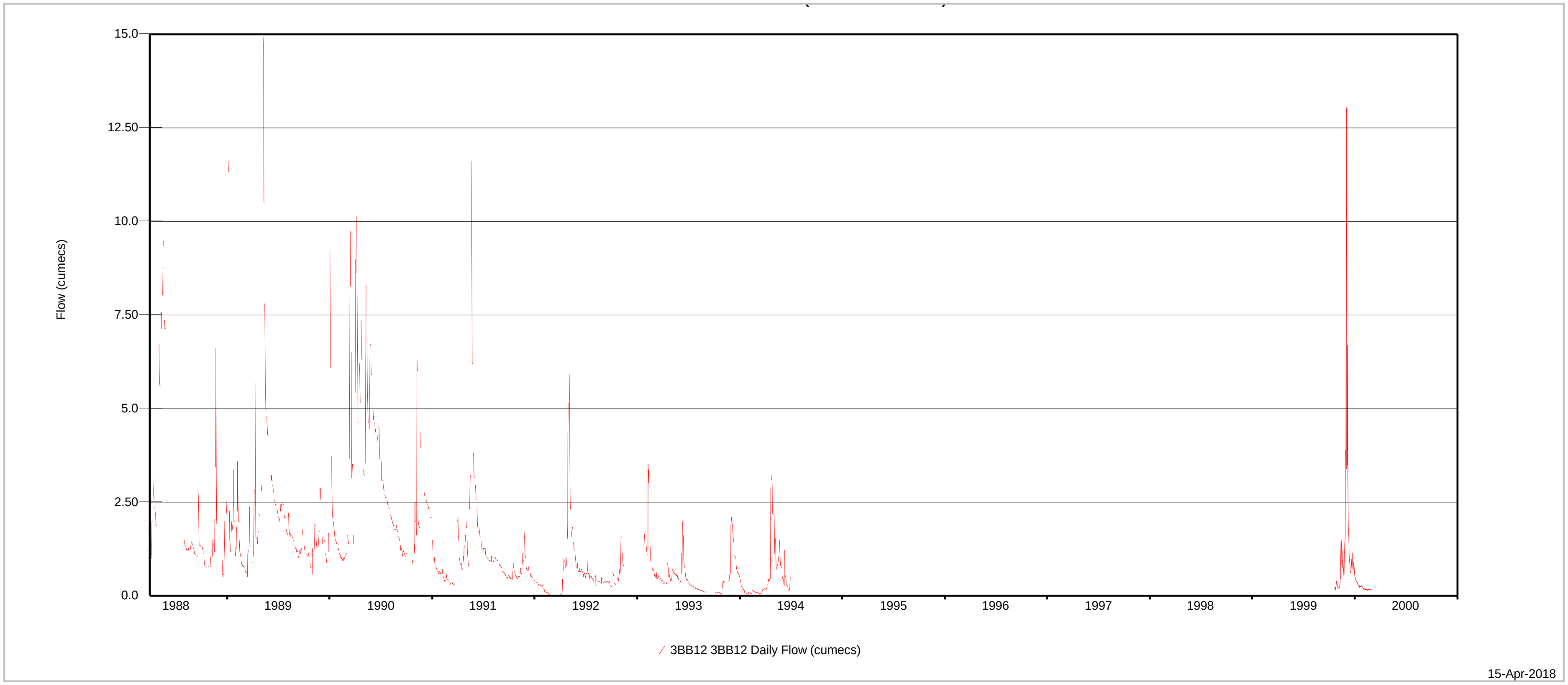


Figure 7.3: Time series plot for RGS 3BB12 for the period 1988 - 2000

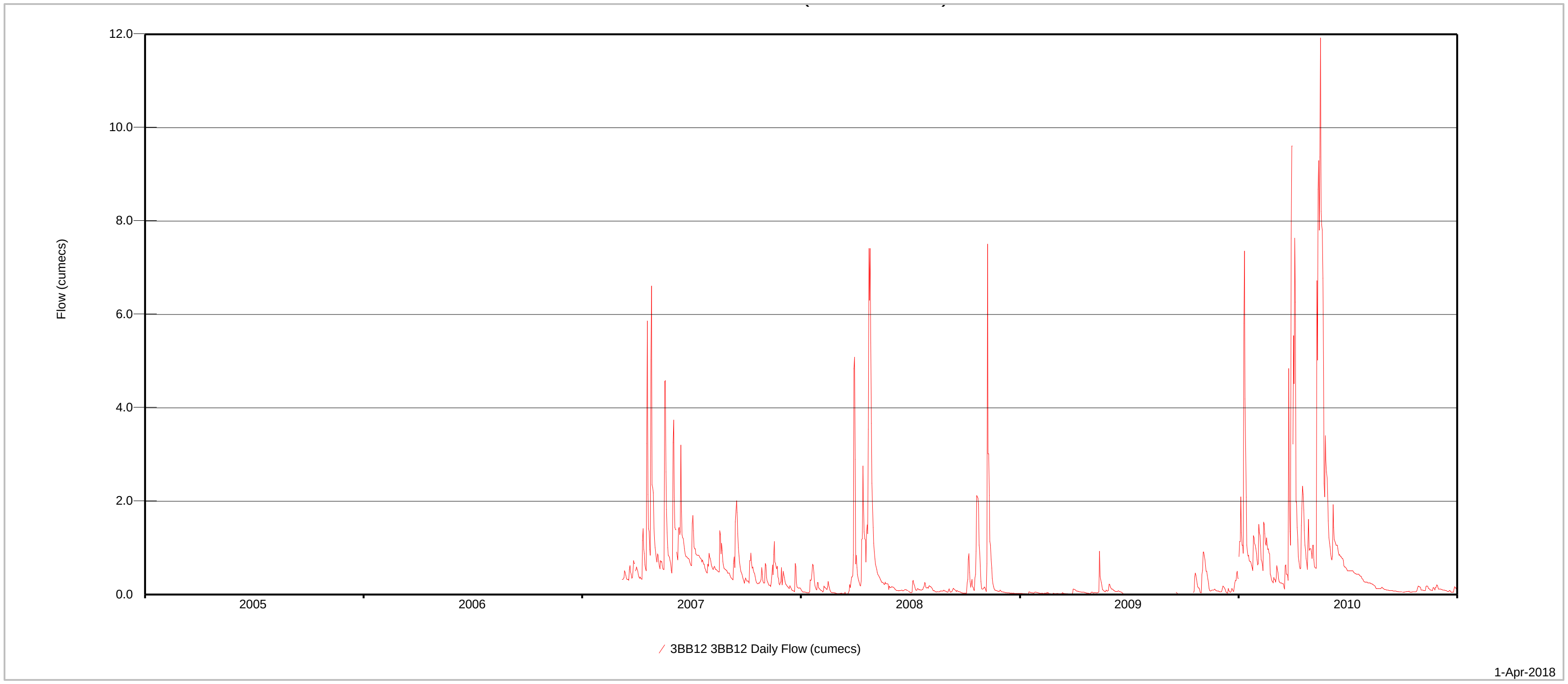


Figure 7.4: Time series plot for RGS 3BB12 for the period 2005 - 2010

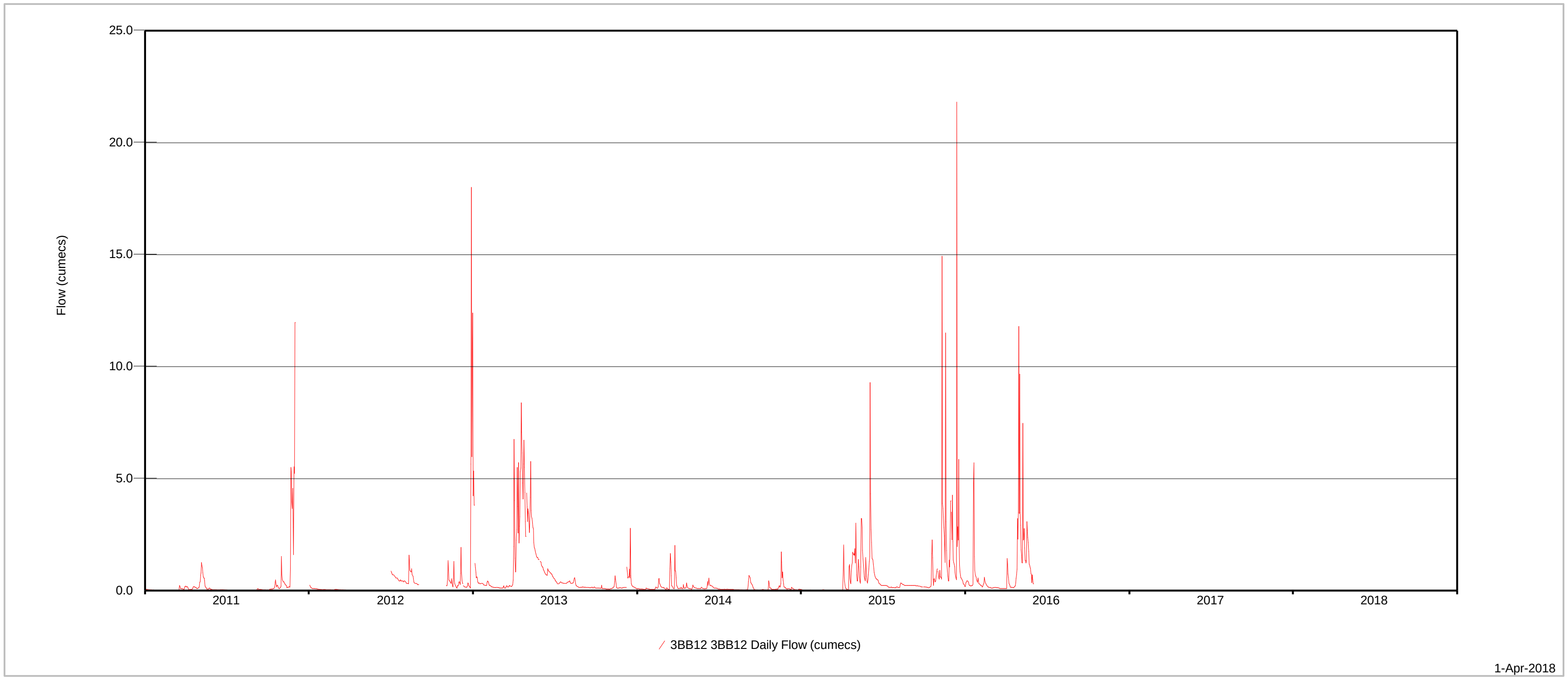


Figure 7.5: Time series plot for RGS 3BB12 for the period 2011 - 2018

7.3APPENDIX 3: Flow Duration Curves

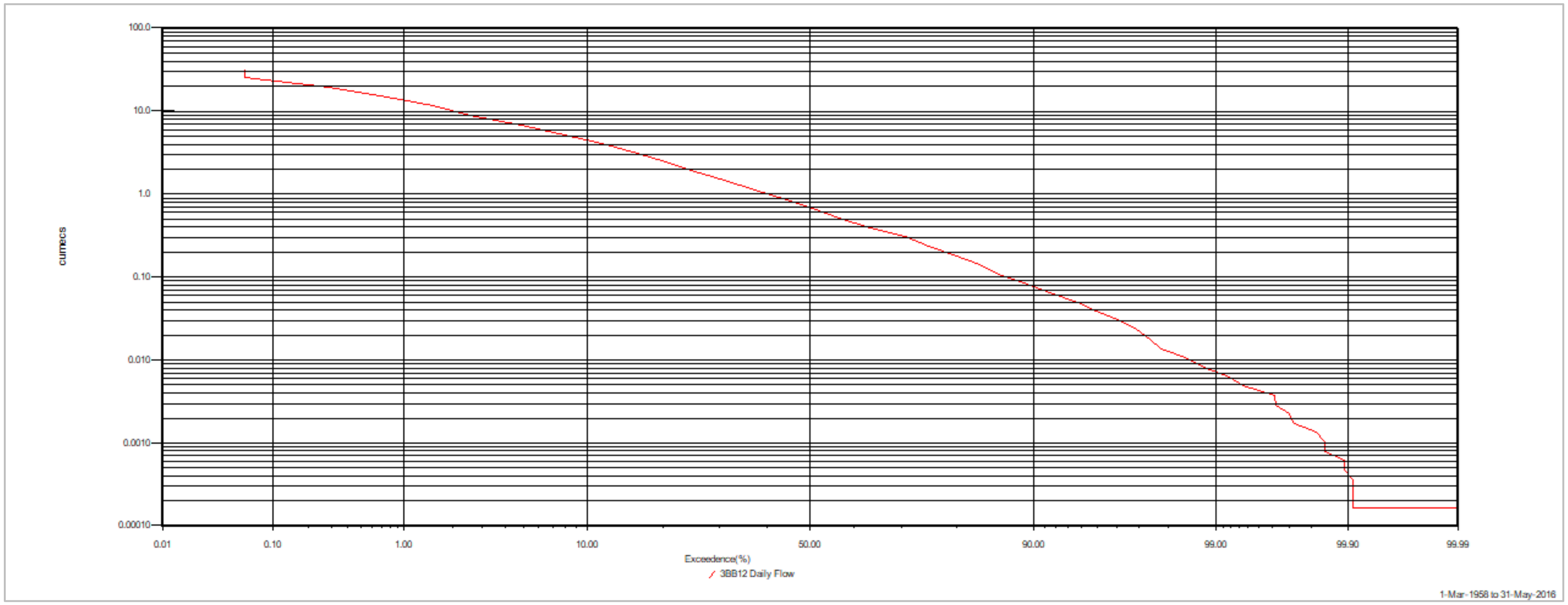


Figure 7.6: Daily flow duration curve for RGS 3BB12 for the period 1958 - 2018

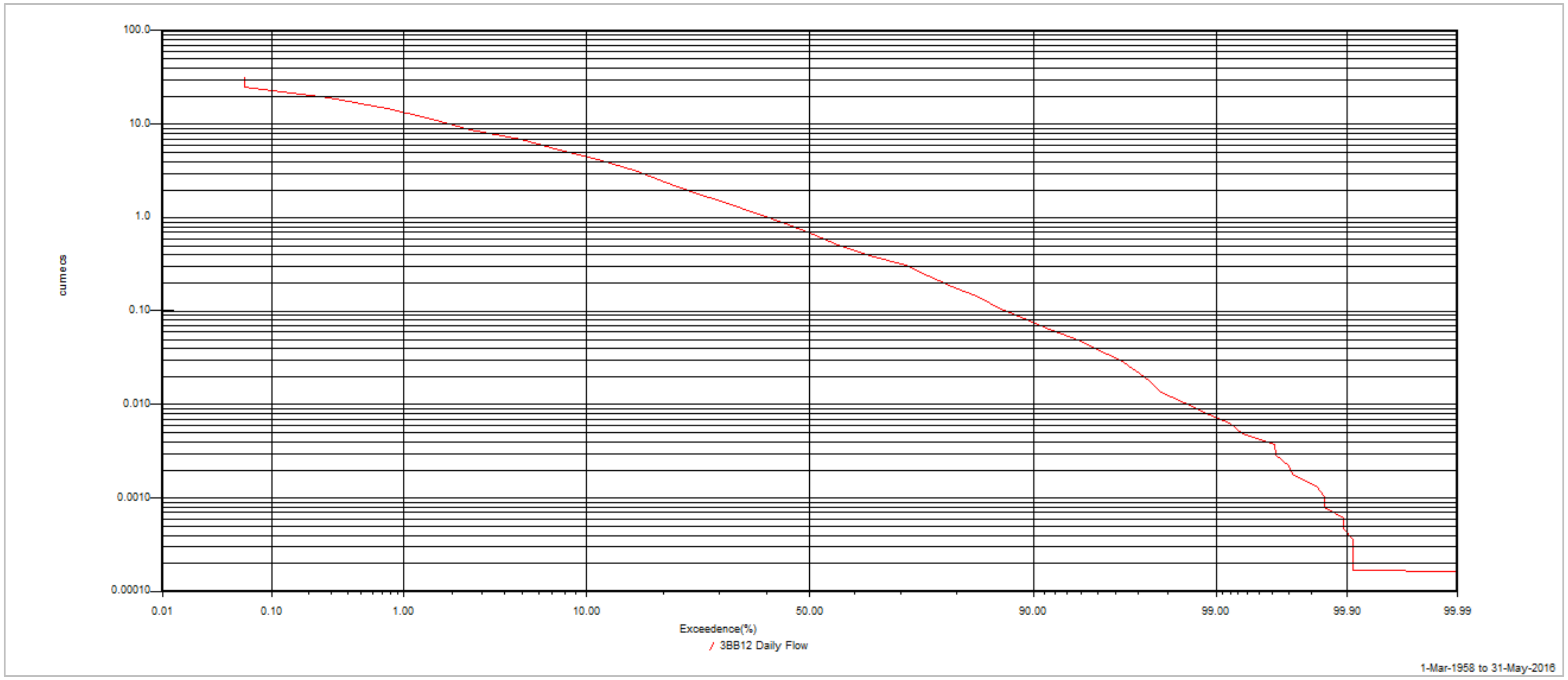


Figure 7.7: Daily flow duration curve for RGS 3BB12 for the period 1958 - 1987

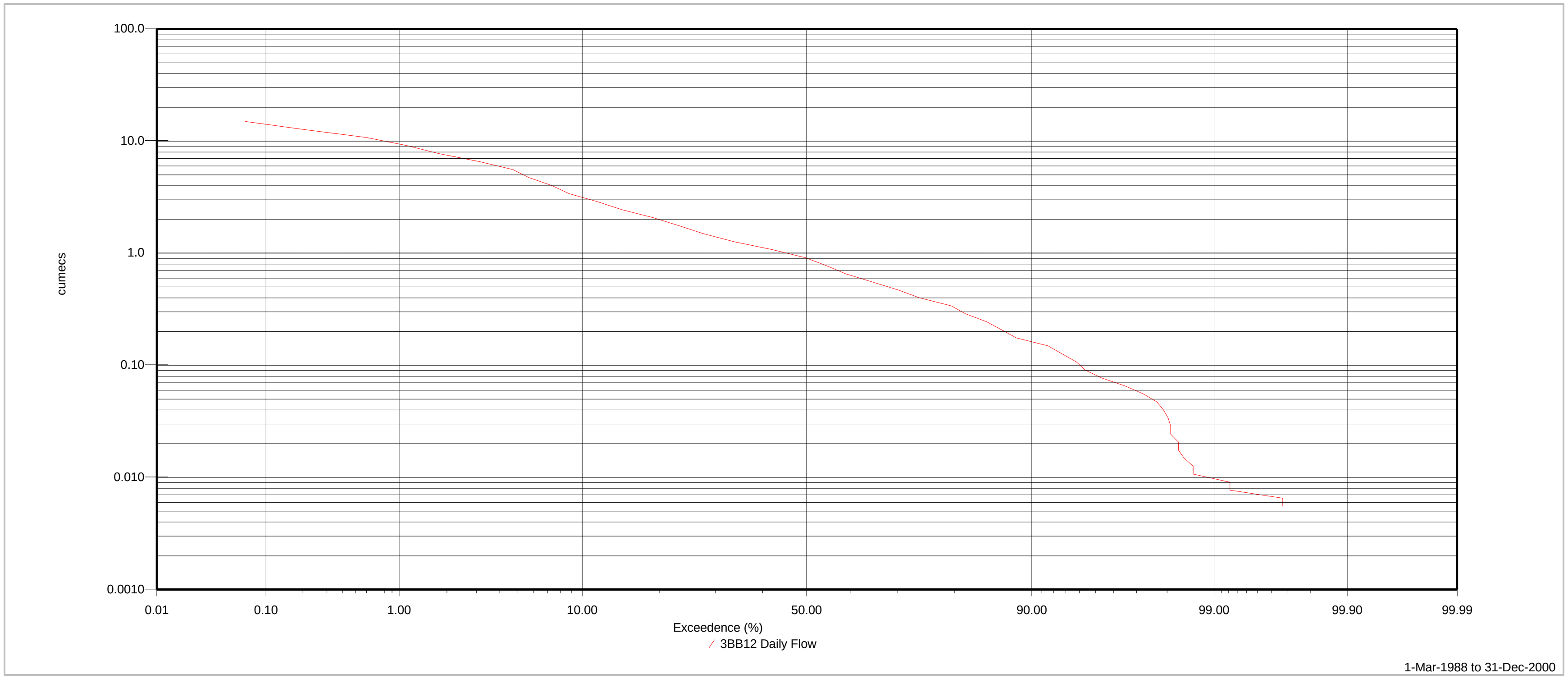


Figure 7.8: Daily flow duration curve for RGS 3BB12 for the period 1987 - 2000

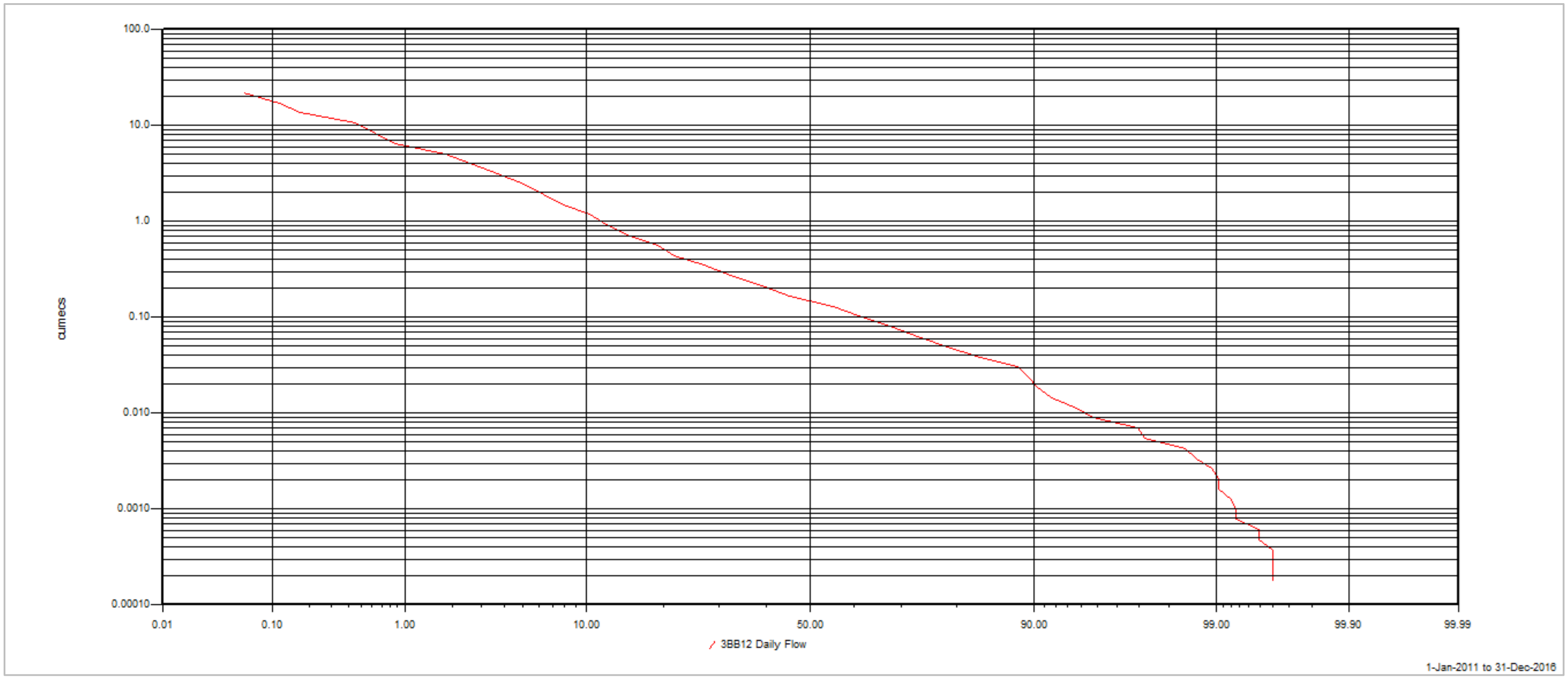


Figure 7.9: Daily flow duration curve for RGS 3BB12 for the period 2011 - 2016

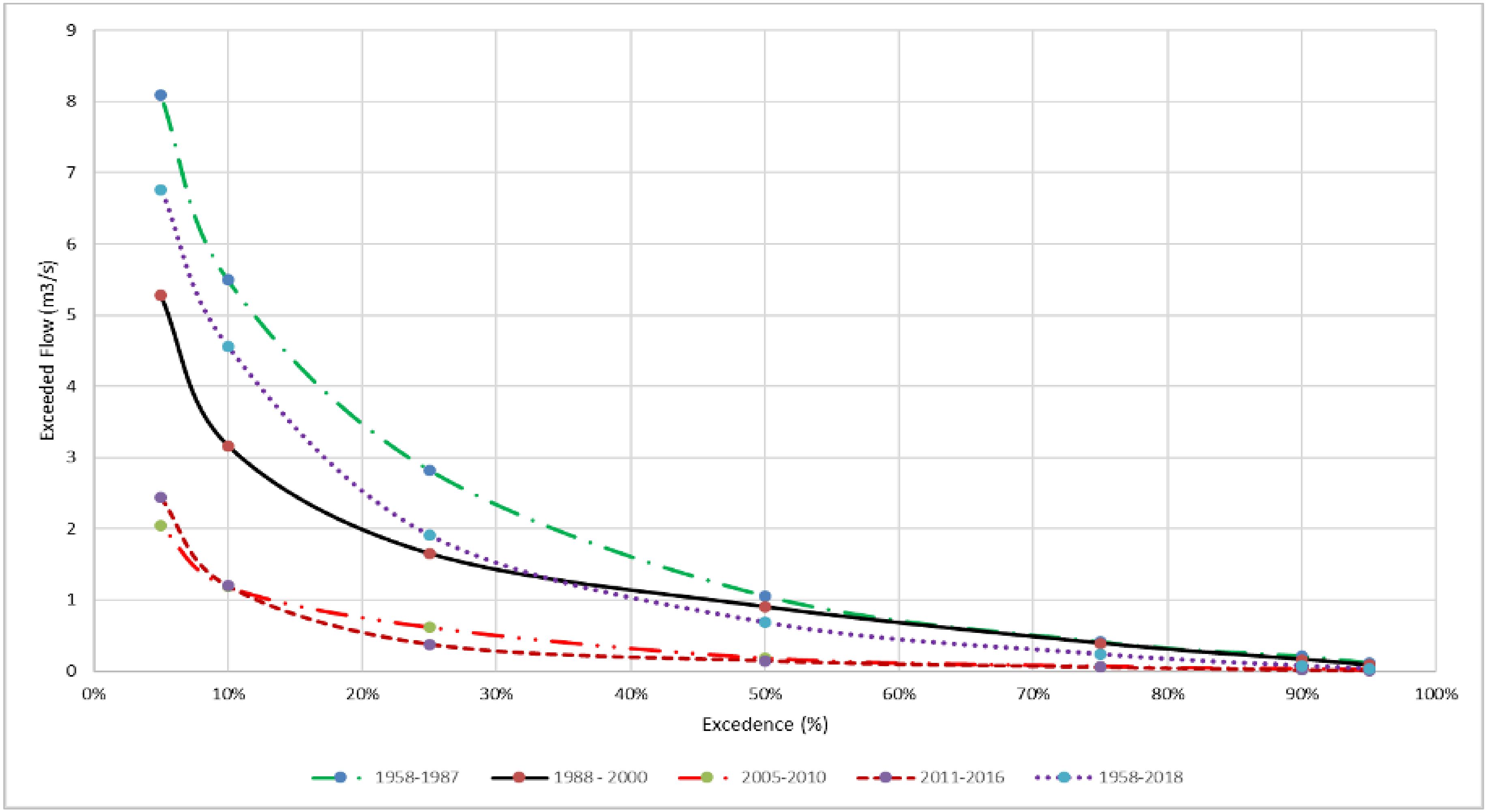


Figure 7.10: Daily flow duration comparison curves for RGS 3BB12 for the different time periods

7.4APPENDIX 4: Low Flow Frequency Graph

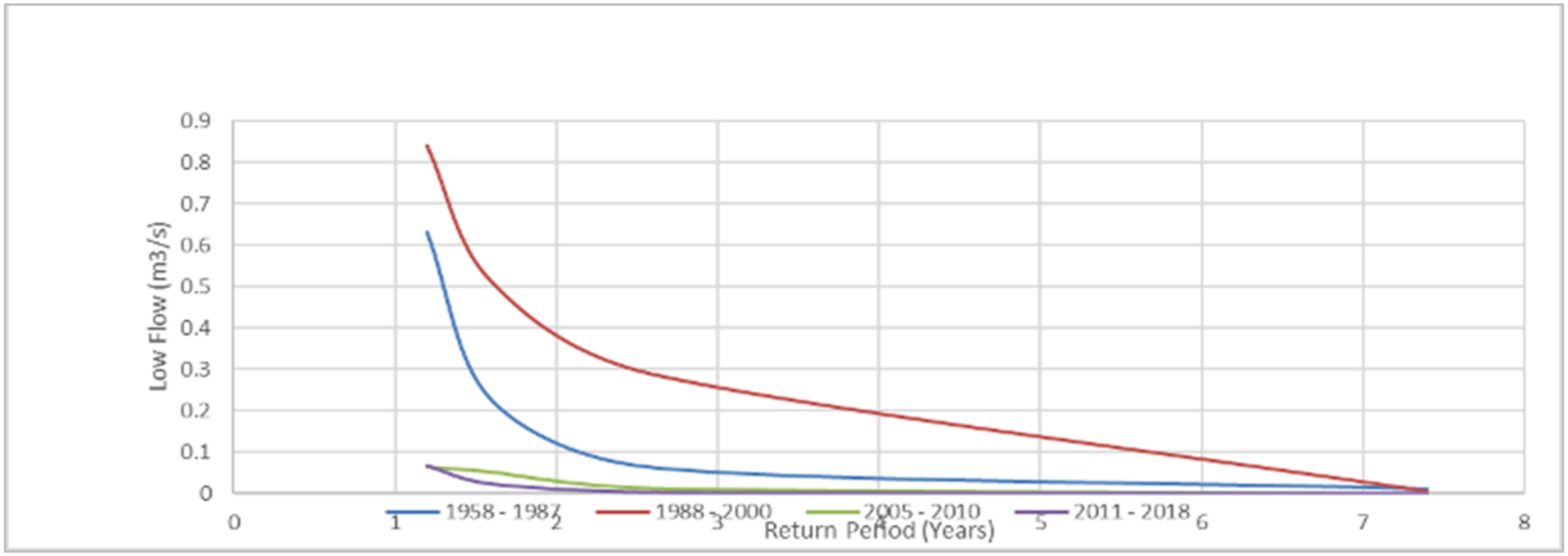


Figure 7.11: Low flow frequency curves comparison for the different time periods

7.5APPENDIX 5: Annual Maximum Flows table

Table 7.2: RGS 3BB12 Annual maximum flow table

	Maximum flow (m3/s)											
Year	1	2	3	4	5	6	7	8	9	10	11	12	Annual Max
1958			1.98	2.15	10.76	4.19	2.72	1.90	1.07	0.32	0.14		10.76
1959			1.61	12.37	20.40	4.78	0.51	0.44	0.46	0.46	4.25	2.49	20.40
1960	0.33	0.23	3.30	3.30	2.55	0.56	0.48	0.41	0.44	1.26	8.49	1.26	8.49
1961	0.16	0.10	0.19	2.02	4.00	0.33	0.26	0.75	1.02	9.28	32.31	17.43	32.31
1962	15.37	5.86	3.59	4.83	17.43	5.08	3.74	2.96	2.03	2.38	4.27	4.27	17.43
1963	5.33	2.96	1.92	22.01	9.75	9.75	6.13	4.04	2.51	2.67	3.41	9.75	22.01
1964	7.55	1.54	3.03	9.75	7.55	5.16	2.83	3.23	1.70	1.39	2.89	2.70	9.75
1965	1.75	0.67	0.41	6.50	4.58	0.86	0.67	0.53	0.27	1.25	2.83	2.38	6.50
1966	2.03	0.94	5.16	12.55	13.42	2.89	1.70	1.39	2.09	0.98	4.58	0.67	13.42
1967	0.16	0.18	0.14	5.77	19.74	6.13	4.67	2.76	2.14	3.81	3.52	2.51	19.74
1968	0.63	1.64	7.06	11.82	8.89	9.42	4.11	3.16	1.97	1.16	13.42	20.64	20.64
1969	3.52	3.03	2.51	1.70	14.06	1.30	1.97	1.02	0.56	0.41	2.83	1.44	14.06
1970	1.59	0.60	0.94	19.30	5.77	6.68	3.45	1.25	1.16	0.74	2.45	0.56	19.30
1971	0.74	0.25	0.47	5.86	23.27	2.57	5.95	1.41	0.94	0.51	0.68	0.79	23.27
1972	1.13	0.85	0.31		1.75	5.42	0.45		0.37	0.66	6.50	1.13	6.50
1973	5.51	5.77	4.75	15.50	13.93	9.10	5.59	5.08	4.58	4.75	4.35	4.67	15.50
1974	4.75	4.19	5.95	17.56	20.64	11.70	21.40	8.99	8.78	7.55	9.53	6.97	21.40
1975	0.43	0.45	0.51	2.89	1.92	0.43	0.31	0.33	0.31	0.30	0.82	0.68	2.89
1976	0.51	0.51	0.51	1.86	0.77	0.43	0.47	0.49	0.63	0.66	2.10	0.54	2.10
1977	0.17	0.23	0.18	23.43	24.23	6.74	2.46	1.78	0.90	0.65	14.62	2.91	24.23
1978	2.98	1.68	14.98	21.71	21.09	7.03	5.34	2.56	1.77	2.56	2.56	3.37	21.71
1979	1.22	5.15	7.25	4.62	8.38	4.88	4.13	2.20	1.58	1.10	5.71	1.72	8.38
1980	0.88	2.38	1.06	3.22	8.38	4.80	1.77	1.18	0.95	0.84	17.10	3.74	17.10
1981	1.39	0.77	3.37	18.52	20.49	6.71	3.44	2.56	1.58	1.44	1.22	1.67	20.49
1982	0.54	0.23	0.20	5.15	1.98	1.18	1.02	0.65	0.71				5.15
1983				24.39	3.66	1.35	1.39	0.91					24.39
1984													

	Maximum flow (m3/s)												
Year	1	2	3	4	5	6	7	8	9	10	11	12	Annual Max
1985													
1986													
1987	1.14	0.20	0.20	2.09	3.37	0.98	0.68	0.54	0.31	0.25	0.71	0.59	3.37
1988	0.65	0.16	0.54	11.47	9.48			1.48	2.82	1.30	6.61	2.56	11.47
1989	11.61	3.59	2.38	5.71	14.93	3.37	2.50	2.20	1.77	1.35	2.88	1.72	14.93
1990	9.23	1.26	9.73	10.12	8.26	5.06	3.66	2.32	1.58	1.39	6.30	2.75	10.12
1991	1.48	0.71	1.48	2.09	11.61	2.95	1.30	1.06	0.81	0.88	1.72	0.77	11.61
1992	0.41	0.20	0.01	5.15	5.90	0.88	0.95	0.54	0.39	0.71	1.58		5.90
1993	2.50	3.51	0.71	0.88	0.71	1.98	0.39	0.19	0.11	0.10	0.65	2.09	3.51
1994	0.44	0.16	0.20	3.22	2.20	1.22							3.22
1995													
1996													
1997													
1998													
1999										0.39	3.90	13.03	13.03
2000	0.59	0.20											0.59
2001													
2002													
2003													
2004													
2005													
2006													
2007			0.73	6.61	4.58	3.74	1.70	1.37	2.01	0.89	1.14	0.67	6.61
2008	0.65	0.28	5.08	7.41	1.10	0.16	0.31	0.19	0.14	2.12	7.51	0.06	7.51
2009	0.06	0.05	0.12	0.11	0.93	0.14	0.01	0.01	0.05	0.46	0.91	0.50	0.93
2010	7.36	1.55	9.60	7.63	11.92	1.93	0.51	0.27	0.11	0.19	0.21	0.17	11.92
2011	0.08	0.02	0.23	0.20	1.26	0.04	0.03	0.01	0.10	1.53	11.97		11.97

7.6APPENDIX 6: Flow Duration curves calculation sheets

FLOW DURATION CURVES CALCULATION SHEETS

1958-1987		1958-2018		1988 - 2000		2011-2016		2005-2010	
95 percentile (Q95)	0.118	Mean daily flow	1.682	Mean daily flow	1.427	Mean daily flow	0.53	Mean daily flow	0.562
90 percentile (Q90)	0.211								
75 percentile (Q75)	0.413	95 percentile (Q95)	0.038	95 percentile (Q95)	0.082	95 percentile (Q95)	0.009	95 percentile (Q95)	0.015
50 percentile (Q50)	1.059	90 percentile (Q90)	0.076	90 percentile (Q90)	0.162	90 percentile (Q90)	0.02	90 percentile (Q90)	0.027
25 percentile (Q25)	2.825	75 percentile (Q75)	0.238	75 percentile (Q75)	0.389	75 percentile (Q75)	0.058	75 percentile (Q75)	0.064
10 percentile (Q10)	5.494	50 percentile (Q50)	0.684	50 percentile (Q50)	0.901	50 percentile (Q50)	0.148	50 percentile (Q50)	0.178
5 percentile (Q5)	8.098	25 percentile (Q25)	1.907	25 percentile (Q25)	1.648	25 percentile (Q25)	0.38	25 percentile (Q25)	0.612
		10 percentile (Q10)	4.556	10 percentile (Q10)	3.165	10 percentile (Q10)	1.2	10 percentile (Q10)	1.184
Mean daily flow	2.214	5 percentile (Q5)	6.768	5 percentile (Q5)	5.275	5 percentile (Q5)	2.445	5 percentile (Q5)	2.046

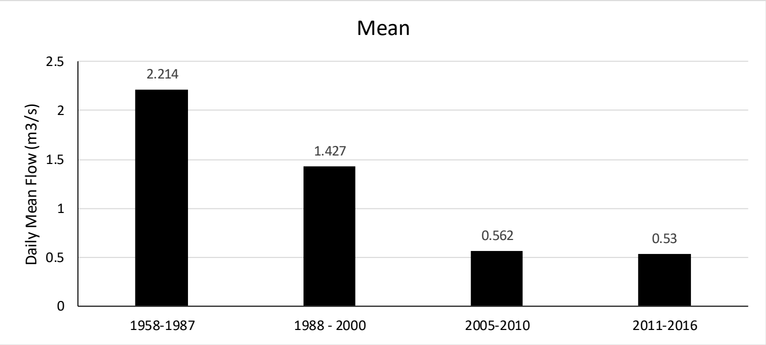
Percentiles in cumecs

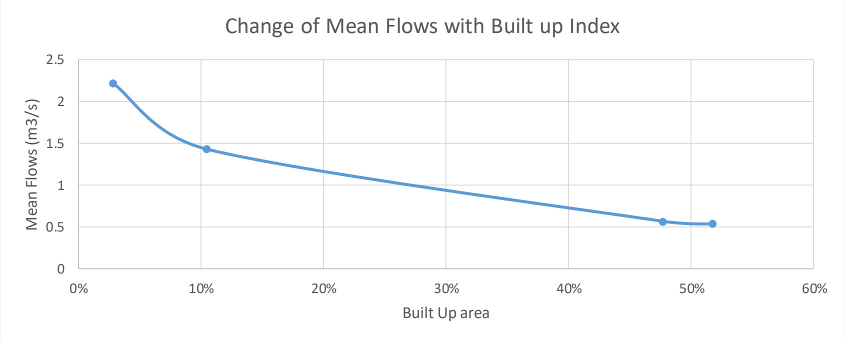
Exceedence (%)	**1958-1987**	**1988 - 2000**	**2005-2010**	**2011-2016**	**1958-2018**
95%	0.118	0.082	0.015	0.009	0.038
90%	0.211	0.162	0.027	0.02	0.076
75%	0.413	0.389	0.064	0.058	0.238
50%	1.059	0.901	0.178	0.148	0.684
25%	2.825	1.648	0.612	0.38	1.907
10%	5.494	3.165	1.184	1.2	4.556
5%	8.098	5.275	2.046	2.445	6.768
Mean	2.214	1.427	0.562	0.53	1.682

Years	**1958-1987**	**1988 - 2000**	**2005-2010**	**2011-2016**	**1958-2018**
Mean	2.214	1.427	0.562	0.53	1.682

1987	2000	2005	2010	2018
3%	10%	27%	48%	52%

	Mean Flow	Built Up Index
1987	2.214	3%
2000	1.427	10%
2010	0.562	48%
2018	0.53	52%





LOW FLOWS CALCULATION SHEET

1958 - 1987

Water year	Start Date	Rank	Flow (cum	Return Per	Exceedance Probability
1973	09-Nov-73	1	1.414	1	0.023
1962	24-Dec-62	2	1.156	1.1	0.065
1964	20-Feb-64	3	0.858	1.1	0.106
1963	05-Feb-63	4	0.633	1.2	0.148
1979	05-Sep-79	5	0.348	1.2	0.189
1981	05-Mar-81	6	0.307	1.3	0.231
1974	31-Dec-74	7	0.278	1.4	0.272
1980	27-Mar-80	8	0.269	1.5	0.313
1968	01-Feb-68	9	0.225	1.6	0.355
1975	01-Jul-75	10	0.201	1.7	0.396
1976	17-Nov-76	11	0.086	1.8	0.438
1959	25-Oct-59	12	0.08	1.9	0.479
1965	13-Oct-65	13	0.075	2.1	0.521
1958	26-Nov-58	14	0.067	2.3	0.562
1969	28-Dec-69	15	0.062	2.5	0.604
1966	11-Jan-66	16	0.062	2.8	0.645
1987	31-Mar-87	17	0.059	3.2	0.687
1960	28-Feb-60	18	0.058	3.7	0.728
1961	23-Feb-61	19	0.058	4.3	0.769
1977	13-Mar-77	20	0.05	5.3	0.811
1978	10-Dec-78	21	0.01	6.8	0.852
1967	26-Feb-67	22	0.006	9.4	0.894
1971	22-Feb-71	23	0.002	15.5	0.935
1970	13-Mar-70	24	0.002	43.1	0.977
1972	Insufficient data				
1982	Insufficient data				
1983	Insufficient data				
1984	Insufficient data				
1985	Insufficient data				
1986	Insufficient data				

Average number of days the minimum starts from the beginning of the water year : 172

Average Daily Flow	Mean Annual Minimum	Units
2.214	0.265	cumecs
247.8	29.7	Runoff; mm

1988 - 2000

Water year	Start Date	Rank	Flow (cum	Return Per	Exceedance Probability
1990	22-Oct-90	1	0.841	1.2	0.136
1989	13-Mar-89	2	0.512	1.6	0.379
1991	21-Mar-91	3	0.288	2.6	0.621
1992	18-Mar-92	4	0.005	7.4	0.864
1988	Insufficient data				
1993	Insufficient data				
1994	Insufficient data				
1995	Insufficient data				
1996	Insufficient data				
1997	Insufficient data				
1998	Insufficient data				
1999	Insufficient data				
2000	Insufficient data				

Average number of days the minimum starts from the beginning of the water year : 130

Average Dai	Mean Annual I	Units
1.399	0.411	cumecs
156.6	46	Runoff; mm

Return Period (Years)	1958 - 1987	1988 - 2000	2005 - 2010	2011 - 2018
1.2	0.633	0.841	0.064	0.068
1.6	0.225	0.512	0.052	0.024
2.6	0.062	0.288	0.013	0.004
7.4	0.01	0.005	0	0
Mean Annual Minimum	0.265	0.411	0.032	0.024

2005 - 2010

Water yea	Start Date	Rank	Flow (cum	Return Per	Exceedance Probability
2007	21-Dec-07	1	0.064	1.2	0.136
2010	01-Oct-10	2	0.052	1.6	0.379
2008	17-Mar-08	3	0.013	2.6	0.621
2009	30-Jul-09	4	0	7.4	0.864
2005	Insufficient data				
2006	Insufficient data				

Average number of days the minimum starts from the beginning of the water yea

Average D	Mean Annual I	Units
0.562	0.032	cumecs
62.8	3.6	Runoff; mm

2011 - 2018

Water yea	Start Date	Rank	Flow (cum	Return Per	Exceedance Probability
2013	30-Oct-13	1	0.068	1.2	0.136
2014	28-Sep-14	2	0.024	1.6	0.379
2011	30-Jul-11	3	0.004	2.6	0.621
2015	10-Feb-15	4	0	7.4	0.864
2012	Insufficient data				
2016	Insufficient data				
2017	Insufficient data				
2018	Insufficient data				

Average number of days the minimum starts
from the beginning of the water year : 2006

Average D	Mean Annual M	Units
0.53	0.024	cumecs
59.3	2.7	Runoff; mm

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