EFFECTS OF LAND USE/LAND COVER CHANGE AND RAINFALL VARIABILITY ON HYDROLOGICAL CHARACTERISTICS OF RIVER RUIRU WATERSHED, KIAMBU COUNTY, KENYA

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NOVEMBER, 2021

DECLARATION

I declare that this thesis is my original work and has not been presented for the award of a degree or any other award in any other university.

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DEDICATION

I dedicate this work to my husband David and my sons Ian, Ryan and Isaac.

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May God bless you ALL.

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ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
APHA	American Public Health Association
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
BOD	Biochemical Oxygen Demand
CIDP	County Integrated Development Programme
CWFs	Catchment Water Functions
DEM	Digital Elevation Model
DO	Dissolved Oxygen
DPSIR	Driving forces, Pressures, States, Impacts and Responses
E. coli	*Escherichia coli*
ESIA	Environmental and Social Impact Assessment
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GLUE	Generalized Likelihood Uncertainty Estimation
GOK	Government of Kenya
GPS	Global Positioning System
GWQ	Groundwater contribution to discharge
HPC	Heterotrophic Plate Count
HRUs	Hydrologic Response Units
ISRIC	International Soil Reference and Information Centre

IWRM	Integrated Water Resources Management
KENSOTER	Kenya Soil and Terrain Database
KMD	Kenya Meteorological Department
KSS	Kenya Soil Survey
LATQ	Lateral runoff
LULC	Land use/land cover
LULCC	Land use/land cover change
MEA	Millennium Ecosystem Assessment
MEMR	Ministry of Environment and Mineral Resources
MOA	Ministry of Agriculture
MPN	Most Probable Number
MSS	Multi-Spectral Scanner
NCEP-CFSR	National Centre for Environmental Prediction-Climate Forecast system Reanalysis
NEMA	National Environment Management Authority
NO_3LATQ	Nitrates in the lateral runoff
NO_3SURQ	Nitrates in the surface runoff
N.ORG	Organic Nitrogen
NSE	Nash-Sutcliffe Efficiency
NTU	Nephelometric Turbidity Units
NWCCP	National Water Catchment Conservation Programme

OAT	One- at-Time
OLI/TIRS	Operational Land Images/ Thermal Infra-Red Sensor
PARASOL	Parameter solution
PBIAS	Percent bias
PSO	Particle Swarm Optimization
P.ORG	Organic Phosphorus
PPU	Percent Prediction Uncertainty
R^2	Coefficient of determination
RSR	Observations Standard Deviation Ratio
SCS-CN	Soil Conservation Service-Curve Number
SDGs	Sustainable Development Goals
SPSS	Statistical Package for Social Sciences
STISA	Science, Technology and Innovation Strategy for Africa
SUFI-2	Sequential Uncertainty Fitting version 2
SURQ	Surface runoff
SWAT	Soil and Water Assessment Tool
SWATCUP	Soil and Water Assessment Tool- Calibration and Uncertainty Program
TDS	Total Dissolved Solids
TM	Thematic Mapper
TSS	Total Suspended Solids
UNEP	United Nations Environmental Programme

UNICEF	United Nations International Children's Education Fund
USDA-ARS	United States Development Authority- Agricultural Research Service
USGS	United States Geological Survey
WRA	Water Resources Authority
WRMA	Water Resource Management Authority
WRUA	Water Resource User Association
WCAs	Water Catchment Areas
WGEA	Working Group on Environmental Auditing
WHO	World Health Organization
WRI	World Resource Institute
WWAP	World Water Assessment Programme

ABSTRACT

Watersheds and their water resources are highly vulnerable to land use/land cover changes and seasonal rainfall variability as they directly influence basin hydrological characteristics in terms of water quantity and quality. This study assessed the effects of land use/land cover change and rainfall variability on hydrological characteristics of River Ruiru watershed in Kiambu County. The study integrated the use of remote sensing, Geographic Information System (GIS), water quality sampling, hydrological modelling and statistical methods to collect and analyse the collected data. Results of land use/land cover change analysis indicated that built-up areas, annual crops and perennial crops (tea and coffee) increased by 3.068%, 35.848% and 11.493% respectively between 1976 and 2017. However, it was observed that perennial crops increased gradually between 1976 and 1995 but declined by 1.94% between 1995 and 2017. Grassland, shrubland and forestland declined by 7.48%, 13.25% and 29.79% respectively between 1976 and 2017. Consequently, Soil and Water Assessment Tool (SWAT) model simulation results indicated that the land use/land cover changes that occurred in River Ruiru watershed between 1984 and 2017 had effects on the quantity of river discharge and water quality for drinking purposes. Surface runoff (SURQ), lateral flow (LATQ) and groundwater contribution to discharge (GWQ) increased from 30.25mm/yr, 8.48mm/yr and 9.95mm/yr to 181.25mm/yr, 11.44mm/yr and 10.66mm/yr respectively. Moreover, the nitrates in surface runoff (NO_3SURQ), nitrates in lateral runoff (NO_3LATQ), Organic Nitrogen (N.ORG) and Organic Phosphorus (P.ORG) increased from 0.05kgN/ha/yr, 0.06kgN/ha/yr, 5.77kgN/ha/yr and 0.87kgP/ha/yr to 1.47kgN/ha/yr, 0.19kgN/ha/yr, 70.60kgN/ha/yr and 8.86kgP/ha/yr respectively**.** In additions, findings from the study indicated that temporal rainfall variability had effects on the quantity of river discharge and water quality of River Ruiru. Based on regression analysis, the correlation between the observed and predicted value of dependent variable indicated an association of R=0.972 between temporal rainfall variability and quantity of river discharge hence showing a strong positive linear relationship. Similarly, Pearson's correlation analysis results showed that temporal rainfall variability was strongly and positively correlated to NO_3, N.ORG and P.ORG with R=.695, p<.001; R=.781, p<.001 and R=-.780, p<.001. Furthermore, results from a paired sample t-test indicated that pH, turbidity, Dissolved Oxygen (DO), electrical conductivity and Total Dissolved Solids (TDS) had higher mean during wet season (M=8.40, M=79.00, M=51.20, M=87.00 and M=54.20) than in dry season (M=6.80, M=11.60, M=43.40, M=73.00, and M=45.40). The difference for these water quality parameters between dry and wet seasons was significant (P=0.003, P=0.034, P=0.005, P=0.013 and P=0.014). Moreover, findings from the study indicated that DO, TDS, electrical conductivity, total phosphorus and total nitrogen values were within World Health Organization (WHO) and National Environment Management Authority (NEMA) recommended values. However, the results for the total coliforms and E. *coli* indicated that River Ruiru was severely polluted with faecal organisms. In conclusion, land use and land cover changes and temporal rainfall variability have affected the quantity of river discharge and water quality in River Ruiru watershed. As such, remedial actions to address the hydrological effects of land use/land cover change and temporal rainfall variability both by national and county governments are required.

CHAPTER ONE

INTRODUCTION AND BACKGROUND TO THE STUDY

1.1 Background of the problem

Many ecosystems, especially basins of important rivers, are threatened by changes in land use/land cover caused by human activity and natural processes (Burcher *et al.,* 2007; Salajegheh *et al.,* 2011). The consequences of human activities and climatic variability on water resources have long been a concern in hydrology, given the deteriorating water shortage problems and the rising frequency of water-related disasters around the world (Ren *et al.,* 2002; Scanlon *et al.,* 2007; IPCC 2007). Therefore, quantifying the linkages between environmental pressures and landscape conditions and change is vital for understanding vulnerabilities of a wide range of environmental values and ecological services (Dirwai *et al.,* 2021).

The water cycle is influenced by both climate change and human activity (Xia *et al.,* 2011). Human-induced land use has transformed hydrologic behavior by altering the nature and flowpaths of runoff (Hooke, 2000), while climate change has affected precipitation amounts and types (Waterson, 2005; Sato *et al.,* 2007). Miller *et al.* (2002) posits that hydrologic response is an integrated indicator of watershed condition and changes in land cover which affects the overall condition and function of a watershed. Thus**,** a better understanding of the relationships between land cover, climate and runoff at a watershed scale can be used to compare different parts of the watershed, identify those that are at risk or susceptible to change and therefore aid in management attempts to limit undesirable impacts (Katana *et al.,* 2013a) and develop sustainable river basin management strategies (Chen *et al.,* 2012).

Africa has the second largest annual rate of land cover change (Lambi *et al.,* 2003) while the Sub-Saharan region is the most vulnerable to the changing land use and climate (Ringler *et al.*, 2010; Tompson *et al.,* 2010; Chikowo *et al.,* 2014). Recent developments indicate an increasing trend of natural land cover conversion in this region (Brink *et al.*, 2014; Yira *et al.*, 2016; Guzha *et al.,* 2018; Merchant *et al.*, 2018). These transformations have led to changes in the distribution and dynamics of different types of terrestrial ecosystems (Gonzalez *et al.*, 2012; Niang *et al.*, 2014; Ofori *et al.*, 2021) leading to major ramifications on the economies of various Sub-Saharan African countries, particularly on water resources (GWP, 2015; Ngoran *et al.*, 2015). Consequently, many heavily over-exploited river basins in food producing areas are already functioning at the limit of water resources (FAO, 2008). The current state with respect to future management of water resources for large parts of Sub-Saharan Africa is very uncertain (Hughes, 2019). Thus, sustainable management and development of the region's water resources is key to economic growth (UN-water 2015)

Water stress and scarcity are prevalent issues in most East African countries, with water demands exceeding available renewable water resources in numerous river catchments (GWP, 2015). Due to unsustainable land use practices and climate change in river catchments, the availability of usable freshwater in terms of water quality and quantity has rapidly decreased (Ngoye & Machiwa, 2004; Odada *et al.*, 2004; Wang *et al.*, 2007; Huang *et al.*, 2013). Land productivity has been impacted by growing population and limited land available for agriculture owing to land subdivision and unsustainable land management practices, causing communities to intensify farming into water catchment areas (WCAs) in search of more land which eventually affect the catchment water functions (CWFs) (Campbell *et al.*, 2003a).

In Kenya, various river catchments and water towers have been gradually characterized by human settlement, deforestation, wetland reclamation and unsustainable agricultural activities (UNEP, 2009; Aura *et al.,* 2011). Catchment degradation in Kenya is estimated to cost Kenya Shillings 3.3 billion each year (TNC, 2016). A number of drivers of degradation have severely degraded Kenya's water catchment areas over the last 40 years, including rapid population growth, unplanned urban and peri-urban settlement developments, agricultural land expansion, poor governance, inappropriate land use practices and a lack of appreciation of the value of a clean and healthy environment in supporting quality life. The natural forest, which has an area of less than 30% of the total catchment area, is under threat from the on-going rapid urbanization (MEMR, 2012). Projections indicate that if no measures are taken, water availability will decline to 235 m^3 per capita per annum by 2025 which is considered to be below the limits of water barrier (GOK, 2009a; WRMA, 2011; Kibily & Kosgei, 2018). The upper Athi Catchment has been experiencing land use and land cover changes due to agricultural expansion and urbanization and these changes are distributed according to agro-ecological zones (Katana *et al.*, 2013b). Thus, protecting water resources is a priority issue in natural resource management so as to sustain both human and ecological communities (Salajegheh *et al.*, 2011; Ellis, 2013).

According to Yasin & Clemente (2014) efficient watershed management necessitates a rational and efficient decision-making framework capable of addressing a wide variety of environmental and resource management issues. Therefore, an understanding of changes in land use and water use over the next 30 to 50 years is crucial for sustainability (UNU-IIASA, 2003), and foundations for effective natural resource management (Thomas, 2001; Awasthi *et al.,* 2002) must be built on the variability of time and space of the resources, as well as the role of human cultures and institutions in bridging the gap.

1.2 Statement of the problem

River Ruiru watershed traverses rural, urban and peri-urban areas in the upper Athi catchment. A historical analysis of the watershed indicates that in 1940, about 50% of the watershed was under natural forest cover but this declined to 43% by 1948 and 30% by 1965 (MEMR, 2012). From 1940 to 1947, deforestation was undertaken primarily for agricultural purposes (more than 50 hectares). Between 1948 and 1964, small tea holdings (less than 1 to 5 hectares) had largely replaced the forest, particularly at steep headwater areas. The changes concomitant to these land use transformations coupled with the reduction in forest cover from 50% to 30% from 1948 to 1964 led to the generation of increased runoff.

The watershed is characterized by high population growth, movement of people move from rural to urban environment especially in Ruiru Municipality, higher demands for food security as well as increased agricultural, industrial and quarrying activities. According to the Kiambu County Integrated Development Plan 2018-2022 (2018), Ruiru sub-county which is within River Ruiru watershed has the highest number of people living in urban areas in Kiambu County with a population of 319,518 in 2018 and is projected to increase to 359,556 in 2022.

Moreover, the influence of the city of Nairobi has also led to tendency towards land use change from agricultural to commercial and settlement, especially within the urban centres (ESIA, 2014). Consequently, the watershed has experienced many land use/land cover changes due to population pressure and these environmental changes coupled with temporal rainfall variability may have had an impact on the hydrological characteristics of River Ruiru. This study therefore assessed the effects of land use/land cover change and temporal rainfall variability on the quantity of river discharge and water quality of River Ruiru watershed in Kiambu County.

1.3 Objectives

1.3.1 General objective

The general objective of this study was to assess the effects of land use/land cover change and rainfall variability on the hydrological characteristics of River Ruiru watershed, Kiambu County.

1.3.2 Specific objectives

The specific objectives of the study are;

i. To establish the extent of land use/land cover changes in River Ruiru watershed from 1976 to 2017.

ii. To assess the effects of land use/land cover change on the quantity of river discharge in River Ruiru watershed.

iii. To assess the effects of land use/land cover change on water quality in River Ruiru watershed.

iv. To evaluate the effects of temporal rainfall variability on the quantity of river discharge in River Ruiru watershed.

v. To evaluate the effects of temporal rainfall variability on water quality in River Ruiru watershed.

1.4 Hypotheses to be tested for significance

i. H_0 There is no significant land use/land cover change that has occurred in River Ruiru watershed from 1976 to 2017.

ii. H_0 Land use/land cover change has no significant effect on the quantity of river discharge in River Ruiru watershed.

iii. H_0 Land use/land cover change has no significant effect water quality in River Ruiru watershed.

iv. H_0 Temporal rainfall variability has no significant effect on the quantity of river discharge in River Ruiru watershed.

v. H_0 Temporal rainfall variability has no significant effect on water quality of River Ruiru watershed.

1.5 Research questions

i. What land use/land cover changes have occurred in River Ruiru watershed from 1976 to 2017?

ii. How has land use/land cover change affected the quantity of river discharge in River Ruiru watershed?

iii. How has land use/land cover change affected water quality in River Ruiru watershed?

iv. Has temporal rainfall variability affected the quantity of river discharge in River Ruiru watershed?

v. Has temporal rainfall variability affected water quality in River Ruiru watershed?

1.6 Justification and significance of the study

According to Kiambu County Integrated Development Plan (2018), forests and rivers are the main degraded areas in River Ruiru Watershed due to major deforestation caused by population demand for shelter, fuel and agriculture. The Government of Kenya (2009b) notes that the origin of the land question was after independence. The contemporary manifestations of the land question were several developments in the country which had several impacts and led to low productivity and poverty. These impacts include; severe land pressure and fragmentation of land holdings into uneconomic units, deterioration of land quality due to poor land use practices, uncontrolled development, urban growth and environmental pollution and destruction of forests, catchment areas and areas of unique biodiversity.

River Ruiru watershed is an important water resource as it includes Ruiru 1 and the proposed Ruiru 2 dams important for inter-basin water transfer to Nairobi City County. This is due to the fact that the towns around the city of Nairobi that share water resources from the Aberdares are among the worst hit by water scarcity resulting from the ever increasing demand. The capacity of water resources in the headwater regions has been declining with time due to a number of factors including catchment degradation and reduced rainfall to recharge the sources (ESIA, 2014; GOK, 2007a). River Ruiru is also one of the major perennial tributaries of River Athi which provides water to the population in the vast semi-arid parts of Kenya for various purposes before discharging into the Indian Ocean.

The findings from this study will enable the quantification of change and analysis of the direction of change between various land use/land cover types that have occurred in River Ruiru watershed from 1976 to 2017. It will help assess watershed hydrological vulnerabilities resulting from land use/land cover change and temporal rainfall variability from 1984 and 2017. Water resource availability in the right quality and quantity is an important factor to any development activities. Thus, information on available water resources in the watershed in sufficient quantity and acceptable quality for use will contribute to socio-economic development of the country.

The findings of this study will help in the attainment of the Sustainable Development Goals (SDGs) six and fifteen which emphasize on ensuring availability and sustainable management of water and sanitation for all and protecting, restoring and promoting sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss (UNCSD, 2012). Africa's Shared Water Vision 2025 envisages an Africa where there is an equitable and sustainable use and management of water resources for socio-economic development. The Science, Technology and Innovation Strategy for Africa (STISA, 2024) identifies the protection of our space as a priority area prerequisite to building an integrated and prosperous Africa.

This study will help in the efforts of pursuing integrated water resource planning and aid in the management of water resources on a watershed basis thus addressing the potential impacts and deterioration of water resources. As such, it will guide in the implementation of the Big Four Agenda (GOK, 2020) as far as land and crop management and identification of the appropriate areas for building low cost houses, establishment of manufacturing enterprises and health facilities is concerned. Moreover, the social pillar of the Kenya vision 2030, targets to provide its citizens with a clean, secure and sustainable environment by the year 2030 (GOK, 2002; GOK, 2007b; GOK, 2016). The Government of Kenya (2010) also acknowledges that the environment is a heritage that must be managed sustainably. Indeed part two of chapter five of the constitution provides for the management and conservation of the environment in order to *inter alia* conserve biological diversity and ensure that the right of all to a clean and secure environment is upheld.

Finally, the study will add to the existing knowledge with a view of promoting land use management practices.

1.7 Scope and Limitations of the Study

The hydrological characteristics of a river are affected by various factors such as geology, human and climatic factors. This study concentrated on land use/land cover change (agricultural and urban development) and climate influences in terms of temporal rainfall variability as these are the major factors affecting hydrological characteristics of a watershed. The hydrological characteristics covered in this study are river discharge and water quality. Water quality analysis also involves a wide range of parameters. This study looked at the parameters associated with agricultural, urban and industrial development which affect water quality standards for drinking purposes during dry and wet seasons. These included temperature, pH, electrical conductivity, turbidity, TSS, TDS, total nitrogen, total phosphorus, Dissolved Oxygen, BOD and faecal coli forms. During water quality sampling, it was assumed that the dry season and wet seasons were going to occur normally. There were also constraints in collecting hydrological data since the available river discharge and water quality data had gaps. The study intended to analyse land use/land cover for River Ruiru watershed immediately after independence. However, this study used the year 1976 as the baseline for land use/land cover analysis based on the available cloud free landsat image. Moreover, during SWAT model calibration and validation, the river discharge data used were for the years 2007 to 2013 as it had no missing data. Other meteorological data such as recorded wind speed, relative humidity and solar radiation required for SWAT weather data input were unavailable hence downloaded from global weather data set website (http://globalweather.tamu.edu/). Consequently, 1984 was taken as the baseline for SWAT hydrological modelling based on the available SWAT weather data and available cloud free landsat image for the watershed. There are also various hydrological models which can be used in hydrological studies based on their applicability to simulate the input of land use and climate change, performance prediction and model functionality and complexity. This study made use of the Soil and Water Assessment Tool (SWAT) model because of its applicability particularly in areas where historical monitoring data are limited or do not exist as in the case of River Ruiru Watershed.

1.8 Operational Terms and Definitions

Discharge: It is the quantity of water moving down a river per unit of time, expressed in cubic meters per second.

GIS methodology: It is an approach that provides the ability to capture and analyse spatial and geographic data.

Hydrological characteristics: Refer to the quantity of river discharge and water quality characteristics of a river.

Land cover: This is the physical and the biophysical characteristics or state of earth's surface captured in the distribution of the vegetation, water, desert, ice and other physical features of the land including those created through human activities such as settlements.

Land use: It refers to the intended use or management of the land cover type by human beings. It involves both the manner in which the biophysical attributes of the land are manipulated and the intent underlining that manipulation. It also refers to the land used by humans for habitats concerning economic activities. This study has used the terms lands cover and land use simultaneously.

Land use and land cover changes (LULCC): It is the shift in intent and/or management that constitute land use/land cover as defined in this study. It is a general term referring to the human modifications on the earth's terrestrial surface.

Spatial-temporal rainfall variability: The degree to which rainfall amounts vary across an area or through time.

Water quality: It is the physical, chemical and biological characteristics of water at which it is deemed fit for its intended use as shown in appendix 5.

1.9 Conclusions

This chapter outlined the background of the study, stated the problem and the justification of the study guided by the general objective and the corresponding specific objectives. The hypotheses that were tested and the research questions guiding the study were highlighted. In addition, the significance and the contribution of the study, scope and limitations of the study and how the study tried to overcome the limitations have been outlined. Finally the chapter highlighted the operational terms and definitions used in the study. Thus, this chapter guided the literature reviewed in the subsequent chapter.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter gives a review of related literature from other studies by various scholars and researchers on the effects of land use/land cover change and temporal rainfall variability on the quantity of river discharge and water quality in various watersheds. These studies and researches were cited and sources acknowledged. In addition, various gaps were exposed and a conceptual framework on how to fill these gaps was diagrammatically illustrated.

2.2 Conceptual Framework

This study adopted and modified the DPSIR Framework (Bradley & Yee, 2015) developed by the European Environmental Agency (EEA, 1999) shown in Figure 2.1 in developing a strategy for Integrated Environmental Assessment. This framework has been used by the United Nations (UNEP, 2007) for many resource applications (Borja *et al.*, 2006; Mysiak *et al.*, 2005). The framework defines a chain of causal links starting with driving forces (economic sectors, human activities) through pressures (emissions, wastes) that lead to states (physical, chemical and biological), and impacts (on ecosystems, human health and functions) leading to responses (prioritization, target setting, indicators). It is useful for describing the various cause-effect relationships between the sources and impacts of environmental problems (Kristensen, 2004).

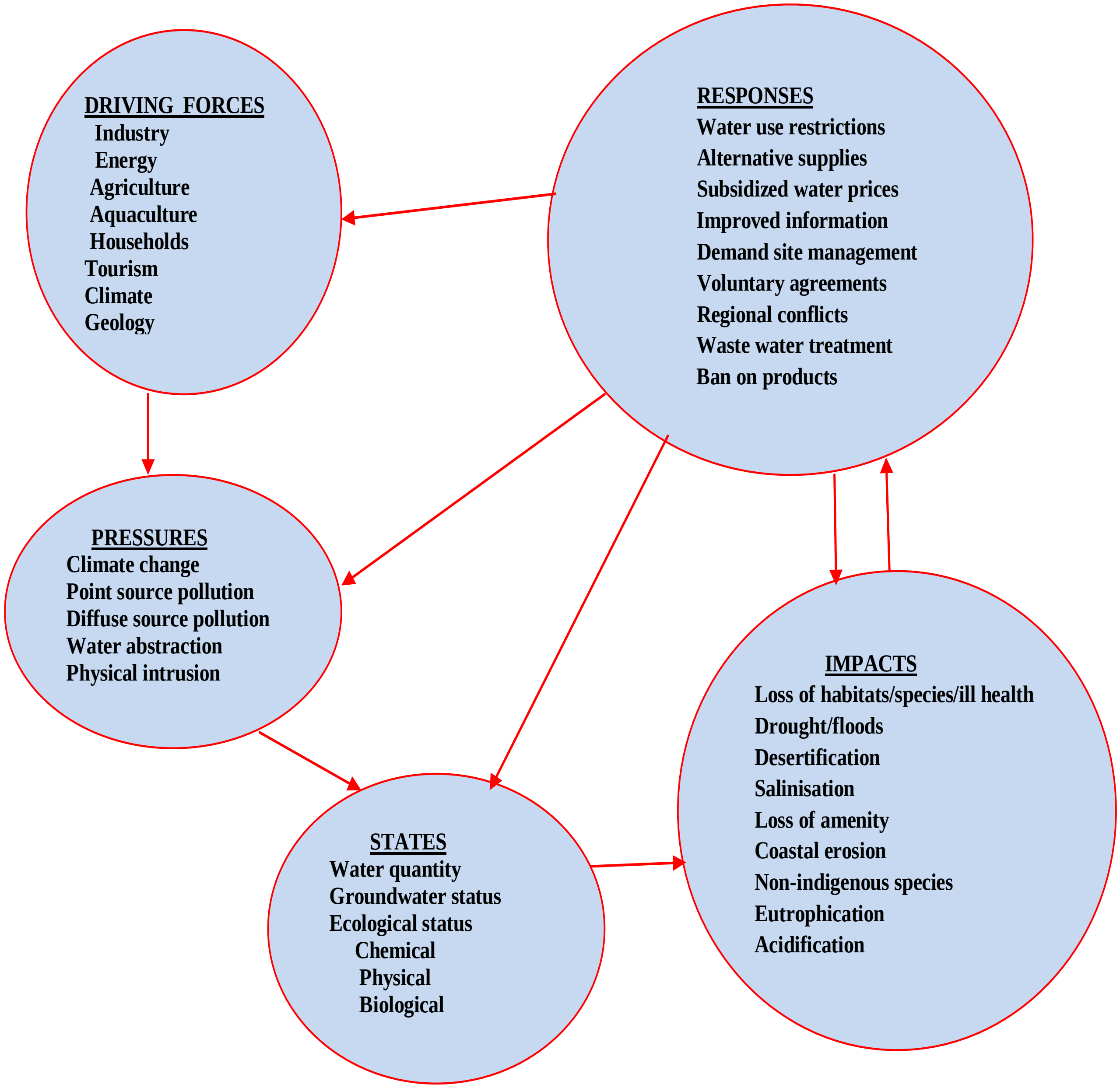

Figure 2.1: A generic DPSIR for water (European Environmental Agency, 1999)

The modified DPSIR Framework shown in Figure 2.2 was adopted in this study to guide in the assessment of the effects of land use/land cover change and temporal rainfall variability on hydrological characteristics (quantity of river discharge and quality) in River Ruiru watershed.

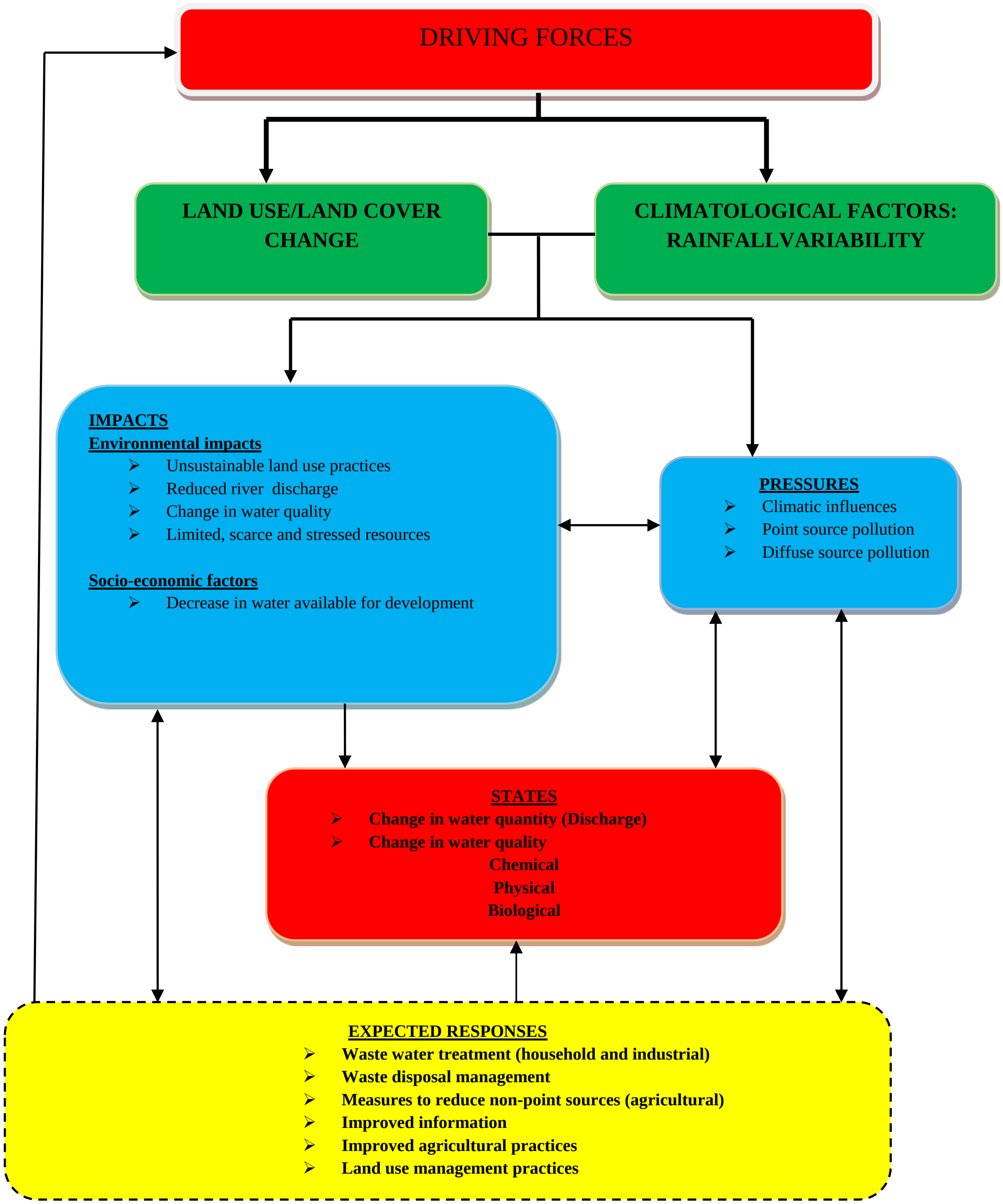

Figure 2.2: A conceptual framework showing the DPSIR Framework (adopted and modified from European Environmental Agency, 1999; Bradley & Yee, 2015)

According to EEA (2005) and Maxim *et al*.(2009) driving forces are factors that stimulate human activities and exert 'pressure' on the environment such as excessive use of natural resources, changes in land use and emissions and wastes. As a result of these pressures, the 'state' of the environment is affected in terms of the quality of different environmental compartments (air, water, soils) in relation to the functions these compartments perform (Gabrielson & Bosch, 2003). The quality of ecosystems and human welfare are determined by changes in the physical, chemical, and biological status of the environment. As a result, changes in the state could have an environmental and economic influence on ecosystem functioning, life support capabilities, and, eventually, human health and society's economic and social performance. A 'response' by the society or policy makers due to an undesired impact can affect any part of the chain between driving forces and impacts (Yee *et al.*, 2012).

Irvine *et al.* (2005) while reviewing the implementation of mathematical models in Ireland noted that driving forces are activities in the catchment that contribute to pressures on water resources. Although there are multiple interconnected factors, population increase has historically been the main force behind most land use changes (Mekuria, 2005; Bashir, 2012). With the increasing growth in population and the subsequent socio-economic pursuits such as urbanization, industrial production, tourism and agricultural activities demand for water has increased rapidly (WWAP, 2006). In addition, land conversion for agricultural, residential, industrial, and urban expansion, which is linked to the growing population, has a long-term impact on the functioning of environmental systems and processes (Lambin *et al.* 2001; Seto *et al.*, 2002; Long *et al.*, 2007). Briassoulis (2006) notes that land use change is the outcome of a complex web of interactions between the bio-physical and socio-economic forces over space and time while Jat *et al.* (2008)

concluded that in an urban environment, natural and human-induced environmental changes are of concern today because of the worsening environmental and human health.

Seto *et al.* (2004) while monitoring land use in the Pearl Delta concluded that the growing population and growing socio-economic necessities create pressure on land which results in unplanned and uncontrolled changes in LULC. Thus, the state of water is determined by pressures exerted by human activities and by natural factors such as climate and geology (Kristensen, 2004; Peters *et al.,* 2005). Changing the land use of river basins, in addition to direct changes in the hydrological regime of river basins, can have a significant impact on the hydrological cycle (Lev, 2004). Other common effects of increased human disturbances in a watershed include increase in water volume, decrease in the reaction time of stream discharge to storm events, increase in runoff affecting stream channels and decrease in water quality (Salajegheh *et al.,* 2011).

According to Tsvetkova (2007), land use decisions have considerable impacts on water and other natural resources. Human activities are restricted by a number of rules and land management plans around the world due to their alleged impacts on water resources (Forsyth, 2005). Thus, one component of the knowledge base required in applying the principles of integrated water resource management (IWRM) is an understanding of how land use and land cover change affect water resources (Calder, 1998). Reliable data is therefore needed to design policies and comprehensive management principles for long-term resource exploitation (Mati *et al.,* 2005). Therefore, by sampling and quantifying the effects of land use/land cover on water resources, we can develop recommendations for better watershed management (Bowden *et al.,* 2015). There is also a need for a detailed land use/land cover change analysis using high resolution images to identify critical areas for rehabilitation and development of strong environmental laws so as to ensure sustainable land development (Katana *et al.*, 2013b).

2.3 Land use/land cover change

In recent years, global land use has shifted dramatically (Ramankutty *et al.*, 2002; Lambin *et al.*, 2003). Olson *et al.* (2008) noted that land use/land cover changes are the primary drivers of global environmental change with potentially disastrous consequences on human livelihoods. These changes interact with socio-economic and political factors to determine the vulnerability of river catchments and people to perturbations in their water resources (Turner *et al.*, 2003; Sohl *et al.,* 2012). Thus, understanding the possible consequences of LULCC on water resources is indispensable for better water resources management, reconstructing past LULCC and for predicting future changes which will help in expanding sustainable management practices meant for preserving vital landscape functions (Hietel *et al.*, 2004; Masese *et al.*, 2012).

LULCC are the main anthropogenic activities that influence water flow and quality of rivers (Dale *et al*., 2000; Khatri & Tiagi, 2015).They are also the most important factors to be considered in global change study (Houghton, 1994; Lambin, 1997; Houghton *et al.,* 1999; Loveland *et al.*, 2000; Schneider & Eugster, 2005) and the most vital components of the terrestrial environmental systems (Lin *et al.*, 2009). Li *et al.* (2018) posit that linking the effects of LULCC on the hydrological cycle is critical for long-term water resource management.

Kiage *et al.* (2007) in their study on land use/land cover change in Lake Baringo catchment in Kenya concluded that various parts of East Africa are experiencing dramatic changes in land cover/land use at a wide range of spatial and temporal scales, due to both climatic variability and human activities. Other studies have found that the trends and direction in hydrologic response can be derived directly from the corresponding trends and direction in land cover change (Hernandez *et al.,* 2000; Opeyemi, 2006). However, due to lack of spatial and temporal data, the effects of land use/land cover changes on water resources connected with human activities and natural causes are poorly documented (Chu *et al.*, 2013). Therefore, by understanding the effects of land use/land cover changes and natural factors in the past, managing the current situation with modern GIS tools and modelling the future, it is possible to develop plans for various uses of natural resources and conservation (Zamani *et al.,* 2012).

DeFries & Eshleman (2004) in their study on land use change and hydrologic processes emphasized the importance of understanding the impact of land use change on water resources which they identify as a fundamental research topic for the decades ahead. Cheruto *et al.* (2016) concluded that land use/land cover pattern and its spatial distribution are the major fundamentals for the foundation of an effective land use strategy required for appropriate development of an area. This is particularly essential because of the current attention provided to sustaining ecosystem goods and services in ecosystem state or condition that are perceived throughout the world (MEA, 2005a; Farber *et al.,* 2006; Muthukrishnan *et al.,* 2006). In a study on the impact of geomo-hydrometric characteristics and land use/land cover change on water resources management in the River Gucha-Migori catchment in the Lake Victoria Basin, Obiero (2010) recommended that hydrological modeling be used to better understand catchment dynamics for integrated watershed management. The study also recommended the use of modern tools such as GPS and GIS in water resource management. In addition, Kirui (2008) analysed catchment hydrologic response under changing land use in upper Molo river catchment and concluded that the impacts of land use change on catchment response should be carried out for a period of more than three decades and the use of models in simulating catchment response should incorporate extensive use of GIS and remote sensing. According to Cheruto *et al.* (2016) consistent land use/land cover mapping should be carried out in order to quantify and characterize land use/land cover changes as it will help establish trends and enable resource managers to predict realistic change scenarios helpful for natural resource management. Their study also emphasizes that multi-temporal satellite data are very useful for comprehensive detection of LULCC.

2.4 Effects of land use/land cover change on the quantity of river discharge

The hydrological cycle of a basin is a multifaceted process impacted by climate, physical characteristics of the basin and human activities (Green *et al.,* 2007; Ma *et al.,* 2008; Chang *et al.,* 2015). Effects of land use change and rainfall variability on the water cycle are usually reflected in the long-term spatial and temporal variation of water balance components such as surface runoff, soil moisture, evapotranspiration, groundwater and streamflow (Li *et al.,* 2009; Fang *et al.,* 2013; Katana *et al.,* 2013a; Memarian *et al.,* 2014; Deng *et al.,* 2015). Thus, Kang *et al.* (2004) in their study on the impacts of human activities on the water-land environment of the Shijang river basin concluded that while striving towards sustainable development, it is imperative to analyse the consequences of water-related human activities in order to improve the existing water management practices.

Consequently, changes in river flow regimes such as high peak flows, lower base flows, wider river channels, and silt deposition downstream have resulted from changes in natural land cover (Mutie *et al.,* 2006; Dadhwal *et al.,* 2010). It also has effects on river discharge indicating changes in the hydrological characteristics of the watershed (Allan, 2004; Bhat *et al.,* 2006; Hopkins, 2009; Petchprayon *et al.,* 2010). It has equally been noticed that urbanization and agricultural expansion contribute to an increase in impervious surface area which can lead to an increase in surface runoff and decline in infiltration (Baker & Miller, 2013; Koneti *et al.,* 2018). These changes have a significant impact on the hydrological compartment, and they have become an important aspect of modern techniques to managing natural resources and monitoring environmental changes (Opeyemi, 2006).

2.5 Effects of land use/land cover change on water quality

Water comprises over 70% of the earth's surface and therefore indeed the most valuable natural resource that exists on the planet without which life would be non-existent (Akali *et al.,* 2011). Water plays a vital role in the global economy (WWAP, 2006; Baroni *et al.,* 2007) and a sufficient (adequate, safe and accessible) supply must be available to all (WHO, 1993; WHO, 1995). As anthropogenic activities intensify, land use/land cover change is strongly correlated with water quality parameters (Griffith *et al.,* 2002; Aheam *et al.,* 2005; Tran *et al.,* 2010; Huang *et al.*, 2013; Bowden *et al.,* 2015; Ding *et al.*, 2015) as water quality of rivers can be affected by changes in the land cover patterns within the watershed (Yong & Chen, 2002; Ngoye & Machiwa, 2004; Chen & Lu 2014). Land uses also alter the natural functions of watershed by impending or altering waterflow and impacting water quality (Salajegheh *et al.*, 2011).

According to Shaw (2004) the world is facing global water quality crisis. With over 41% of world's population living in river basins, there is a real cause of concern on the likely effects of human induced activities on the river basin's water resources (MEA, 2005b). World Commission on Water (2007) noted that the world's major rivers are being extremely depleted and polluted, degrading and destroying the surrounding ecosystems, thus threatening the health and livelihood of people who depend upon them for irrigation, drinking and industrial water. In Africa, the deterioration of the quality of water resources due to land use changes has been increasing leading to severe health risks to both humans and ecosystems (Pullanikkati *et al.*, 2015).

Anthropogenic factors which affect water quality include impacts caused by agriculture such as use of fertilizers, manures and pesticides, animal husbandly activities, inefficient irrigation practices, deforestation, pollution due to industrial effluents and domestic sewage, mining and recreational activities (Peters & Meybeck, 2000; Buck *et al.*, 2004; Alam *et al.*, 2006; Zhang *et al.*, 2007; Hussein *et al.*, 2008; Khatri & Tyagi, 2015; Li *et al.*, 2018).

Kibichii *et al.* (2007) and Kasangaki *et al.* (2008) in their studies on land use and macro vertebrate assemblages noted that in East Africa, land use changes resulting from rapid urbanization and clearance of forests to create room for agriculture and settlement have emerged as main stressors of streams and rivers. These changes have the potential to have a significant influence on water resources (Stonestrom *et al.*, 2009), mostly in regions where water availability is limited and could result in an increase in water scarcity thus leading to a deterioration of living conditions (Wagner *et al.*, 2013). Therefore, quantitative assessment of the implications of land use change on water quality is vital for basin environmental conservation as well as the long-term development and management of water resources (Li *et al.*, 2013).

In Kenya, water resources are gradually becoming polluted at point and non-point sources as a result of urbanization, agricultural and industrial activities (WGEA, 2013). According to international standards, Kenya is categorized as a water scarce country with the currently available freshwater of 400 m^3 per capita per annum in comparison to the 1000 m^3 per capita per annum recommended by the United Nations (GOK, 2007b; MEMR, 2012). Marshall (2011) notes that, for many years there has been an increased need for development and management of water resources in Kenya because of the increasing population as well as the country's increasing use of water for agriculture. Moreover, evaluating the influences of land use/land cover change on hydrological characteristics is key for both understanding the effects of LULCC on hydrological processes over the earth surface (Shi *et al.,* 2007) and managing and developing watersheds (Woldesenbet *et al.,* 2017).

According to Bruijnzeel (2004) in a study on the hydrological functions of tropical forests, it is necessary to expand research efforts to establish the effects of land use and land cover change at various spatial scales on downstream waters and to observe how change in watersheds have affected stream conditions through long-term analysis. Therefore, future studies should incorporate the impacts of land use change on stream water quality (Manashi, 2016). Zeng *et al.* (2015) in their study concluded that a more comprehensive analysis of the effects of climate variables, land use and land cover changes and other water-related human activities is required in further work.

2.6 Effects of temporal rainfall variability on the quantity of river discharge and water quality

Global climate change is one of the major factors that directly affects hydrological processes and conditions (Trettin *et al.,* 2006; Dai *et al.,* 2013; Kim *et al.,* 2013; Khoi & Suetsugi, 2014; Zhang *et al.,* 2016) particularly the change of rainfall and temperature, which generally determines the future runoff of a basin (Wang *et al.,* 2009). Climate variability is equally believed to have led to global warming and changing patterns of precipitation, while human activities have changed the temporal and spatial distribution of water resources in various watersheds especially in Sub-Saharan Africa (Ye *et al.,* 2003; Milly *et al.,* 2005).

Arnaud *et al*. (2011) in their study on the sensitivity of hydrological models to uncertainty in rainfall input noted that spatial rainfall variability is one of the major sources of uncertainty in streamflow simulation. Wang *et al.* (2015) while simulating the hydrological responses to climate change of the Xiang river basin in China considered hypothetical scenarios and revealed that the quantity of river discharge is greatly correlated to precipitation while weakly correlated to temperature under humid climatic conditions. Szczesniak & Piniewski (2015) observed that though temporal and spatially variable precipitation is the main driving force in all semi distributed models such as SWAT, temporal variability is the most fundamental aspect in hydrological modelling. Thus, an accurate assessment of the effect of temporal rainfall variability on water quantity is essential for understanding the effects of catchment response (Singh, 1997).

Moreover, climate-related river water quality issues have started to receive considerable attention in recent years (Delpla *et al.,* 2009; Whitehead *et al.,* 2009). Water resources and have been found to change as temperature and rainfall change (IPCC, 2007; Varol *et al.,* 2012; Li *et al.,* 2015). High precipitation during the wet season can either decrease the pollutant concentration by dilution or degrade water quality due to increased surface runoff from anthropogenic activities (Ling *et al.,* 2017; Zha *et al.,* 2018). According to Bae (2007) water quality of rivers is affected by both point and non-point source pollutants and rainfall events play an important role as carriers of these pollutants. Consequently changes of flow rate of rivers between rainy season and dry season could bring difficulties in maintaining a river's water quality (Kang, 1995; Lee *et al.*, 2005). Thus, Zeng *et al.* (2015) in their study on the effects of climate change and human activities on surface runoff in Luan river basin concluded that a more in-depth analysis of the effects of climate variables, land use and land cover changes and other water-related human activities is required in further work.

2.7 Identified gaps from reviewed literature

Table 2.1 outlines the gaps that were identified during literature review.

Table 2.1: Gaps identified during literature review

AUTHOR (S)	STUDY	GAPS IDENTIFIED
Obiero Kennedy (2010)	The influence of geomo-hydrometric characteristics and land use/land cover change on water resources management in River Gucha-Migori catchment, Lake Victoria Basin, Kenya.	Hydrological modelling should be carried out to improve on the understanding of the catchment dynamics for integrated watershed management. The study recommends the use of modern technologies such as GPS and GIS in water resource management.
Kirui (2008)	Analysis of catchment hydrologic response under changing land use: The case study of upper Molo River catchment, Kenya	The impacts of land use change on catchment response should be carried out for a period of more than three decades and the use of models in simulating catchment response should encompass extensive use of GIS and remote sensing.
Drissia & Anitha (2015)	Effects of land use change on discharge using Mapshed model in sub-basins of Bharathapuzha River Basin, India.	Further study using other hydrological models which may give robust results is required.

Cheruto *et al.* (2016)	Assessment of land use/land cover change using GIS and Remote Sensing techniques. A case study of Makueni County, Kenya.	Consistent land use/land cover mapping should be carried out in order to quantify and characterize land use/land cover changes as it will help establish trends and enable resource managers to predict realistic change scenarios helpful for natural resource management. Their study also emphasizes that multi-temporal satellite data is central for comprehensive detection of LULCC.
Zeng *et al.* (2015)	Effects of climate change and human activities on surface runoff in Luan River Basin.	They concluded that a more indepth analysis of the effects of climate variables, land use and land cover changes and other water-related human activities is required in further work.

2.8 Conclusions

Many studies have been conducted in different river catchments to assess the effects of land use/land cover and climate variability on hydrological processes. Based on the various gaps exposed in the reviewed literature, the current study considered a wide range of literature and suggested on how to fill such gaps as explained in the proceeding chapters.

CHAPTER THREE

RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

This chapter covers the regional background to the study area as well as data collection and analysis techniques. The data collected for the study included land use/land cover data, ground truth data, Digital Elevation Model (DEM), hydro-meteorological data and water quality data. Data analysis techniques included land use/land cover analysis, hydrological modelling and statistical data analysis. An experimental research design which aimed to describe the variation of information under conditions that were hypothesized to reflect the variation was used. The change in the independent variable (land use/land cover and temporal rainfall variability) was hypothesized to result in a change in the dependent variable (quantity of river discharge and water quality).

3.2 Regional background to the study area

3.2.1 The study area

The study area was River Ruiru watershed which has an area of 484.515 km^2 (Thubu, 2012). The area has a population of 671,646 persons (GOK, 2019). It lies between longitude 36°40'E and 37°00'E and latitude 1°10'S and 0°50'S as shown in Figure 3.1. River Ruiru originates from Kikuyu plateau and drains to the southeastern slopes of the Aberdare ranges in Kiambu County.

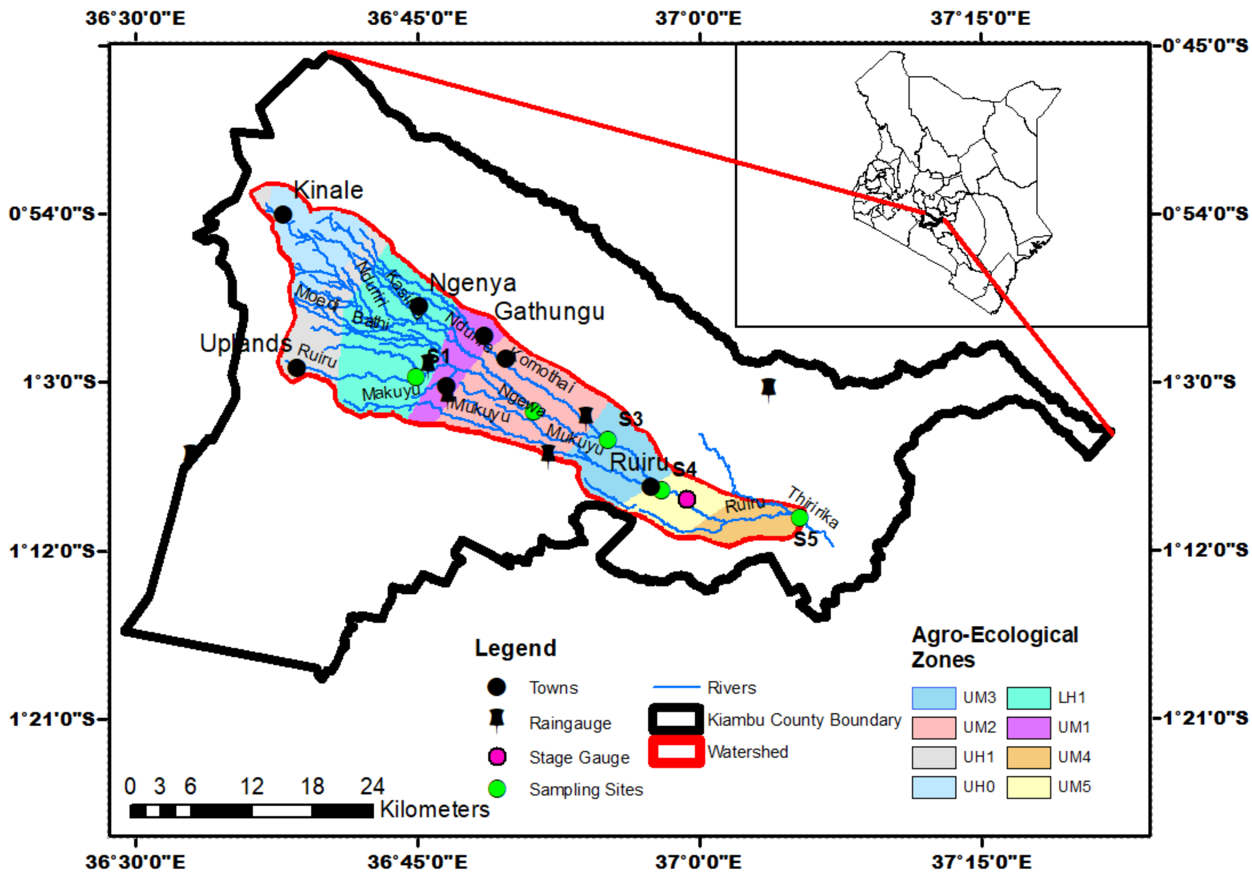

Figure 3.1: River Ruiru watershed (watershed delineated from Digital Elevation Model-hydro-processing of ASTER, 30m spatial resolution downloaded from USGS-Earth explorer website)

3.2.2 Climate

The watershed is located in medium rainfall potential area of Athi Basin with moderate and reliable rainfall. It has two distinct rainy seasons: The long rains experienced in March-April-May (MAM) and short rains experienced in October and November. Rainfall pattern in the watershed has changed in the recent past with years recording less than the mean annual rainfall becoming more frequent. The temporal rainfall variability over the years varies between 590mm to 1390mm (CIDP, 2018).

The mean temperature is 26℃ with temperature ranging from 17.1℃ in the upper highlands to 34℃ in the lower midlands and shows an increasing trend in the recent past. July and August are the months during which the lowest temperatures are experienced while January, February and March are the hottest months (ESIA, 2014).

3.2.3 Hydrology

River Ruiru watershed is hydrologically located within the Athi Basin 3BC sub-basin administered from upper Athi Water Resource Authority (WRA) in Kiambu. The watershed is covered by a well distributed dense lateral river network. Ruiru River is the major river in the watershed with its main tributaries being Makuyu, Gatamaiyu and Komothai (ESIA, 2014).

3.2.4 Land use and land cover patterns

River Ruiru watershed has four dominant land cover types which include trees, settlements, grasslands and croplands (CIDP, 2018). The land cover has high temporal variations with the wet season exhibiting high vegetation cover (high biomass) and the dry season exhibiting very low vegetation cover (low biomass). The upper part is predominantly forested but is currently threatened by encroachments into the forest area. Change in land use and land cover patterns due to change of user from agricultural commercial enterprises to residential, peri-urban and urban settlements as shown in Appendix 1 is the main cause of declining quality and quantity of water in the watershed.

3.2.5 Topography and agro-ecological zones

The area has an undulating landscape, with steep valleys where the rivers cross. It is also dominated by highly dissected ranges. The land use potential may be described according to the country's agro-ecological zones which may be categorized as medium to high potential falling under zones UM3, UM2, UH1, UH0, UM1, UM5, UM4 and LH1 as shown in Figure 3.1 and Table 3.1 (Jaetzold & Schmidt, 1983; Jaetzold *et al.*, 2006).

Table 3.1: River Ruiru watershed Agro-ecological zones (Jaetzold & Schmidt, 1983)

AEZ No.	**Agro-Ecological zones**	**Belts of Z**
III	Semi-humid	UM3
II	Sub-humid	UM2
I	Humid	UH1
0	Per humid	UHO
I	Humid	LH1
I	Humid	UM1
V	Semi-arid	UM5
IV	Transitional	UM4

3.2.6 Socio-economic activities and livelihoods

The land in River Ruiru watershed is put under diverse uses which include industrial, agricultural, commercial and public land with public land and utilities (CIDP, 2018). Table 3.2 presents the socio-economic activities and livelihoods of the community in River Ruiru watershed categorized into upper, middle and lower zones.

Table 3.2: Socio-economic activities and livelihoods (CIDP, 2018)

Economic activities	Distribution	Activities with great influence on water resources
✓ Dairy farming ✓ Farming ✓ Industries ✓ Businesses ✓ Quarrying activities	**<u>Upper zone:</u>** Farming, dairy farming and small business ventures **<u>Middle zone</u>**: Industries, large scale farming, hospitality, learning institutions, quarrying, small plots **<u>Lower zone:</u>** Quarrying, businesses, small plots, subsistence farming, learning institutions, sand harvesting	✓ Farming, ✓ Industries, ✓ Hospitality, ✓ Learning institutions

3.3. Data collection techniques

3.3.1 Land use/land cover data

Land use/land cover data of four landsat MSS, TM and OLI/TIRS images for 1976, 1984, 1995 and 2017 were obtained from USGS-Earth explorer (http://www.earthexplorer.usgs.gov/) website in Geotiff format as shown in Table 3.3. Three multi-temporal landsat images for 1976, 1995 and 2017 were used for land use/land cover change analysis of River Ruiru watershed while landsat images for 1984 and 2017 were used to assess the effects of land use/land cover change on the quantity of discharge and water quality using SWAT model. Multi-temporal analysis of satellite images is effective for change analysis because of high correlation between imagery spectral variation and land use change (Green *et al.,* 1994). These landsat images were selected based on the availability of cloud free landsat images, available SWAT input weather data for the study area and also a time interval that is long enough for land use/land cover change to have measurable impacts on hydrologic response. The selected images were taken during the dry seasons of the year to avoid uncertainties, clouds, and possible errors resulting from seasonal differences between time points (December-January-February-March). It has been suggested that by using images taken during the dry season will reduce confusion between dense forest vegetation and small-scale agricultural plots at forest edges (Maingi & Marsh, 2001; Toll, 2002). Landsat imagery was used due to its longest history of service with a relatively high spatial resolution and its wide application for land cover classification across the world (Kibena *et al.,* 2014). The use of these new data with higher spatial resolutions has the potential of more accurate analysis (Boyle *et al.,* 2014; Fisher *et al.,* 2018).

Table 3.3: Satellite image metadata and date of acquisition

Year	Acquisition date	Sensor ID	Path	Row	Producer	Resolution
1976	11/02/1976	MSS	180	061	USGS	80m
1984	17/12/1984	TM	168	061	USGS	30m
1995	30/01/1995	TM	168	061	USGS	30m
2017	28/12/2017	OLI-TIRS	168	061	USGS	30m

3.3.2 Ground truth data

Ground truth data was collected in the month of January which was a dry season and it was used for image classification and accuracy assessment. Stratified random sampling method recommended by Congalton & Green (2009) was employed for selecting the reference points since it ensures that all classes and sub-classes of interest are accounted for in the accuracy assessment. This method has also been found to give better results in smaller study areas (Hashemian *et al.*, 2004).

3.3.3 Digital Elevation Model

Digital Elevation Model with a spatial resolution of 30m was obtained by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) which was downloaded from USGS-Earth explorer website (http://www.earthexplorer.usgs.gov/). It was used for delineating the watershed spatial extent and stream network. It was also used during SWAT hydrological modelling.

3.3.4 Hydro-meteorological data

3.3.4.1 Meteorological data

Rainfall data from five ground-based weather stations shown in Table 3.4 and Appendix 2 and maximum and minimum temperature data from Thika Agromet station presented in Appendix 3 were acquired from Kenya Meteorological Department. Wind speed, solar radiation and relative humidity data were obtained from global weather data set of the National Centre for Environmental Prediction (NCEP) (http://globalweather.tamu.edu/) Climate Forecast System Reanalysis (CFSR). This data was used for weather data definition in SWAT model. Rainfall data was further used to assess the effects of temporal rainfall variability on the quantity of river discharge and water quality.

Table 3.4: Rainfall stations in the watershed

Station Name	Station ID	Data available	Altitude	Geo-coordinates	Status of the data
Githunguri Agricultural station	9136098	1970-2017	1999m	36°47'E, 01°04'S	Complete
Jacaranda Coffee Research	9136084	1970-2017	1608m	36°54'E, 01°05'S	Complete
Tatu City	9136092	1970-2017	1554m	36°47'E, 1°08'S	Complete
Ndoondu Estate-Kiambu	9136018	1970-2017	1655m	36°52'E, 01°07'S	Complete
Thika Meteorological Station	9137048	1970-2017	1463m	37°06'E 1°01'S	Complete

3.3.4.2 River discharge data

Mean daily discharge data in cubic meters (m^3s^{-1}) for Ruiru River was obtained from Water Resources Authority (WRA) in Kiambu for the period between 2007-2013 for the gauge station 3BC8 located in Ruiru Bridge. This data was used for calibration and validation of the SWAT model. The discharge data for the period from 2007-2013 was chosen as it was complete with no missing data.

3.3.5 Water quality data

According to Patil *et al.* (2012) the selection of water quality assessment parameters depends on the needs and objectives of the assessment. The current study considered water quality parameters that affect drinking water standards as per World Health Organization (2011) and National Environment Management Authority (2006) standards shown in appendix 5. Water quality samples for electrical conductivity, pH, temperature, turbidity, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), dissolved oxygen, Biochemical Oxygen Demand (BOD), total nitrogen, total phosphorus, total coliforms and *Escherichia coli* (E. coli) were collected in the field during the dry season in January 2018 and February 2018 and wet season in April 2018 and May 2018 as demonstrated in Plate 3.1.

(a) (b)

Plate 3.1: Water quality sampling in River Ruiru (a) Downstream Ruiru dam (36°45'E, 1°02'S) and (b) Kwa Maiko (36°51'E, 1°04'S)

The samples were collected in duplicates and three times for each season and entered into a tabular database as presented in Table 3.5. Sampling for the dry season was done on 29/01/2018, 15/02/2018 and 26/02/2018 while for the wet season was done on 10/04/2018, 24/04/2018 and

10/05/2018. Water samples were taken from five sampling sites; at Ruiru dam (downstream), Kwa Maiko, Jacaranda coffee research centre, Ruiru town (downstream), Ruiru sewerage treatment plant (downstream) as shown in Figure 3.1 that were representative of different land use and land cover types based on different agro-ecological zones and settlement patterns within the study area. An extensive field survey was performed throughout the study area using GPS GARMIN 64s equipment to obtain accurate GPS coordinates for mapping water sampling sites.

Table 3.5: Tabular database for *in-situ* and laboratory water quality analysis

<table>
<tr><th>Sampling sites</th><th>Sampling site labels</th><th>GPS locations</th><th colspan="2">Water quality parameters analysed</th><th>Dates for water quality sampling (Dry and wet seasons)</th></tr>
<tr><td>Ruiru dam (downstream)</td><td>S1</td><td>1°02S, 36°45E</td><td rowspan="5">In-situ water quality analysis
Temperature
pH
Turbidity
Thermal conductivity
Dissolved Oxygen (DO)</td><td rowspan="5">Laboratory analysis
TSS
TDS
BOD
Total Nitrogen and Total Phosphorus
Faecal coliforms</td><td rowspan="5">Dry season
29/01/18
15/02/2018
26/02/2018
Wet season
10/04/2018
24/04/2018
10/05/2018</td></tr>
<tr><td>Kwa Maiko</td><td>S2</td><td>1°04S, 36°51E</td></tr>
<tr><td>Jacaranda coffee research</td><td>S3</td><td>1°06S, 36°54E</td></tr>
<tr><td>Ruiru town (downstream)</td><td>S4</td><td>1°09S, 36°58E</td></tr>
<tr><td>Ruiru sewerage plant (downstream)</td><td>S5</td><td>1°10S, 37°02E</td></tr>
</table>

The collected water samples were subjected to the standard procedures for testing physicochemical and biological water quality for drinking purposes in the field and in the laboratory according to APHA (1998). Water quality analysis was done both in the field and in the laboratory. The water samples for laboratory analysis were immediately placed in a lightproof insulated box containing ice packs with water to ensure rapid cooling. The samples were transported to the Central Water Testing Laboratories (Nairobi) for analysis and quantification. The samples were refrigerated at temperature of 4°C while waiting for analysis.

The time between sample collection and analysis never exceeded 6 hours and 24 hours was considered as the absolute maximum. The obtained average values for each parameter were compared with the standard values set by WHO (2011) and the local standards set by the NEMA (2006) as shown in appendix 5. The average values of the duplicates were later subjected to inferential data analysis for the wet and dry seasons and the corresponding sampling sites.

3.3.5.1 Field Testing

The following water quality parameters were measured *in situ* using equipment acquired from Water Resources Authority office in Kiambu.

3.3.5.1.1 Temperature

Temperature was measured using an electronic thermometer in °C. The thermometer was rinsed with a portion of the sample and the sample was discarded. The thermometer (or the probe) was then immersed in the sample. It was held in the sample for approximately one minute or sometimes longer for the temperature reading to be become constant. The temperature was read and recorded to the nearest 0.1°C.

3.3.5.1.2 pH

It was measured by using an electronic pH meter as it is accurate and free from interferences. The electrodes having been rinsed with distilled water was removed from water and blotted dry. The electrodes and a small beaker were rinsed with a portion of the sample. A sufficient amount of the sample was poured into the small beaker to allow the tips of the electrodes to be immersed to a depth of about 2 cm and at least 1 cm away from the sides and the bottom of the beaker. The temperature of the water sample was measured and the temperature adjustment dial set accordingly. After the needle stopped moving, the pH meter was turned on and the pH of the sample was read on the dial meter and recorded.

3.3.5.1.3 Turbidity

It was measured in nephelometric turbidity units (NTU) using a nephelometer which was used to compare a reference solution to the sample after shaking the sample bottle and shining a beam of light through it. The sample was poured into a glass tube, placed inside the instrument with a reference solution. The result was read directly from the instrument.

3.3.5.1.4 Electrical conductivity/Thermal conductivity

Electrical conductivity is the ability of water to conduct an electronic current depending on the concentration of ions in a solution. It was measured using a conductivity meter in micromhos per centimeter (µmhoscm^{-1}). At least three portions of the sample were used to rinse the conductivity. Because conductivity is temperature dependent, the temperature of a portion of the sample was adjusted to 20±1.1℃ or as close to that temperature as possible. The conductivity cell containing the electrodes was immersed in a sufficient volume of the sample for the liquid level to be above the vent holes in the cell. Care was taken to avoid air bubbles clinging to the electrodes and to ensure the cell is not closer than 2cm to the sides and bottom of the container. The temperature of the sample was observed and recorded to the nearest 0.1℃. The meter was turned on and the meter reading recorded. Electrical conductivity increases with temperature at a rate of 1.9 per cent per ℃. Conductivity measurements are therefore most accurate when made at the same temperature as that at which the cell constant is determined. Once the conductivity of the sample has been measured, the calculation is as in equation 3.1.

$$\text{Conductivity}=\frac{C_m \times K_C}{(0.019(t-20)+1} \text{µmhos cm}^{-}1 \text{……………..Equation 3.1 (UNEP/WHO, 1996)}$$

Where;

K_c = Cell constant (cm^{-1})

C_m = Measured conductivity of sample at ℃ (μmhos cm^{-1})

3.3.5.1.5 Dissolved Oxygen (DO)

Dissolved Oxygen concentration depends on the physical, chemical and bio-chemical activities in the water body. It was measured using the electrometric method in mg/l suitable for field determination and simple to perform. The electrode was rinsed in a portion of the sample to be analysed for dissolved oxygen. The electrode was immersed in the water ensuring a continuous flow of water past the membrane to obtain a steady response on the meter. The meter reading, temperature, make and model of the meter were then recorded.

3.3.5.2 Laboratory tests

Water samples were collected and taken to Central Water Testing Laboratories (Nairobi) for chemical and biological analysis according to the standard methods described in APHA (1998).

3.3.5.2.1 Total Suspended Solids

The Total Suspended Solids (TSS) were estimated gravimetrically (Wetzel, 2001) in mg/L. The filter paper was weighed to an accuracy of 0.1mg and placed in a Buchner funnel. A sufficient volume of the sample was filtered. The funnel and the filter were later washed with a little de-ionized water. They were later washed and the filter transferred to a drying oven for 30 minutes at a temperature of 105℃. Finally the filter was removed from the oven and transferred with a pair of clean tweezers to desiccators for 5 minutes to dry completely. The filter was then weighed to an accuracy of 0.1mg. TSS was later calculated as the difference between the initial and final weight of the filter after filtration of an adequate sample volume and drying at 105℃ using equation 3.2.

Suspended solids in mg/l = (f-i) mg × 1000/S …………….Equation 3.2   (UNEP/WHO, 1996)

Where;

f = Final weight of the filter

i = Initial weight of the filter

S = Volume of sample used

3.3.5.2.2 Total Dissolved Solids (TDS)

The ion concentrations in $mg1^{-1}$ of constituents which were required to calculate TDS were as follow;

Calculated TDS = 0.6 (alkalinity) + Na + K + Mg + Cl + SO_4 + SiO_3 + (NO_3-N) + F Equation 3.3 (UNEP/WHO, 1996)

The measured TDS concentration should be higher than the calculated value because a significant contributor may not be included in the calculation. The acceptable ratio is;

$$1.0 < \frac{MeasuredTDS}{CalculatedTDS} < 1.2$$ ……………………..Equation 3.4 (UNEP/WHO, 1996)

A well-mixed, measured portion of a sample was filtered and the filtrate evaporated to dryness in a weighed dish and dried to constant weight at 180°C. The increase in dish weight represents the TDS as indicated in equation 3.5.

$$TDS = \frac{(A-B)\times IOOO}{Samplevolumeinml} mg1^{-1}$$ ………………………Equation 3.5 (UNEP/WHO, 1996)

Where;

A= Weight of dish + solids (mg)

B= Weight of dish before use (mg)

3.3.5.2.3 Biochemical Oxygen Demand (BOD)

Biochemical Oxygen Demand was determined by the dilution method which was used as an approximate measure of the amount of biochemically degraded organic matter in the sample. BOD_5 was determined as the difference between the initial and five-day DO content after five-day incubation of the water samples. The dissolved oxygen content was determined before and after incubation for 5 days at 20℃. The difference gave the BOD of the sample after allowance was given for dilution.

3.3.5.2.4 Total Nitrogen and Total Phosphorus

Water samples for the determination of total nitrogen and total phosphorus were collected using 250ml bottles, fixed immediately using 1ml concentrated sulphuric acid and transported to the laboratory for standard analysis according to APHA (1998). Total nitrogen was determined according to persulfate digestion. The temperature DRB200 reactor was set to a temperature of 105℃. Three vials were cleaned for use in this experiment. Using a funnel, the contents of total nitrogen persulfate reagent powder pillow was added to two HR total nitrogen hydroxide digestion reagent vials. To one of the vials, 0.5ml of the sample was added and to the other, 0.5ml of de-ionized water was added to prepare blank. To the third vial, only the sample was put to it. All the vials were capped and shaken vigorously for at least 30 seconds to mix. The vials were then be put in the reactor and left for 30 minutes. The content in the blank vial was then put into the spectrometer and readings taken. This was then be followed by the sample vial with the reagent and finally the one without reagent. Total Nitrogen (TN) from all the sampling sites was calculated using equation 3.6.

TN in mg/l = F (E_1 Sample - (E_O+E_{B1})…………………… Equation 3.6 (UNEP/WHO, 1996)

Where;

$$F=\frac{Sample concentration in mg/l}{E_{1\,Sample}}$$

E_O= Absorbance of the sample without reductant

E_{B1}= Absorption of distilled water + reagent

E_1 = Absorption of sample with reagent

Total Phosphorus was determined according to persulfate digestion (Ryan *et al.*, 2001). The temperature DRB200 reactor was set to a temperature of 105℃. Three vials were cleaned for use in this experiment. Using a funnel, the contents of total phosphorus persulfate reagent powder pillow was added to two HR total nitrogen hydroxide digestion reagent vials. To one of the vials, 0.5ml of the sample was added and to the other, 0.5ml of de-ionized water was added to prepare blank. To the third vial, only the sample was put to it. All the vials were capped and shaken vigorously for at least 30 seconds to mix. The vials were then put in the reactor and left for 30 minutes. The content in the blank vial was then put into the spectrometer and readings taken. This was then followed by the sample vial with the reagent and finally the one without reagent. Total Phosphorus (TP) from all the sampling sites was calculated using the equation;

TP in mg/l = F (E_1 Sample - (E_O+E_{B1})………………………Equation 3.7 (UNEP/WHO, 1996)

Where;

$$F=\frac{Sample concentration in mg/l}{E_{1\,Sample}}$$

E_O= Absorbance of the sample without reductant

E_{B1}= Absorption of distilled water + reagent

E_1 = Absorption of sample with reagent

3.3.5.2.5 Faecal coliforms

The heterotrophic plate count (HPC) technique was used to detect the total coliforms while the most probable number (MPN)/multi-tube (MT) method was used to detect *Escherichia coli* (*E. coli*) as it is effective in highly turbid samples. One ml of each sample or dilution was placed into 80mm diameter plates and mixed with molten plate count agar and incubated at 37℃ for 48 hours in triplicates where counting was done on the dilution. The following equation was used to calculate the volumes of faecal coli forms;

Viable count/g = n × 1/dilution …………………….Equation 3.8 (UNEP/WHO, 1996)

3.4 Data analysis techniques

3.4.1 Land use/land cover change analysis

The spatial extent analysis of River Ruiru watershed was done in ArcGIS 10.4.1 functions based on 1976, 1995 and 2017 landsat images. Three bands B2, B3 and B4 representing the RGB colours were imported into the ArcMap. A composite of the three bands was formed using the image analysis tool. The study area was extracted through masking in the arctool box then projected into UTM WGS 1984 southern hemisphere zone 37S. Training samples were then created based on different colours of the study area, landsat images and the signature file. Land use classification was done using image classification tool-maximum likelihood classification method. False colour composites (Bands 432) were used for the visual examination and interpretation of the images. Maximum likelihood classification method was used as it is the most widely used per-pixel method which takes into account spectral information of land cover classes (Qian *et al.*, 2007). The maximum likelihood decision rule is based on the probability that a given pixel belongs to a specific class (Manugula *et al.*, 2017) and that the statistics for each individual class in each band is evenly distributed.

The images were classified into seven land use types using supervised classification based on Anderson *et al.* (1976) land use/land cover classification system. These land use types include built-up areas, annual crops, plantation (tea and coffee), grassland, shrubland, forestland and waterbody.

3.4.2. Land use/land cover accuracy assessment

For any image classification data to be useful in land use change detection, it is important to perform accuracy assessment for individual classification (Owojori & Xie, 2005). After image classification, accuracy assessment was conducted to determine the level of acceptance and the process of change detection. In the current study, accuracy assessment was done on landsat 8 OLI/TIRS 2017 satellite image, as its ground truth data were available. As noted by Coppin *et al.* *(*2004) it may be difficult to perform accuracy assessment on a multi-temporal change analysis because of the difficulties in obtaining adequate database for historical reference materials. Hence, accuracy assessment is usually limited to the recent image that is serving as the reference by using ground control points which are collected as part of the data needed for land use/land cover change analysis. The method suggested by Congalton & Green (2009) was used in performing accuracy assessment once the final land use classes were obtained. The accuracy of the classification was assessed by comparing classified land use/land cover classes in 2017 with their corresponding classes identified from a series of Global Positioning System (GPS) reference points acquired during fieldwork and Google Earth high resolution imagery. The confusion matrix method was used for accuracy assessment. This is generally accepted as a standard approach in remote sensing (Fan *et al.*, 2007). A confusion matrix is a cross-tabulation of the mapped versus the reference class. Overall accuracy, user's and producer's accuracy as well as the kappa statistics that removes the effect of random change on accuracy (Green & Congalton, 2004; Skidmore, 1999) were then derived from the error matrices.

The kappa coefficient (k) was then calculated using the following equation:

$$k = \frac{N\sum_{i=I}^{r} xii - \sum_{i=I}^{r}(Xi+*X+i)}{N^2 - \sum_{i=I}^{r}(Xi+*X+i)}$$ ……………………………….Equation 3.9 (Congalton, 1991)

Where;

r: Number of row/columns in the confusion matrix

Xii: Number of the observations in row *i* and column *i*

$Xi+$: Total number of rows *i*

$X+i$: Total number of columns *i*

N: Number of observations

The kappa statistics basically offers a statistically valid assessment of the quality of classification and was used to assess overall class accuracy (Osman *et al.*, 2018). It is the measure of agreement between the classification map and the reference data. The overall classification accuracy which is the percentage of correctly classified samples of a confusion matrix (Banko, 1998) was also used in this study. It was computed by dividing the total number of correctly classified samples by the total number of reference samples. It is expressed by the equation;

Overall accuracy $= \frac{1}{N}\sum_{k}^{n} -1akk$ ……………………………..Equation 3.10 (Banko, 1998)

Where;

A: Individual cell values

k+a: Row total

ka+: Column total

n: Total number of classes

N: Total number of samples

Consequently, the mapping accuracy of each land use class was derived from the calculated producer's accuracy and user's accuracy using the following equations;

Producer's accuracy= $\frac{aii}{\sum_{i-1}^{n} a_i+}$ ……………………….Equation 3.11 (Congalton & Green, 2009)

User's accuracy= $\frac{aii}{\sum_{i-1}^{n} a+1}$ ……………………….. Equation 3.12 (Congalton & Green, 2009)

Where;

aii: Number of samples correctly classified

ai+: Column total for classes

a+i: Row total for classes

3.4.3 Hydrological modelling

The effects of land use/land cover change on the quantity of river discharge and water quality were assessed by integrating remotely sensed data, GIS and the Soil and Water Assessment Tool (SWAT). The integration of SWAT with GIS and remote sensing tools is helpful in analysing and evaluating spatiotemporal land use /land cover dynamics (Thakur *et al.*, 2016; Hossain, 2017). ArcSWATv2012.10.1.18 was downloaded from the SWAT model website (http://swat.tamu.edu/software/arcswat) and installed in ArcGISv10.4.1.

Two independent SWAT runs were carried out on a monthly basis based on the 1984 and 2017 ArcGIS generated land use maps. The following hydrological characteristics were compared for the two years; surface runoff contribution to discharge (SURQ), lateral flow contribution to discharge (LATQ), groundwater contribution to discharge (GWQ), nitrates in the surface runoff (NO_3SURQ), nitrates in lateral flow (NO_3LATQ), organic nitrogen (N.ORG) and organic phosphorus (P.ORG).

3.4.3.1 SWAT model selection and description

Hydrologic models have become indispensable tools for analyzing hydrological processes and the effects of current anthropogenic forces on the hydrologic system (Sarkar & Kumar, 2012; Shirke *et al.,* 2012; Dwarakish & Ganasri, 2015; Suliman *et al.*, 2015). It is critical to examine the applicability of a hydrologic model to simulate the influence of land use and climate variability, as well as its prediction performance, when choosing one for a specific application (Abushandi & Merkel, 2013).

In this study, classified land use/land cover data and weather data were input into the Soil and Water Assessment Tool (SWAT) (Arnold *et al.,* 1998) hydrological model and run to simulate the effects of land use/land cover change and temporal rainfall variability on the quantity of discharge and water quality. The SWAT (Arnold *et al.,* 1998) is a physically-based semi-distributed hydrological model developed by the USDA-ARS (Agricultural Research Institute). It has been broadly used to examine the hydrological impacts of land use/land cover change in various U.S agencies, universities and research institutes. The model can describe various components of a hydrological process and is thought to be the most rational technique to study the hydrological response to LULCC (Savadore *et al.,* 2015). It operates at a wide range of scales with complex terrain features including various soils, land use and management conditions over a daily time-step. As evidenced by numerous international SWAT conferences, hundreds of SWAT-related papers presented at various scientific meetings, and several publications published in peer reviewed journals, the model has acquired international acceptance as a robust interdisciplinary watershed modeling tool (Gassmann, *et al.*, 2007). The application of the SWAT model also opens up new avenues for research into the effects of human activities on water resources, both in terms of quantity and quality (Bouslihim *et al.,* 2016).

The SWAT model sub-divides a basin into sub-basins connected by a stream network and subsequently delineates such sub-basins into Hydrologic Response Units (HRUs) consisting of unique combinations of land use and soils. Areas with the same soil type and land use form a HRU, a basic computational unit assumed to be homogenous in hydrologic response to land cover change. The model application can be sub-divided into the following steps; data preparation, sub-basin discretization, Hydrologic Response Unit definition, parameter sensitivity analysis, calibration and validation and uncertainty analysis.

The model simulates the hydrology into land and routing processes. In the land phase, the amount of water sediment and other non-point loads are calculated from each HRU and summed up to the level of sub-basins. Each sub-basin controls and directs the loads towards the basin outlet. In the routing phase, the flow of water sediment and other non-point sources of pollution are defined through the channel network to an outlet of the basin. According to Zhang *et al.* (2009) the hydrological routines within SWAT account for snowfall and melt, vadose zone processes such as infiltration, evaporation, plant uptake, lateral flows and percolation and groundwater flows.

The interface in GIS (Arc-SWAT) is convenient for the definition of watershed hydrologic feature and storage, as well as the organization and manipulation of the related and tabular data (Di Luzio *et al.,* 2002). Arc-SWAT environment also offers the facility to input spatially referenced data and thereby improves its capability to represent spatial heterogeneity. Arc-SWAT breaks the pre-processing into four main steps which include watershed delineation, HRU analysis, weather data definition and SWAT simulation. It is also an effective tool in analysing the impacts of land use/land cover changes on hydrological characteristics in areas with limited data (Thakur *et al.,* 2016). The model also makes use of Geographic Information System (GIS) and Digital Elevation Model (DEM) to delineate watersheds and extract networks.

The model in addition offers continuous-time simulation, high level of spatial detail, unlimited number of watershed sub-divisions, well-organized computation and capability to simulate changes in land management. SWAT can also run with minimum data inputs, which is helpful when working in areas with limited data especially when modelling ungauged watersheds (Mango *et al.,* 2011). Daily climatic inputs such as daily precipitation, maximum and minimum air temperature, solar radiation, wind speed and relative humidity can be generated internally in the model using monthly climate statistics that are based on long-term weather records

The other basis for the selection of SWAT model owed to its worldwide use for variety of application. The model has gained noteworthy publicity having been used widely for various applications world over with remarkable success (Ndomba & Birhamu, 2008). The application of SWAT model in flow and pollutant loadings has compared satisfactorily with measured data for a variety of watersheds scales (Arnold *et al.,* 1999; Salel *et al.,* 2000; Santhi *et al.,* 2001). The model moreover incorporates functionalities of several other models thus permitting the simulation of climate, hydrology, plant growth, erosion, nutrient transport and transformation, pesticide transport and management practices (Levesque *et al.*, 2008). The model software is freely available for download on the SWAT website. There is also a great amount of user support accessible on this site-including user forum, educational videos and user manuals. More detail about the SWAT theory one can refer to the theoretical documentation available online (http://swat.tamu.edu/).

3.4.3.2 SWAT Model input data

The SWAT model requires land use, soil, topographic and weather data.

3.4.3.2.1 Land use/land cover data

To assess the effects of land use/land cover change on the quantity of river discharge and water quality, two land use/land cover maps of 1984 and 2017 were used in this study. They were obtained by visual interpretation of landsat TM and OLI/TIRS images remotely retrieved from USGS-Earth Explorer website (http://www.earthexplorer.usgs.gov/). The images were classified into seven land use/land cover types in accordance to Anderson *et al.* (1976) land use classification system using supervised maximum likelihood classification tool in ArcGIS 10.4.1. These land use/land cover classes were then reclassified to match classes that are comparable to the SWAT land use and land cover data as shown in Table 3.6.

Table 3.6: Reclassification of land use/land cover types to SWAT land use/land cover classes

User land use/land cover	SWAT land use/land cover	SWAT land use/land cover code
Built-up areas	Residential	URBN
Annual crops(mixed farming)	Agricultural land-Generic	AGRL
Perennial crops (Tea and coffee)	Forest-mixed	FRST
Grassland	Range grasses	RNGE
Shrubland	Range-grasses	RNGB
Forestland	Forest-evergreen	FRSE
Waterbody	Water	WATR

3.4.3.2.2 Digital Elevation Model

A Digital Elevation Model (DEM) with a spatial resolution of 30m was derived from ASTER satellite data in GEO TIFF file format downloaded from the USGS-Earth Explorer website. This resolution is generally reliable for most regions of the world and enables for accurate assessment of landscape elements that influence hydrological processes (Olang', 2009). The DEM was used to delineate the watershed into sub-basins and then into smallest representative unit of the watershed, that is ,the Hydrologic Response Units (HRUs) based on specific land use, soil and slope characteristic features, compute the outlet point of the watershed and to compute the drainage and stream density of the entire watershed.

3.4.3.2.3 Meteorological data

Rainfall data from five ground-based weather stations shown in Table 3.4 and Appendix 2 and minimum and maximum temperature data presented in Appendix 3 were acquired from Kenya Meteorological Department and prepared according to the SWAT model ASCII (.txt) table format. Wind speed, solar radiation and relative humidity data were obtained from global weather data set of the National Centre for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) website in ASCII (.txt) table format (http://globalweather.tamu.edu/).

3.4.3.2.4 Soil data

The SWAT model requires different soil textural and physico-chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. This study used digital soil data acquired from the Kenya Soil and Terrain Database (KENSOTER) soil classification system that describes soil types for Kenya (KSS ISRIC,2007) that are linked to FAO soil classification system which was then manually linked with the SWAT database.

3.4.3.2.5 Hydrological data

Daily discharge data for calibration and validation of the SWAT model was obtained from Water Resources Authority in Kiambu for the period from 2007-2013 for the gauge station 3BC8. This is the period which had complete data.

3.4.3.3 SWAT Model set up

SWAT model set up involved the following procedures;

3.4.3.3.1 Watershed delineation

Watershed delineation was done in ArcSWAT model delineation functions using a DEM with a spatial resolution of 30m generated from ASTER. Watershed delineation process consisted of five major steps; DEM set up, stream network definition, outlet and inlet definition, watershed outlets and selection definition and calculation of sub-basin parameters. Once the DEM set up was done and outlet specified on the DEM, the model automatically calculated the flow direction and flow accumulation. Subsequently, stream network, sub-watersheds and topographic parameters were calculated using their respective tools.

3.4.3.3.2 Hydrological Response Units Analysis

Hydrological Response Unit analysis involves defining land use/land cover, soil and slope characteristics. During HRU analysis, the land use/land cover and soil maps were imported into the ArcSWAT and the slope defined based on the DEM. These were later reclassified and overlay process done using HRU analysis functions. The HRUs were created by defining the threshold of land use/land cover, soil and slope over the sub-basin area at 5% using the multiple HRU definition. This threshold value indicates that land use/land cover, soil and slope classes which form at least 5% of the area will be considered in HRU. Subsequently, Ruiru watershed was divided into 91 HRUs each with unique land use/land cover, soil and slope combinations.

3.4.3.3.3 Weather data definition

The SWAT model requires daily rainfall, maximum and minimum temperature, wind speed, solar radiation and relative humidity from measured data or generated values using daily or monthly average data over a number of years. These data were loaded into the ArcSWAT using the weather stations menu. This was followed by writing the SWAT input tables.

3.4.3.3.4 SWAT run and Simulation

After successfully loading the above data, the model was set to run twice using the land use/land cover maps for the year 1984 and the year 2017 to generate the expected output on the quantity of river discharge and water quality on a monthly basis.

3.4.3.3.5 Sensitivity analysis

Sensitivity analysis is the first step in building any successful and reliable hydrologic model and is helpful in identifying and ranking the parameters that have substantial impact on specific model outputs of interest (Saltelli *et al.,* 2000). Therefore, sensitivity analysis was done to choose the most sensitive flow parameters (Neitsch *et al.,* 2002; Van Griensvan *et al.,* 2006; Abbaspour *et al.*, 2007; Das *et al.*, 2013). This was achieved using the semi-automatic Sequential Uncertainty Fitting 2 (SUFI-2) in SWAT Calibration and Uncertainty Procedures (SWATCUP) version 5.1.6.2. By comparing four uncertainty analysis SWATCUP techniques (GLUE, PARASOL, PSO & SUFI-2) in terms of model performance, model prediction uncertainty, Khoi & Thom (2015) concluded that the SUFI-2 technique could be run with the smallest number of simulation runs to achieve good prediction uncertainty bands and model performance.

In SUFI-2, the procedures employed to perform sensitivity involve One-at-a time (OAT) and Global Sensitivity Analysis methods. The OAT approach identifies the response from the output by sequentially varying each model parameter by a certain fraction while others are kept at their normal values (Spruill *et al.,* 2000; Turanyi & Rabitz, 2000; Holvoet *et al.,* 2005). This approach is less reliable as the parameter perturbation results in eccentricity from the nominal parameter value (Helton, 1993).

Global sensitivity analysis on the other hand, explores the entire range of parameter values during model simulation process. This technique takes into consideration the sensitivity of one parameter relative to the other in order to give their statistical significance (Abbaspour, 2015). In this method, all the parameters under consideration are concurrently perturbed, allowing investigation of parameters interaction and their influence on model outputs. This method has the potential to capture the full range of model parameter values and also to identify the interactions among parameters (Lilbourne *et al.,* 2006).

In this study, the global sensitivity analysis was used where parameter sensitivities were determined by calculating multiple regression systems which returns the values of the parameters generated by Latin hypercube sampling versus the objective function values (Abbaspour *et al.*, 2007) based on the equation;

$g - \alpha + \sum_{i=1}^{m} \beta_i \, b_i$……………………………………Equation 3.13 (Abbaspour *et al.,* 2007)

Where g is the objective function, α is a regression constant, b_i is the parameter, β_i relates to the technical coefficient attached to the variable *b* while *m* is equal to the number of parameters.

In SUFI-2, the assessment of the sensitive parameters is measured using statistical measurements, t-stat and p-value. These statistics were used to determine the most sensitive parameters and rank the various parameters considered to influence flow and the final selection done based on the significance of the ranked parameters. A t-stat is the coefficient of a parameter divided by its standard error and is a measure of the precision with which the regression coefficient is measured. Therefore, the parameter is sensitive when the coefficient is larger than the standard error. A P-value was determined from student's t distribution table with the values obtained for t-stat for a parameter; where a lower p-value suggests higher sensitivity of the parameter and vice-versa (Abbaspour, 2015).

In the current study, 16 river flow parameters were tested for their sensitivity as presented in Table 3.7. These parameters are useful in estimating the quantity of river discharge from a watershed (Betrie *et al.*, 2011).

Table 3.7: Sensitivity analysis of parameters (Arnold *et al.*, 2012)

Parameters	**Parameter definition**	**Units**	**Classification**	**Initial range**	**Method of variation**
ALPHA_BF	Base flow alpha factor	Days	Groundwater	0-1	Replace
ALPHA_BNK	Base flow alpha factor for bank storage	Dimensionless	Channel	0-1	Replace
CH_K2	Effective hydraulic conductivity in main channel alluvium	mm/h	Channel	0.01-500	Replace
CH_N2	Manning's "n" value for the main channel	mm/h	Channel	0.01-0.3	Replace
CN2	SCS runoff curve number	Dimensionless	Surface runoff	-0.1-0.1	Replace
ESCO	Soil evaporation compensation factor	Dimensionless	Evapotranspiration	0-1	Replace
GW_DELAY	Groundwater delay	Days	Groundwater	0-500	Add

GW_REVAP	Groundwater “revap” coefficient	Dimensionless	Groundwater	0.02-0.2	Add
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur	mm	Groundwater	0-1, 000	Add
RCHRG_DP	Deep aquifer percolation fraction	Dimensionless	Groundwater	0-1	Add
REVAPMN	Threshold depth of water in shallow aquifer for “revap” to occur	mm	Groundwater	0-500	Add
SOL_AWC	Available water capacity of the soil layer	mmH_2O/mm soil	Soil	0-1	Relative
SOL_BD	Moist bulk density	mg/m^3	Soil	0-500	Relative
SOL_K	Saturated hydraulic conductivity	mm/h	Soil	0-500	Relative
SOL_Z	Depth of soil	mm	Soil	0-500	Relative
SURLAG	Surface runoff lag coefficient	Dimensionless	Surface runoff	0.05-24	Relative

3.4.3.3.6 Calibration and validation procedures

Calibration is a process carried out to better parameterize a model to a given set of local conditions thus reducing the prediction uncertainty (Arnold *et al.,* 2012a). Differences between model simulations and observations are minimized and it is hoped that the regional model correctly simulates true processes in the physical system (Abbaspour *et al.,* 2017). Calibration encompasses the adjustment of the model parameters to minimize the difference between observed and simulated flow rates. During calibration process, the model parameters were adjusted to obtain results that best match the observed values. The most dominant parameters were varied in order to acquire accurate simulation (Bouslihim *et al.,* 2016). Calibration was accomplished by comparing the output of the SWAT model with the observed data at the same conditions (Engel *et al.,* 2007; Arnold *et al.,* 2012b).

Validation on the other hand is the process of demonstrating that a given site-specified model is capable of making sufficiently accurate simulations (Arnold *et al.,* 2012a). It is used to build confidence in the calibrated parameters (Abbaspour *et al.,* 2017). During validation, the watershed responses were simulated using the parameters finally obtained during calibration process. Owing to non-existence of observed data for nutrients, the model was calibrated and validated only for discharge.

First, the model was set to run from 1984 to 2017 and then calibrated using monthly discharge data for the period between 2007, 2008 and 2009 while validation was carried out using discharge data for 2012 and 2013. Calibration and validation was done using the semi-automated Sequential Uncertainty Fitting-2 (SUFI-2) calibration method within SWAT Calibration and Uncertainty Procedures (SWAT-CUP) version 5.1.6.2 on a monthly basis.

The SUFI-2 approach within SWAT-CUP is the mostly commonly used method to carry out parameterization, sensitivity analysis, uncertainty analysis, calibration and validation of hydrologic parameters on both daily and monthly time-step (Abbaspour *et al.,* 2007). It is a semi-automated method that makes the calibration process easier to carry within a realizable time bounds (Sloloba & Swayne, 2011). It has gained more significance among researchers for the reason that if carried out manually, the incorporation of large number of parameters in a model can make the calibration process more difficult and computationally extensive (Rosso, 1994; Sorooshian & Gupta, 1996).

3.4.3.3.7 Model uncertainty analysis

According to Abbaspour *et al.* (2017), uncertainty analysis refers to the propagation of all model input uncertainties (mapped in the parameter distribution) to model outputs. Model uncertainty is expressed in SWAT-CUP as 95% prediction uncertainty (95PPU). The SUFI-2 algorithm (Abbaspour, 2011) was used for calibration, validation and uncertainty analysis. The process aims to capture most of the measured data within the 95 percent prediction uncertainty (95PPU). This helped in determining the new ranges and best fitted values that were applied for further iterations to maximize the objective function. The 95PPU was calculated at 2.5 and 97.5% levels of the cumulative distribution of an output variable obtained through Latin Hypercube sampling.

In SUFI-2, the degree to which all parameter uncertainties are accounted for is quantified. To quantify the goodness of calibration/uncertainty performance**,** two statistics/indices were used; p-factor and r-factor. The p-factor is the percentage of measured data bracketed by the 95PPU band (ideal value should approach closer to 1) while the r-factor is an average thickness of the 95PPU band divided by standard deviation of the corresponding measured variable (ideal value should be close to 0) (Abbaspour, 2014).

3.4.3.3.8 Model performance evaluation

Both graphical techniques and quantitative statistical analyses were used to compare the measured or the observed data as suggested by Moriasi *et al.* (2007) in their guidelines shown in Table 3.8. The model performance was evaluated based on four statistical techniques; Nash-Sutcliff Efficiency (NSE), Percent Bias (PBIS), Root Mean Square Error (RMSE)-Observations standard derivation ratio (RSR) and Coefficient of determination (R^2).

Table 3.8: Classification of statistical indices according to Moriasi *et al.* (2007)

CLASSIFICATION	NSE	PBIAS (%)	RSR	R^2
Very good	0.75<NSE≤1.00	PBIAS≤±10	0.00<RSR<0.50	$0.75< R^2 \leq 1.00$
Good	0.65<NSE≤0.75	±10<PBIAS≤±15	0.50<RSR<0.60	$0.60< R^2 \leq 0.75$
Satisfactory	0.50<NSE≤0.65	±15<PBIAS≤±25	0.60<RSR<0.70	$0.50< R^2 \leq 0.60$
Unsatisfactory	NSE≤50	±50≤PBIAS	RSR>0.70	$R^2 \leq 0.25$

3.4.3.3.8.1 Nash-Sutcliffe Efficiency (NSE)

This is the mostly widely used evaluation criterion for the testing the goodness of fit between observed and simulated values. It indicates how well the plots of observation and simulation data fit the 1:1 line. It is computed as shown in equation 3.14.

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}{\sum_{i=1}^{n}\left(Y_i^{obs} - Y^{mean}\right)^2}\right]$$ ………………..…Equation 3.14 (Moriasi *et al.*, 2007)

NSE ranges between -∞ and 1.0 (1 inclusive), with NSE=1 being optimum value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance whereas values ≤0.0 indicates that the mean observed value, which indicates unacceptable performance.

3.4.3.3.8.2 Percent Bias (PBIAS)

Percent Bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Gupta *et al.*, 1999). The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias and negative values indicate model overestimation bias (Gupta *et al.*, 1999), where PBIAS is the deviation of data being evaluated, expressed as a percentage. PBIAS is calculated as shown in equation 3.15.

$$\boldsymbol{PBIAS} = \left[\frac{\sum_{i=1}^{n}\left(\left(Y_i^{obs} - Y_i^{sim}\right)\right) * (100)}{\sum_{i=1}^{n}\left(Y_i^{obs}\right)}\right]$$ …………………………Equation 3.15 (Moriasi *et al.*, 2007)

3.4.3.3.8.3 Root Mean Square Error (RMSE)-Observations Standard Deviation Ratio (RSR)

RMSE is one of the commonly used error index statistics (Chu & Shirmohammadi, 2004; Singh *et al.*, 2004; Vasquez-Amabile and Engel, 2005). Although it is commonly accepted that the lower the RMSE, the better the model performance, only Singh *et al.* (2004) have established a guideline to qualify what is considered a low RMSE based on the observation standard deviation ratio (RSR). Based on the recommendation by Singh *et al.* (2004), a model evaluation statistics known as the RMSE-Observations Standard Deviation and it combines both an error index and the additional information recommended by Legates and McCabe (1999). RSR is calculated as the ratio of the RMSE and standard deviation of measured data as shown in equation 3.16.

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs}-Y_i^{sim}\right)^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs}-Y^{mean}\right)^2}\right]}$$ ....Equation 3.16 (Moriasi *et al.*, 2007)

RSR incorporates the benefits of error index statistics and includes a normalization factor, so that the resulting statistics and reported values can apply to various constituents. It varies from the optimal value of zero, which indicates zero RMSE or residual variation and therefore perfect model simulation, to a large positive value. The lower the RSR, the lower the RMSE and the better the model simulation performance.

3.4.3.3.8.4 Coefficient of determination (R^2)

This is another goodness of fit criterion used in the SWAT model evaluation to describe the degree of collinearity between simulated and observed data. It describes the proportion of variance in measured data. It ranges from 0 to 1, with higher values indicating less error and typically values greater than 0.5 are considered acceptable (Santhi *et al.,* 2001; Van Liew *et al.*, 2003). It is computed as shown in equation 3.17.

$$R^2 = \frac{\sum_i\left[\left(Y^{obs} - Y_0^{mean}\right)\left(Y^{sim} - Y_S^{mean}\right)\right]^2}{\sum_i\left(Y^{obs} - Y_0^{mean}\right)^2 \sum_i\left(Y^{sim} - Y_S^{mean}\right)^2}$$ ....Equation 3.17 (Moriasi *et al.*, 2007)

Where;

Y^{obs} is the measured data

$Y^{sim}$is the model simulation output

$Y_0^{mean}$and Y_S^{mean} is the observed data and simulated data of streamflow

i is the *ith* measured or simulated data

n is the total number of observation.

3.4.4 Statistical data analysis

Statistical analysis was done using Statistical Package for Social Sciences (SPSS version 22). Various statistical techniques were used to assess the effects of temporal rainfall variability on the quantity of river discharge and water quality. Initially, the SWAT model was used to aggregate the observed daily rainfall data of the five stations into mean monthly and annual areal rainfall data. The effects of temporal rainfall variability on the quantity of river discharge and water quality was based on simulated discharge and water quality from the calibrated SWAT model and measured water quality data for the dry and wet seasons in 2018. This was due to lack of recorded discharge and water quality data.

The SWAT simulated discharge and water quality data were later subjected to inferential statistical analysis. Regression analysis was used to assess the effects of temporal rainfall variability on the quantity of river discharge. Analysis of Variance (ANOVA), F-test was used to test any significant relationship between temporal rainfall variability and discharge components. During the analysis, 95% level of significance was used as the critical point ($p<0.05$). The effect of temporal rainfall variability on SWAT simulated nitrates (NO_3), Organic nitrogen (N.ORG) and Organic phosphorus (P.ORG) was assessed based on Pearson's correlation equation. A paired sample t-test was performed to compare the effects of temporal rainfall variability on water quality during dry and wet season while Chi-Square test was used to compare water quality of different sampling stations. Descriptive statistics- graphs and tables-were used to present the results.

3.5 Conclusions

This chapter described the regional background and location of the study area and outlined methods of data collection and analysis and created a database for the *in situ* and laboratory water quality analysis. Geo-spatial techniques were used for land use/land cover analysis of 1976, 1995 and 2017 landsat images in ArcGIS 10.4.1 functions. The SWAT model was used to simulate and assess the effects of land use/land cover change on the quantity of river discharge and water quality based on land use/land cover maps for 1984 and 2017. It was also used to generate water quality parameters for 1984 and 2017. Water quality analysis was used to quantify the quality of water for River Ruiru for the wet and dry seasons. Inferential statistical techniques were used to assess the effects of temporal rainfall variability on the quantity of river discharge and water quality while descriptive statistics were used to present results.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results of the study based on the outlined objectives. It includes the extent of change in land use/land cover of River Ruiru watershed from 1976 to 2017 and the effects of land use/land cover change and temporal rainfall variability on the quantity of river discharge and water quality based on landsat images for 1984 and 2017. These results have been summarized in percentages, tables and graphs. Subsequently, the chapter ends with a discussion of the research findings.

4.2 Results

4.2.1 Land use/land cover analysis in River Ruiru watershed between 1976 and 2017

Figures 4.1, 4.2, 4.3 and 4.4 indicate that River Ruiru watershed experienced land use/land cover change from 1976 to 2017. Built-up areas increased by 3.07% from 0.69% in 1976 to 2.16% in 1995 and 3.76% in 2017. Similarly, annual crops increased by 35.85% from 10.79% in 1976 to 38.12% in 1995 and 46.63% in 2017. Perennial crops (Tea and coffee) increased by 11.49% from 4.67% in 1976 and 18.10% in 1995 but declined to 16.16 % between 1995 and 2017. Areas under water bodies slightly increased in the area by 0.1% from 0.21% in 1976, 0.29% in 1995 and 0.31% in 2017. In the same period, forestland declined by 29.79% from 56.42% in 1976, to 30.0% in 1995 and to 26.63% in 2017. Similarly, grassland and shrubland declined by 7.48% and 13.25% respectively between 1976 and 2017. Grassland decreased from 12.55% in 1976, 6.03% in 1995 to 5.07% in 2017. Shrubland declined from 14.68% in 1976, 5.3% in 1995 to1.43% in 2017.

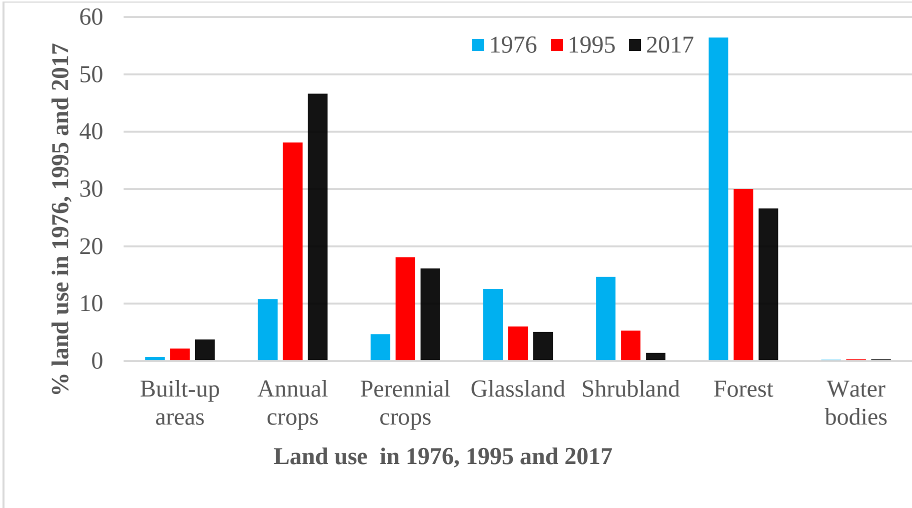

Figure 4.1: Land use/land cover in 1976, 1995 and 2017

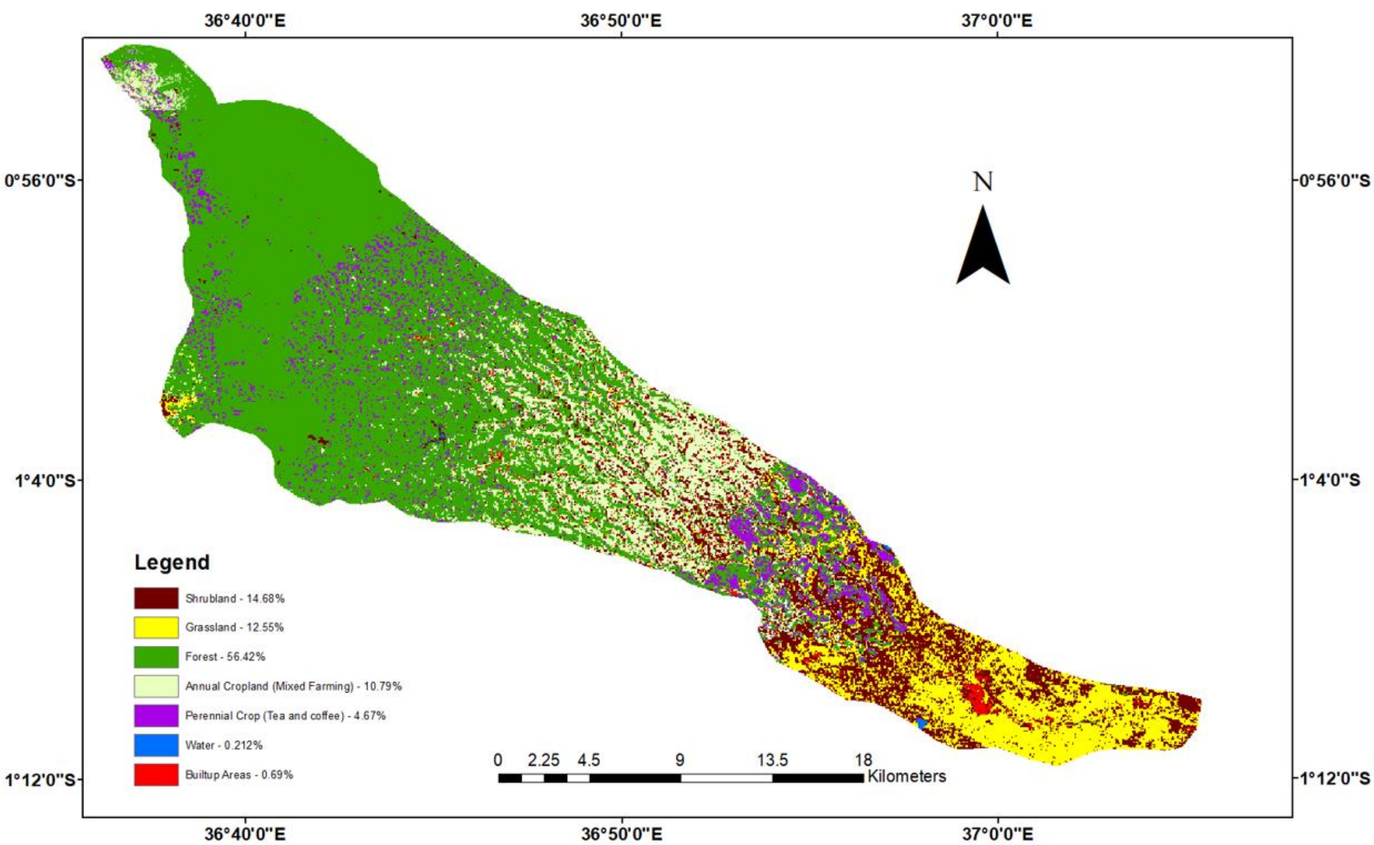

Figure 4.2: Land use/land cover computed from MSS, 1976 in ArcGIS 10.4.1 Analysis functions

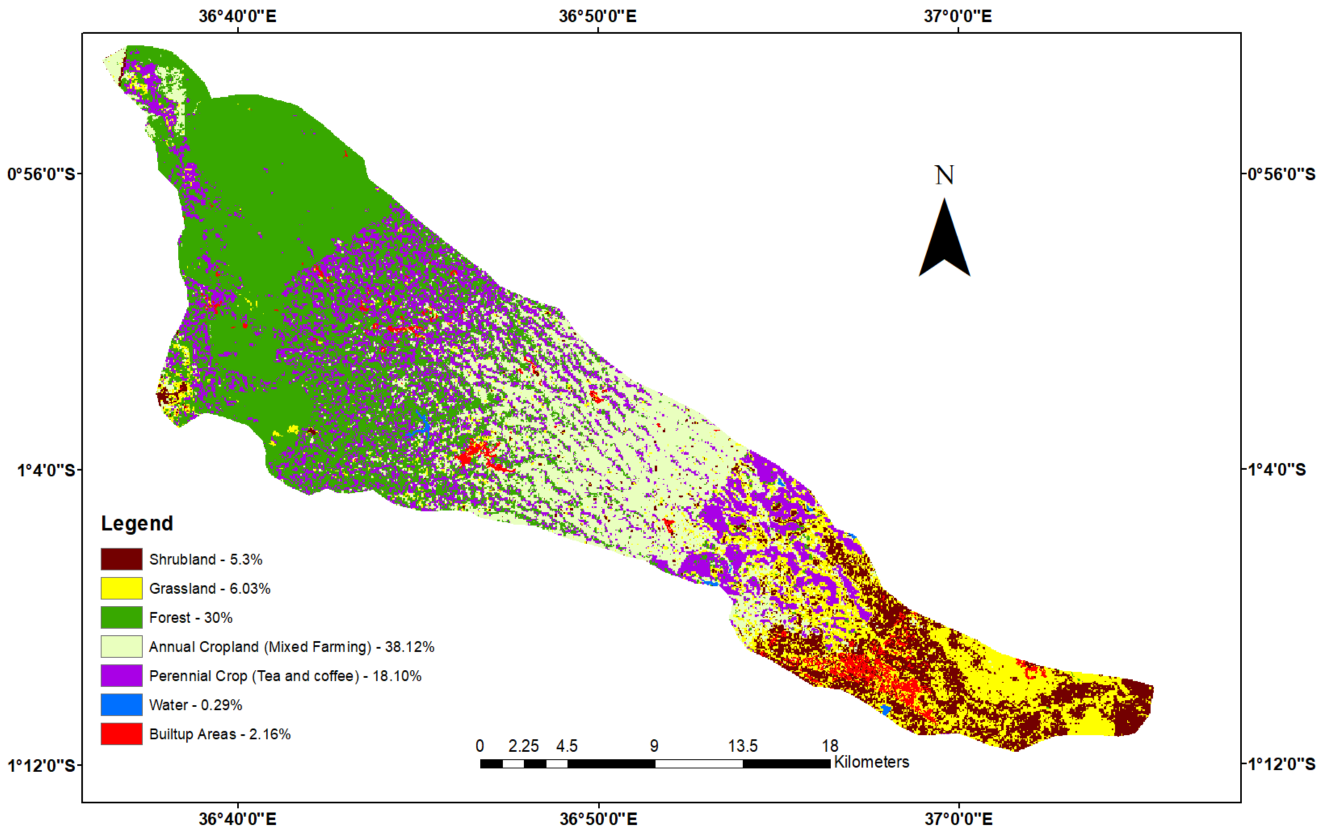

Figure 4.3: Land use//land cover computed from TM 1995 in ArcGIS 10.4.1 Analysis functions

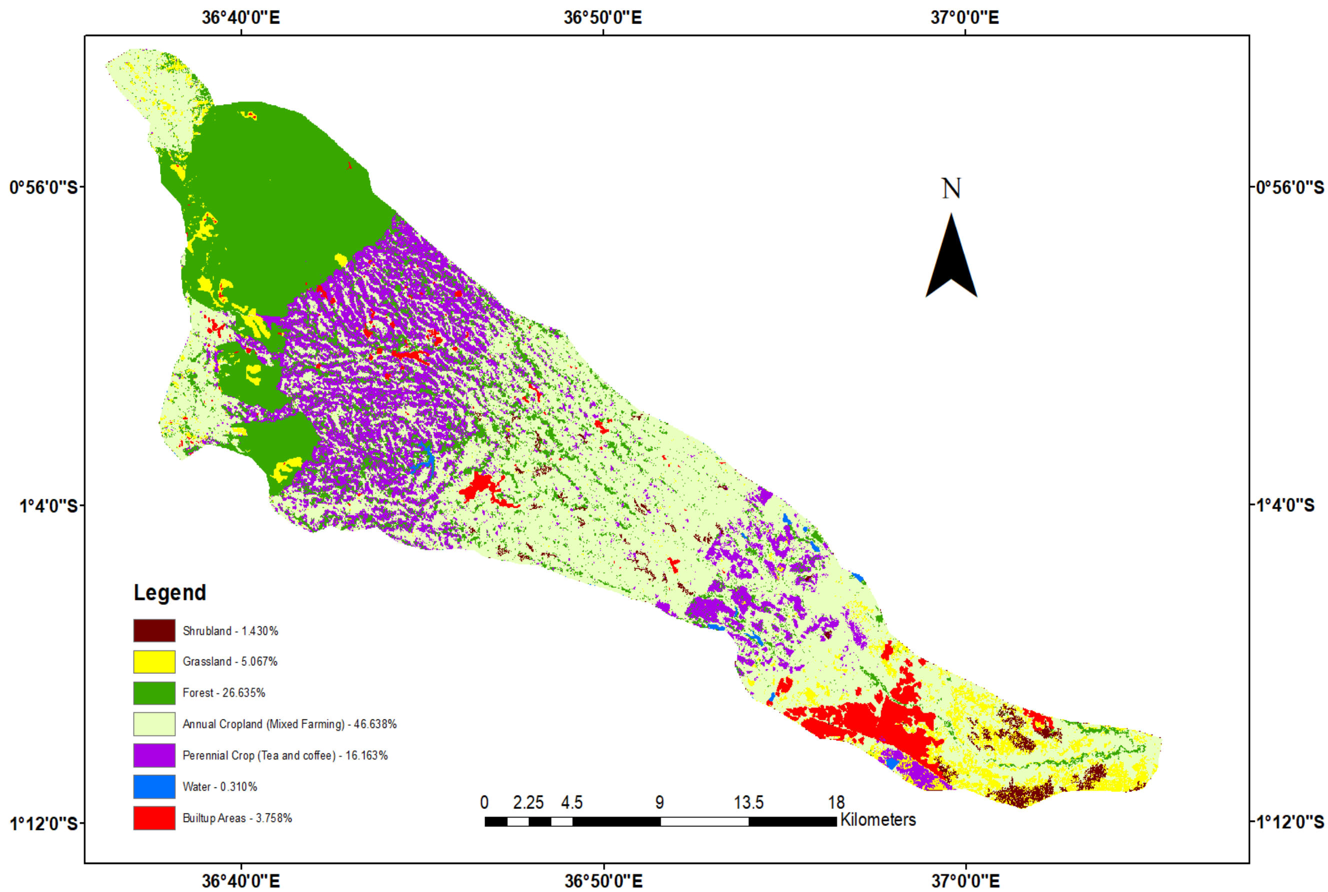

Figure 4.4: Land use/land cover computed from OLI/TIRS, 2017 in ArcGIS 10.4.1 Analysis functions

4.2.2 Land use/land cover accuracy assessment

Table 4.1 presents the results of land use/land cover accuracy assessment based on 2017 land use/land cover classification, high resolution Google Earth images and field control points collected during ground truthing.

Table 4.1: Land use/land cover accuracy assessment

	HIGH RESOLUTION IMAGES OF GOOGLE EARTH AND FIELD POINTS								
LAND USE/LAND COVER CLASSIFICATION OF 2017	Built-up Area	Annual Cropland	Perennial Cropland	Grassland	Shrubland	Forestland	Water bodies	**TOTAL**	**PA%**
Built-up Area	**8**	0	0	0	0	0	0	8	**100.00**
Annual Cropland	1	**7**	0	2	0	0	0	10	**70.00**
Perennial Cropland	0	0	**8**	0	0	0	0	8	**100.00**
Grassland	0	1	0	**5**	0	0	0	6	**83.33**
Shrubland	0	4	0	0	**4**	0	0	8	**50.00**
Forestland	0	1	0	0	0	**7**	0	8	**87.50**
Water bodies	0	0	0	0	0	0	**2**	2	**100.00**
TOTAL	9	13	8	7	4	7	2		
CA%	**88.89**	**53.85**	**100.00**	**71.43**	**100.00**	**100.00**	**100.00**		

Overall Accuracy (%) = (8+7+8+5+4+7+2)/50 * 100 = 41/50 * 100 = 82%

Kappa coefficient= 50(41) – ((8*9)+(10*13)+(8*8)+(6*7)+(8*4)+(8*7)+(2*2))

$(50)^2$ – ((8*9)+(10*14)+(8*8)+(6*7)+(8*4)+(8*7)+(2*2))

Kappa coefficient = 0.79

4.2.3 Effects of land use/land cover change on the quantity of river discharge and water quality

The results of the effects of land use/land cover change on the quantity of river discharge and water quality were based on land use/land cover types of 1984 and 2017.

4.2.3.1 Land use/land cover types for 1984 and 2017

Figures 4.5 and 4.6 show the two land use/land cover images of 1984 and 2017 that were generated from landsat TM and OLI/TIRS classification respectively. Findings from the study indicated that built-up areas increased by 1.83% from 1.9% to 3.8%, annual crops (mixed farming) increased by 15.05% from 31.6% to 46.6% while perennial crops (Tea and Coffee farming) increased by 10.90% from 5.3% to 16.2%. Area under water bodies also slightly increased by 0.095% from 0.22% in 1984 to 0.31% in 2017. On the other hand, grassland declined by 6.21% from 11.3% to 5.1%, shrubland declined by 11.92% from 13.0% to 1.4% while forestland decreased by 10.66% from 36.7% to 26.6% as presented in Figure 4.7 and Figure 4.8.

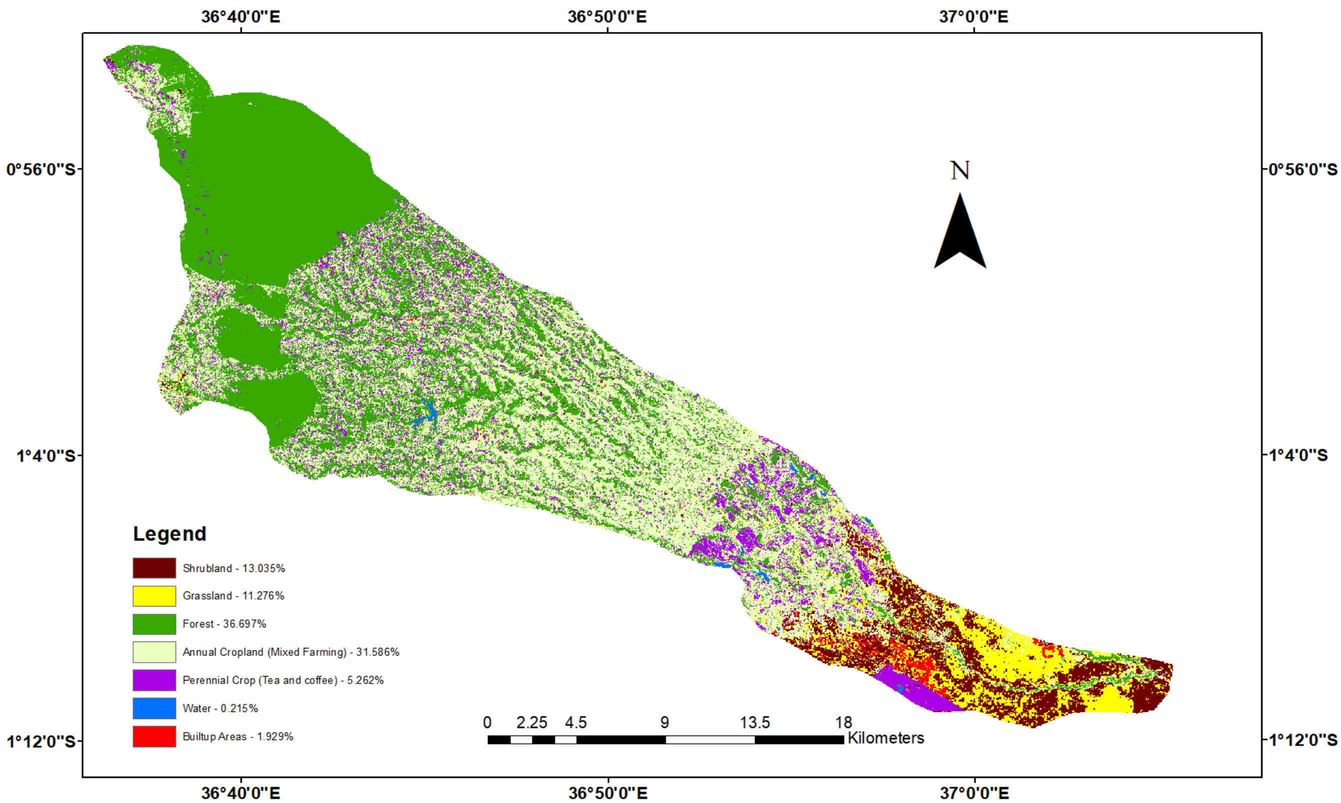

Figure 4.5: Land use/land cover computed from TM 1984 in ArcGIS 10.4.1 Analysis functions

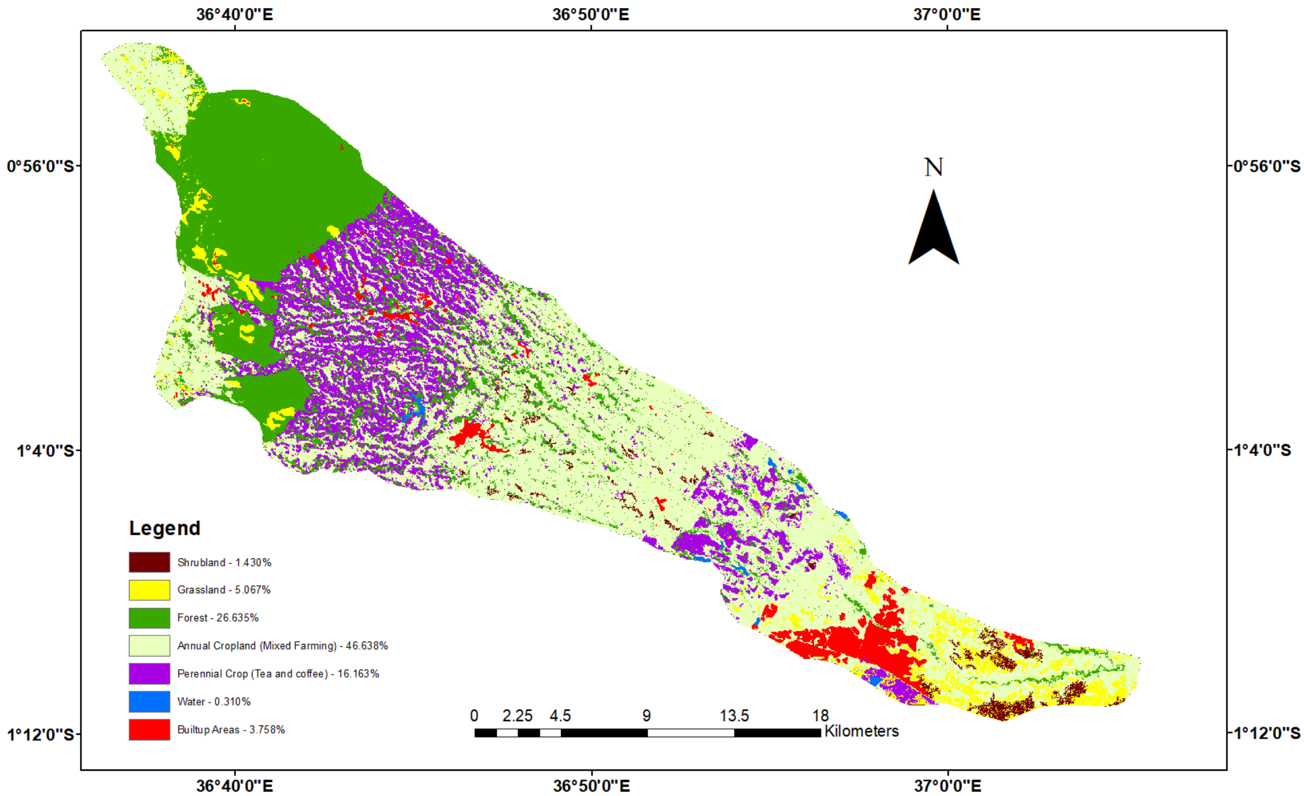

Figure 4.6: Land use/land cover map computed from OLI/TIRS 2017 in ArcGIS 10.4.1 Analysis functions

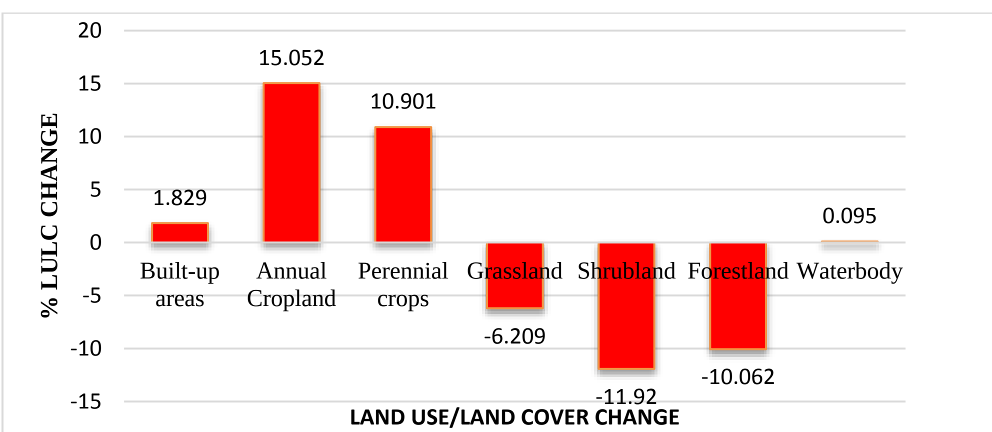

Figure 4.7: Percentage land use/land cover change between 1984 and 2017

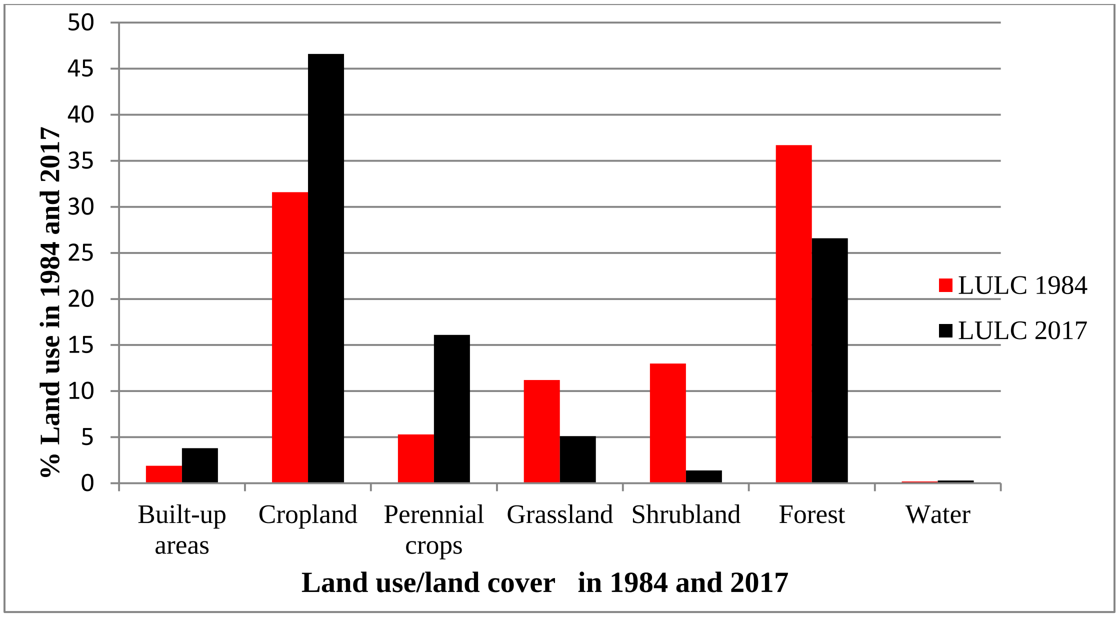

Figure 4.8: Land use/land cover change between 1984 and 2017

4.2.3.2 SWAT Model results

4.2.3.2.1 Model sensitivity analysis

Table 4.2 shows 16 sensitive parameters affecting the quantity of discharge in River Ruiru watershed together with their t-stat, p-value and their ranking while Table 4.3 shows the five most sensitive parameters and their fitted, minimum and maximum values done using SUFI-2 procedure in SWATCUP. The parameters were ranked in terms of their sensitivity to the SWAT model calibration.

Table 4.2: Sensitivity analysis

Parameter Name	**Parameter definition**	**t-stat**	**p-value**	**Ranking**
R__CN2.mgt	SCS runoff curve number	-2.88	0.05	1
R__ALPHA_BNK.rte	Base flow alpha factor for bank storage	-1.27	0.29	2
R__SOL_Z (..).sol	Depth of soil	0.97	0.40	3
R__SOL_BD (..).sol	Moist bulk density	0.70	0.53	4
V__GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur	0.69	0.54	5
R__SOL_K (..).sol	Saturated hydraulic conductivity	0.53	0.63	6
R__ESCO.hru	Soil evaporation compensation factor	-0.50	0.65	7
R__CH_K2.rte	Effective hydraulic conductivity in main channel alluvium	0.47	0.67	8
V__ALPHA_BF.gw	Base flow alpha factor (days)	0.39	0.72	9
R__GW_REVAP.gw	Groundwater “revap” coefficient	0.38	0.73	10
R__RCHRG_DP.gw	Deep aquifer percolation fraction	0.27	0.80	11
V__GW_DELAY.gw	Groundwater delay	0.17	0.87	12
R__SOL_AWC(..).sol	Available water capacity of the soil layer	-0.16	0.88	13

R__CH_N2.rte	Manning's "n" value for the main channel	0.13	0.90	14
R__SURLAG.bsn	Surface runoff lag coefficient	-0.08	0.94	15
R__REVAPMN.gw	Threshold depth of water in shallow aquifer for "revap" to occur	0.04	0.97	16

Table 4.3: The five most sensitive parameters and their fitted, minimum and maximum values done using SUFI-2 procedure in SWATCUP

Parameter Name	Fitted Value	Minimum Value	Maximum Value
R__CN2.mgt	-0.190000	-0.200000	0.200000
R__ALPHA_BNK.rte	0.580000	0.000000	0.800000
R__SOL_Z (..).sol	0.192500	0.000000	0.700000
R__SOL_BD (..).sol	0.285000	0.000000	0.600000
V__GWQMN.gw	0.450000	0.000000	2.000000

**The extensions such as .mgt,rte, sol and .gw refer to the SWAT input file where the parameter occurs. The qualifier R_ refers to the relative change in the parameter where the value from the SWAT database is multiplied by 1 plus a factor in the given range, while the qualifier V_ refers to the substitution of a parameter by a value from the given range.

After calibration, the overall effect of each parameter used was ranked using global sensitivity function within SWAT-CUP. From the analysis, the most discharge-sensitive parameters were CN2.mgt and ALPHA.BNK. The CN2.mgt (SCS runoff curve number for moisture condition II) is an empirical parameter used to predict direct runoff and infiltration from rainfall excess. The curve number estimates runoff based on the relationship between precipitation, hydrologic soil group and land uses. Therefore, the parameter reflects soil permeability, land use and antecedent soil water as it is a function of these conditions (Neisch *et al.*, 2002). ALPHA-BNK is the baseflow alpha factor bank storage (Smedema *et al.*, 1983; Arnold *et al.*, 2012a).

4.2.3.2.2 Model uncertainty analysis

The model was able to bracket 67% of observed data with a large uncertainty band (r-factor=1.12) during calibration. During validation, the model bracketed 96% of the observed data with a slightly larger uncertainty band (r-factor=1.33) as shown in Table 4.4 and Figures 4.9 and 4.10. The mean simulated and mean observed monthly discharge was 0.89 and 1.10 respectively during calibration and 0.64 and 0.65 respectively during validation.

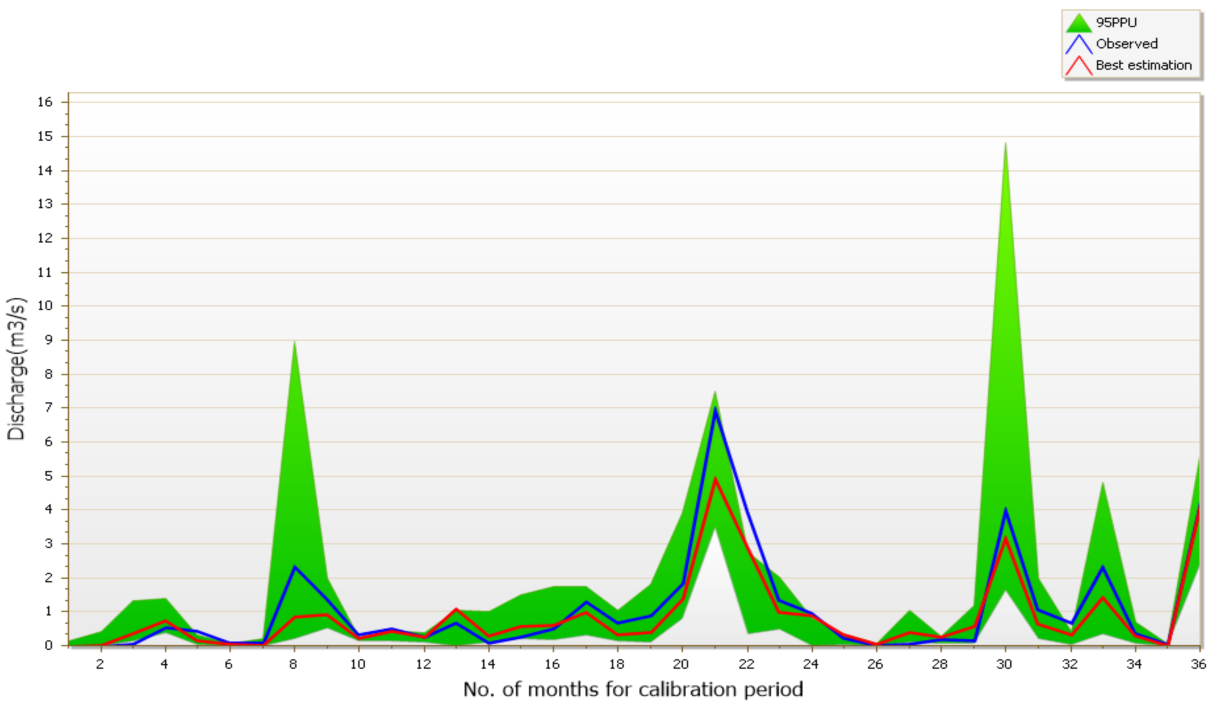

Figure 4.9: Model uncertainty output expressed as 95PPU for calibration period

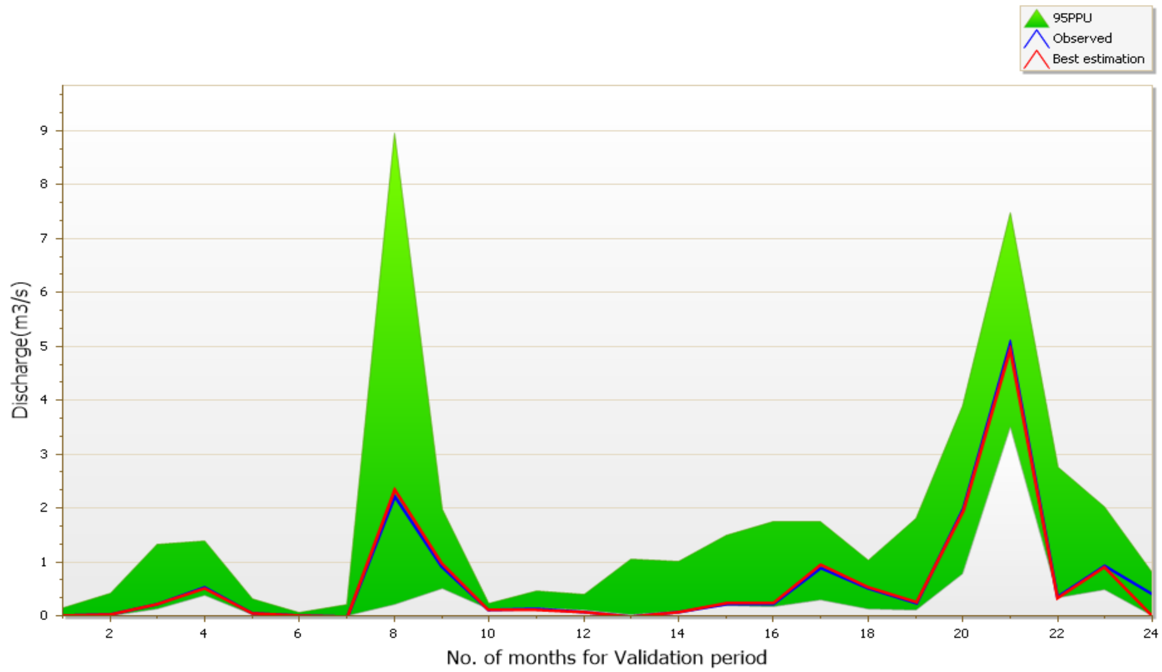

Figure 4.10: Model uncertainty output expressed as 95PPU for validation period

4.2.3.2.3 Model performance evaluation

Calibration and validation outputs for the period 2007-2009 and 2012-2013 showed a good correlation between observed and simulated discharge values with NSE=0.86, PBIAS=19.4, R^2=0.93 and RSR=0.37 during calibration and NSE=0.99, PBIAS=2.0, RSR=0.08 and R^2=0.99 during validation as shown in Table 4.4 and Figures 4.11, 4.12, 4.13 and 4.14.

Table 4.4: Performance evaluation indicators

	NSE	PBIAS	RSR	R^2	Mean_sim(Mean_obs)	Stddev.sim(obs)	P-factor	R-factor
Calibration (2007-2009)	0.86	19.4	0.37	0.93	0.89(1.10)	1.14(1.52)	0.67	1.12
Validation (2012-2013)	0.99	2.0	0.08	0.99	0.64(0.65)	1.09(1.10)	0.96	1.33

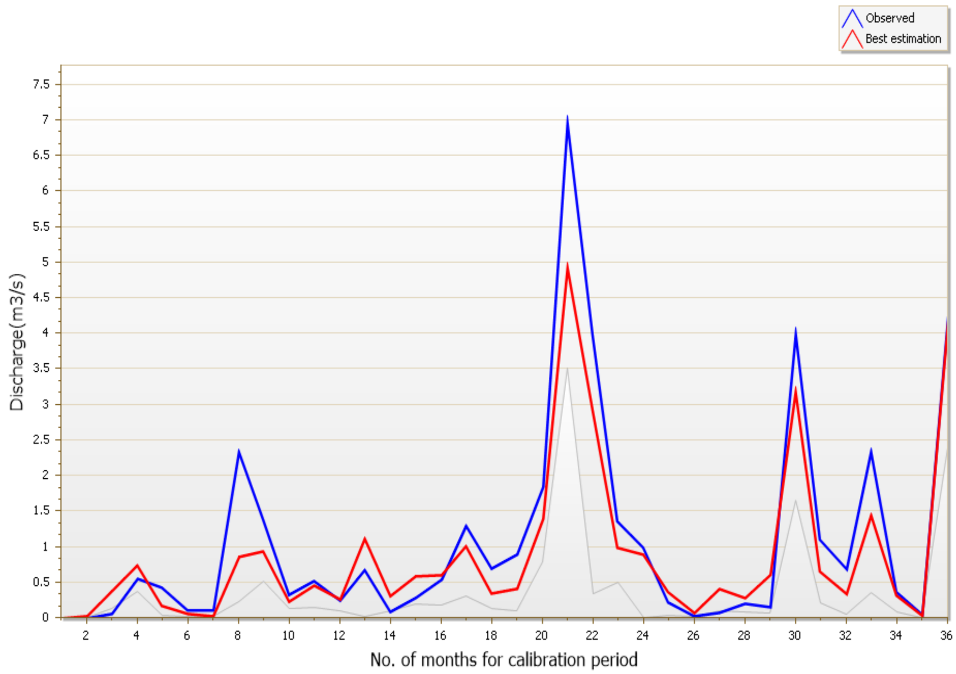

Figure 4.11: Observed and simulated flow hydrograph during calibration period from 2007 to 2009

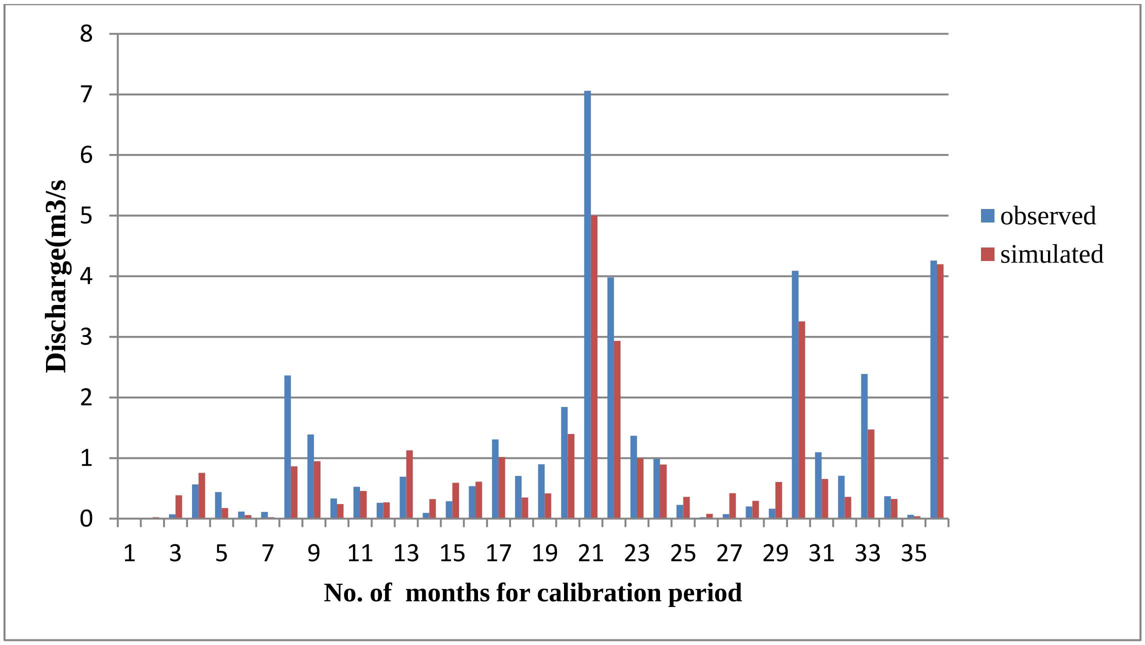

Figure 4.12: Observed and simulated monthly discharge during calibration period from 2007 to 2009

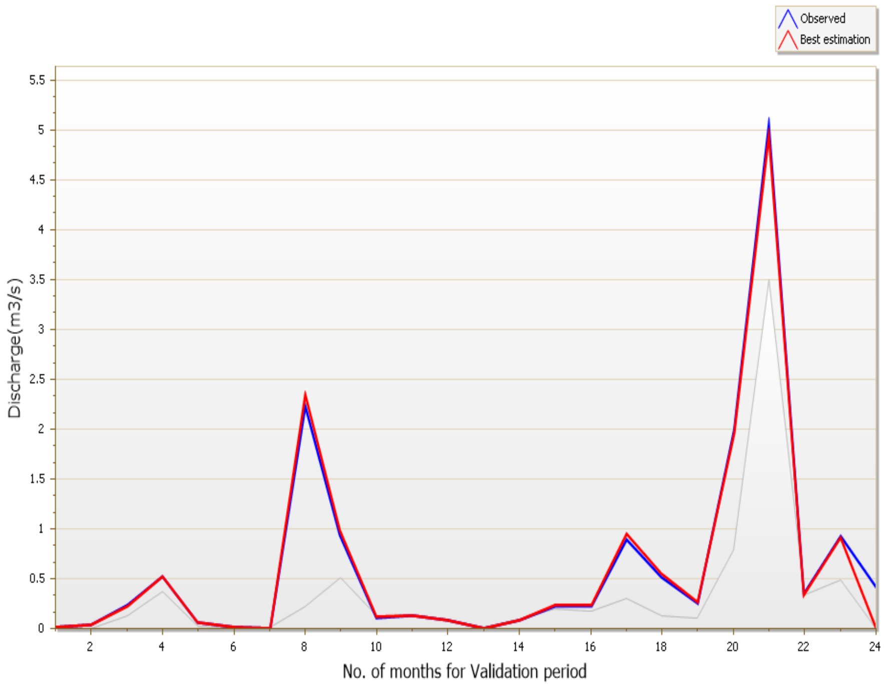

Figure 4.13: Observed and simulated flow hydrograph during validation period in 2012 and 2013

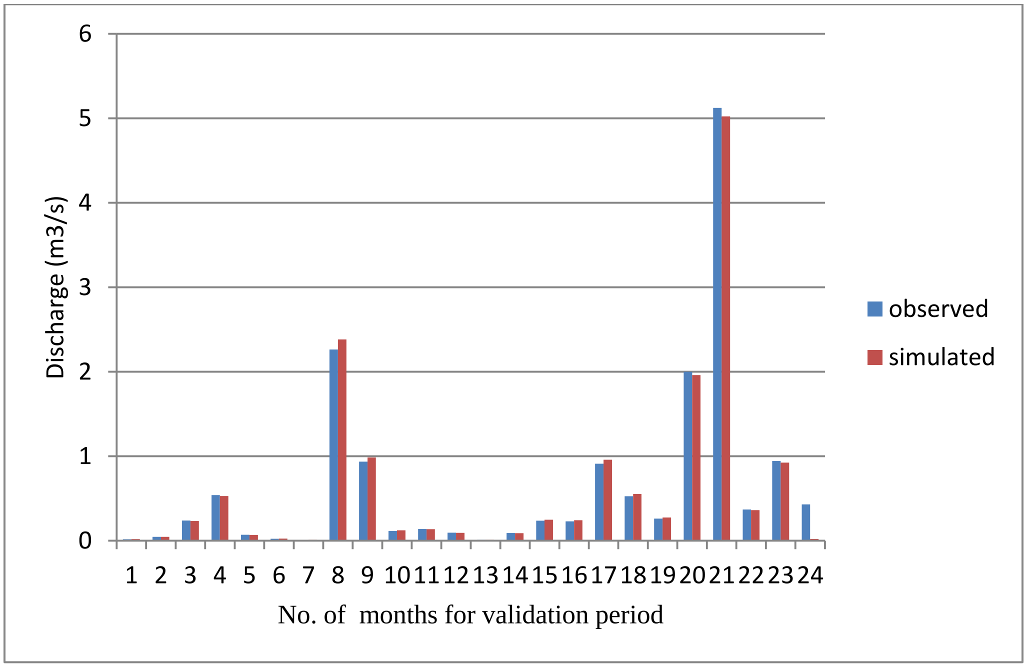

Figure 4.14: Observed and simulated monthly discharge during validation period in 2012 and 2013

4.2.3.3 Effects of land use/land cover change on the quantity of river discharge

Results of the study indicated that River Ruiru watershed has undergone land use/land cover change over the last 33 three years. It was observed that an increase in built-up areas, annual and perennial crops by 1.83%, 15.05% and 10.90% respectively and a decline in grasslands, shrublands and forestland by 6.21%, 11.92% and 10.06% respectively indicated in Figure 4.7 and Figure 4.8 led to an increase in surface runoff contribution to discharge (SURQ) from 30.25mm/yr in the year 1984 to 181.25mm/yr in the year 2017. Results also indicated a slight increase in lateral runoff contribution to discharge (LATQ) and groundwater contribution to discharge (GWQ) from 8.48mm/yr and 9.95mm/yr respectively in the 1984 to 11.44mm/yr and 10.66mm/yr respectively in the 2017 as indicated in Table 4.5 and Figure 4.15.

Table 4.5: Effects of land use/land cover change on the quantity of river discharge components in 1984 and 2017

Discharge component	1984	2017
Surface runoff contribution to discharge (SURQ)	30.25mm/yr	181.25mm/yr
Lateral flow contribution to discharge (LATQ)	8.48mm/yr	11.44mm/yr
Ground water contribution to discharge (GWQ)	9.95mm/yr	10.66mm/yr

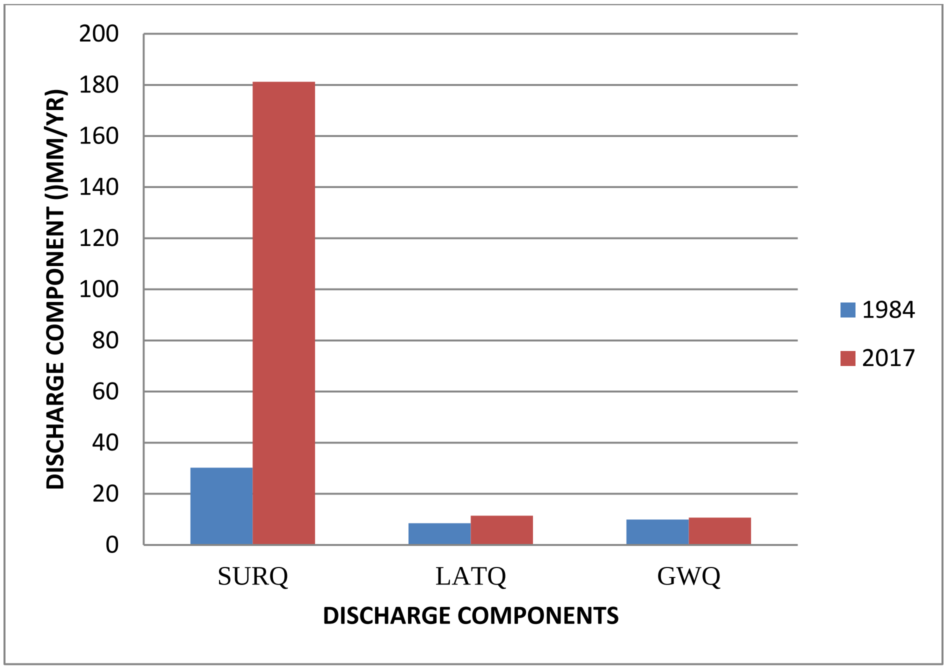

Figure 4.15: Discharge components in 1984 and 2017

4.2.3.4 Effects of land use/land cover change on water quality

The results of the study indicated that changes in land use/land cover between 1984 and 2017 led to a change in water quality of River Ruiru watershed. The nitrates in the surface runoff (NO_3SURQ), nitrates in lateral runoff (NO_3LATQ), organic nitrogen (N.ORG) and organic phosphorus (P.ORG) increased from 0.05kgN/ha/yr, 0.06kgN/ha/yr, 5.77kgN/ha/yr and 0.87 kgP/ha/yr respectively in the year 1984 to 1.47kgN/ha/yr, 0.19kgN/ha/yr, 70.60kgN/ha/yr and 8.86kgP/ha/year respectively in the year 2017 as indicated in Table 4.6.

Table 4.6: Effects of land use/land cover change on water quality

Water quality parameters	1984	2017
NO^3SURQ	0.05kgN/ha/yr	1.47 kgN/ha/yr
NO^3LATQ	0.06 kgN/ha/yr	0.19 kgN/ha/yr
N.ORG	5.77kgN/ha/yr	70.60kgN/ha/yr
P.ORG	0.87kgP/ha/yr	8.86kgP/ha/yr

4.2.4 Effects of temporal rainfall variability on the quantity of river discharge

The results of the effects of temporal rainfall variability on the quantity of river discharge were assessed based on regression analysis as presented in Table 4.7.

Table 4.7: Regression model summary

Model	R	R^2	Std. Error of the Estimate
1	.972	.944	54.8319066

a. Predictors: (Constant), Mean annual rainfall

The R shown in Table 4.7 is the correlation between the observed and predicted value of dependent variable. It indicated a very good association of 0.972 between rainfall variability and discharge. The R^2 is a coefficient of determination and measured the proportion of variance in the dependent variable that is explained by variations in the independent variable (temporal rainfall variability and discharge). The results indicated a 94.4% of variance or correlation between dependent and independent variable which means that 94.4% of variations or changes in discharge were caused by rainfall variability. This implied a strong positive linear relationship between the two parameters.

The ANOVA statistics, *F* (1, 36) = 608.85, p<0.001 in Table 4.8 presents the regression model significance. An F-significance value of p = 0.000 was established showing that there was a probability of 0.0% of the regression model presenting false information. Therefore, the model was very significant.

Table 4.8: Analysis of variance (ANOVA)

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	1830537.120	1	1830537.120	608.852	.000
	Residual	108235.368	36	3006.538		
	Total	1938772.488	37			

From Table 4.9, the following regression model was established;

Discharge = -251.396 + 0.517, temporal rainfall variability P = 0.000

Table 4.9: Regression coefficient

Model		Unstandardized Coefficient		Standard Coefficient	T	Sig.
		B	Std. Error	Beta		
1	Constant	-251.396	20.360		-12.347	.000
	Mean annual rainfall	.517	.021	.972	24.675	.000

a. Dependent Variable: Mean annual discharge

The regression constant showed that when the independent variable (temporal rainfall variability) is constant at zero, the quantity of river discharge would be negative (-251.396). Introduction of temporal rainfall variability increased the level of river discharge by 0.517. This observation was significant at (p<0.001). This means that temporal rainfall variability had a positive and significant effect on the quantity of river discharge at 95% level of significance.

4.2.5 Effects of temporal rainfall variability on water quality

The relationship between temporal rainfall variability and water quality parameters was assessed based on Pearson's correlation. The findings were summarized as shown in Table 4.10.

Table 4.10: Relationship between rainfall variability and water quality parameters (N=38)

	Rainfall variability	NO_3	N.ORG	P.ORG
Rainfall variability	1			
NO3	.695**	1		
	.000			
N-ORG	.781**	.382*.	1	
	.000	.018		
P-ORG	.780**	.393*.	.996**	1
	.000	.015	.000	

Correlation is significant at both 0.01(**) and 0.05(*) levels.

The information in Table 4.10 showed that temporal rainfall variability was strongly and positively correlated to NO_3, N.ORG and P.ORG, (R=.695, p<.001; R=.781, p<.001 and R=-.780, p<.001 respectively). The relationship was significant in each case implying a strong linear relationship between temporal rainfall variability and water quality parameters.

A paired sample t-test was performed to compare water quality during the dry and wet seasons. Findings were as presented in Table 4.11.

Table 4.11: Water quality during dry and wet Seasons

Pair	Variables	Mean	SD	T	Df	Sig.
1	pH1 pH2	6.800 8.400	0.447 0.548	-6.532	4	.003
2	Turbidity1 Turbidity2	11.600 79.000	6.427 50.428	-3.169	4	.034
3	Temperature1 Temperature2	22.800 21.600	1.789 1.1402	1.395	4	.235
4	DO1 DO2	43.400 51.200	14.3805 16.6343	-5.600	4	.005
5	Conductivity1 Conductivity2	73.000 87.000	14.3805 28.045	-4.240	4	.013
6	TDS1 TDS2	45.400 54.200	12.896 17.384	-4.130	4	.014
7	BOD1 BOD2	6.200 7.800	3.564 3.768	-0.726	4	.508
8	TSS1 TSS2	18.000 24.800	4.472 5.454	-0.811	4	.463
9	Total nitrogen1 Total nitrogen2	0.400 0.200	0.346 0.346	-1.126	4	.065
10	Total phosphorus1 Total phosphorus2	0.200 0.800	0.447 0.447	-2.449	4	.070
11	Total coliforms 1 Total coliforms 2	54338.000 5377724.000	38389.394 10570666.706	-1.124	4	.324
12	*E.Coli*1 *E.Coli*2	621.80 3274237.20	399.250 6856927.835	-1.068	4	.346

1-Dry season, 2-Wet season

The results in Table 4.11 showed that the mean of pH of water sampled from the river during the wet season was higher (M=8.40, SD= 0.548) than the sample obtained during the dry season (M=6.80, SD=0.447). A repeated measured t-test showed that the observed difference was significant, t(4)=6.532, P=0.003. Similar observations were made with regard to turbidity, DO, electrical conductivity and TDS. The mean of these water quality parameters during the wet season was higher (M=79.00, SD=50.43; M=51.20, SD=16.63; M=87.00, SD=28.05 and

M=54.20, SD=17.38 respectively) compared to the corresponding water quality during the dry season (M=11.60, SD=6.43; M=43.40, SD=14.38; M=73.00, SD=20.86 and M=45.40, SD=12.90 respectively). A repeated measured t-test showed that the observed difference was significant, t(4)=3.17, P=0.034; t(4)=5.60, P=0.005; t(4)=4.24, P=0.013 and t(4)=4.13, P=0.014 respectively.

The results of the study in Table 4.12 and 4.13 and Plate 4.1 indicate that Ruiru River was highly turbid during both dry and wet seasons except for the area around Ruiru dam. Turbidity levels exceeded the allowable WHO/NEMA levels at Kwa Maiko, Jacaranda Coffee Research Centre, Ruiru town and the area downstream the sewerage plant. The pH was higher than the WHO/NEMA recommended values in all the sampling sites during the wet season while within limit at Ruiru Dam sampling site only during the dry season. The BOD values were above the recommended WHO values in both seasons for all sampling sites though within NEMA limits. The results for the total coliforms and *E. coli* indicated that River Ruiru was severely polluted. Their levels were very high and above WHO/NEMA values in all the sampling sites. Total coliforms were high during dry season while *E. coli* were high during the wet season. The TSS values exceeded the allowable WHO/NEMA limits at the area downstream sewerage treatment plant during the wet season. The DO, TDS, electrical conductivity, total phosphorus and total nitrogen levels were within the WHO/NEMA recommended values during both seasons.

Table 4.12: Mean water quality parameter values for the dry season

Sampling sites	pH	Turb. (NTU)	Temp. ^{0}C	DO (mg/l)	EC (µs/cm)	TDS (mg/l)	BOD (mg/l)	TSS (mg/l)	TN (mg/l)	TP (mg/l)	TC (mg/l)	E. *Coli* (mg/l)
Ruiru dam 1°02S, 36°45E	6.0	3.5	25.8	17.5	61	37.82	4	10	0.0003	0.19	69100	238
Kwa Maiko 1°04S, 36°51E	6.7	7.5	21.7	45.6	53.7	33.29	3	20	0.001	0.14	79150	980
Jacaranda 1°06S, 36°54E	7.0	20.7	21.5	50.8	60.5	37.51	12	20	0.001	0.35	96000	196
Ruiru town 1°09S, 36°58E	6.9	13.5	22.1	52.5	88	54.56	5	20	0.001	0.33	10110	649
Downstream sewerage plant 1°10S, 37°02E	7.3	11.3	22.5	50.0	102	63.24	7	20	0.001	0.54	17330	1046

Table 4.13: Mean water quality parameter values for the wet season

Sampling site	pH	Turb. (NTU)	Temp. (^{0}C)	DO (mg/l)	EC (µs/cm)	TDS (mg/l)	BOD (mg/l)	TSS (mg/l)	TN (mg/l)	TP (mg/l)	TC (mg/l)	E.*Coli* (mg/l)
Ruiru dam 1°02S, 36°45E	7.8	1.5	22.4	22.2	71	44.02	4	10	0.0003	0.58	24200	10800
Kwa Maiko 1°04S, 36°51E	8.8	74	20.6	55.0	64	39.68	7	14	0.001	0.42	242000	141400
Jacaranda 1°06S, 36°54E	8.0	76	20.2	56.0	67	41.54	6	20	0.001	0.58	2420000	687000
Ruiru town 1°09S, 36°58E	7.9	115	22.0	63.0	106	65.54	8	20	0.001	0.65	24200000	15530000
Downstream sewerage plant 1°10S, 37°02E	8.6	130	23.0	60.0	127	78.74	14	60	0.001	1.16	2420	1986

**Turb.-turbidity, Temp.-temperature, DO-dissolved oxygen, EC-electrical conductivity, TDS-Total dissolved solids, BOD-biological oxygen demand, TSS-Total suspended solids, TN-total nitrogen, TP-total phosphorus, TC-total coliforms, E.*coli-Escherichia coli*

Plate 4.1: Turbid water of River Ruiru in various sampling sites: a) 36°51'E, 1°04'S b) 36°54'E, 1°06'S   c) 36°58'E, 1°09'S

To compare the water quality of different sampling sites, the data obtained was cross tabulated and Chi-Square test performed. Findings indicated insignificant differences across different sampling stations as summarized in Table 4.14.

Table 4.14: Comparison of water quality from different sampling stations along River Ruiru

Variable	N	(χ^2)	Df	P	C
pH	5	5.00	4	.287	.707
Turbidity	5	20.00	16	.220	.894
Temperature	5	5.00	4	.287	.707
DO	5	20.00	16	.220	.894
Conductivity	5	20.00	16	.220	.894
TDS	5	15.00	12	.241	.866
BOD	5	20.00	16	.220	.894
TSS	5	5.00	4	.287	.707
Total Nitrogen	5	5.00	4	287	.707
Total Phosphorus	5	5.00	4	.287	.707
Total Coli forms	5	20.00	16	.220	.894
E. coli	5	20.00	16	.220	.894

4.3 Discussion

4.3.1 Land use/land cover change

The findings from the study indicated that built-up areas, perennial and annual crop farming increased by 3.07%, 11.49% and 35.85% respectively in River Ruiru watershed for the last 41 years from 1976 to 2017. The increase in these land use/land cover types could be due to population increase in the area and expansion of agricultural land. However, it was observed that between 1995 and 2017 perennial crop farming declined by 1.94%. This decline could have been contributed by the conversion of coffee estates into residential and commercial lands and conversion into annual crops. This conversion was attributed to low coffee prices in the international market. In the same period, forestland, shrubland and grassland declined by 29.79%, 13.25% and 7.48% respectively due to increased demand for residential, commercial and agricultural land.

These results are consistent with study findings by Obiero (2010) in his study on the influence of geomo-hydrometric characteristics and land use/land cover change on water resources management in River Gucha-Migori catchment who observed that between 1986 to 2008 towns and large cultivated areas increased from 21.5 km^2 and 37.1 km^2 to 39.0 km^2 and 56.5 km^2 respectively while closed forests, open grasslands, closed shrubs and open shrubs decreased from 40.7 km^2, 41.2 km^2, 211.9 km^2 and 1313.8 km^2 to 28.0 km^2, 25.0 km^2, 74.5 km^2 and 268.6 km^2 respectively. Oyedotun (2018) in a study on land use cover change and classification in Chaohu lake catchment observed that built-up areas increased from 3.5% in 1979 to 25.1% in 2015. Similarly, the agricultural land use increased from the area coverage of 29.8% in 1979 to 45.2% in 2015 while forested/vegetated land of the catchment substantially decreased during this period, from 59.8% in 1979 to 22.9% in 2015. Kitheka *et al.* (2019) in their study on the effect of rainfall variability and land use and land cover change in a small tropical river basin observed that between 2000 and 2016 forest and shrub cover increased by 5%, built up areas increased by 35%, tea increased marginally by 5% while coffee decreased by 38%.

Findings from the current study are also comparable with the findings by Cheruto *et al. (*2016) who assessed land use/land cover change in Makueni County and found out that evergreen forests decreased the most from 39% coverage in 2000 to 17% coverage in 2016. Similarly, Panwar & Malik (2017) while evaluating land use/land cover change in Bhimtal Lake catchment observed that during the last 20 years (1995-2015), the settlement area increased from 9.70% to 18.38%, agricultural area has increased from 44.32% to 47.63% while the forest area decreased from 43.58% to 31.47% in their study area. Consequently, Butt *et al.* (2015) in their study on land use change mapping and analysis in Sinily watershed concluded that land use and land cover shift in the watershed was evidenced by the decline in the area of vegetation and water class by 38.2% and 74.3% respectively and augmentation of area covered by classes of settlements by 80.1%, agricultural by 163.7% and barren land by 63.3%.

4.3.2 Land use/land cover accuracy assessment

A kappa coefficient of 79 % and an overall accuracy of 82% were achieved for the 2017 land use/land cover classification indicating a high agreement between the classified image and the reference image. Kappa coefficient ranges from 0 to 1 and values higher than 0.7 are considered acceptable while those equal or lower than 0.4 identify a very low correlation between the classified image and the ground truth (Mohammad, 2013). According to Pontius (2000) a kappa value higher than 0.5 can be considered as satisfactory for modelling of land use change. Landis & Koch (1977) characterized agreement for the kappa coefficient as follows; values > 0.79 are excellent, values between 0.6 and 0.79 are substantial and values of 0.59 or less indicate moderate or poor agreement. Carletta (1996) affirms that a K>0.8 is usually considered as a strong agreement and good accuracy while the acceptable threshold for overall accuracy according to USGS classification is 75%. According to Zhu & Li (2013) such results can be used to study the spatial and temporal patterns of LULC change and evaluate its long-term hydrological impacts.

4.3.3 SWAT Model results

4.3.3.1 Sensitivity analysis

The SCS runoff curve number (CN2) was identified as the most sensitive flow parameter in River Ruiru watershed. This implies that the generation of surface runoff is important for discharge to occur. According to Abbaspour *et al.* (2009) a small value of p-value (<0.05) indicates that the parameter exerts influence on the dependant variable, thus it is sensitive while a value of 0.05 indicates that there is 95% probability that a parameter change affects the dependent variable. Similarly, a number of researchers have identified this parameter to be the most sensitive parameter in their study (Getachew & Malesse, 2013; Khalid *et al.,* 2016; Anaba *et al.,* 2017; Jain *et al.,* 2017). Though the rest of the parameters were found not to be sensitive to the quantity of river discharge in River Ruiru watershed, other studies have found some of them to be sensitive. This is likely as conditions such as land use and land cover, soil characteristics and climatic factors differ from one catchment to another.

4.3.3.2 Model uncertainty analysis

Findings from the study indicated that SWAT model was able to bracket 67% of observed data with a large uncertainty band (r-factor=1.12) during calibration and 96% of the observed data with a slightly larger uncertainty band(r-factor=1.33) during validation. These results indicated that the SWAT model calibration and uncertainty analysis were satisfactory. Abbaspour *et al.* (2007a) recommended that a value of >0.70 or >0.75 for p-value and <1.5 for r-factor would be desirable index for discharge. Similarly, Kimberly (2014) used a calibrated SWAT model and was able to bracket 68% of observed data in a small uncertainty band(r-factor=0.67) during calibration. During validation, the model was able to bracket 71% of the data with a slightly larger uncertainty band (r-factor=1.12). Tang *et al.* (2012) also arrived at a p-factor of 0.85 and r-factor of 1.12 during calibration period (1995-1999) while the p-factor was 0.83 and the r-factor was 2.15 during validation period (2000-2002).

4.3.3.3 Model performance evaluation

Calibration and validation outputs for the period 2007-2009 and 2012-2013 showed a good correlation between observed and simulated discharge values with NSE=0.86, PBIAS=19.4, R^2=0.93 and RSR=0.37 during calibration and NSE=0.99, PBIAS=2.0, RSR=0.08 and R^2=0.99 during validation as shown in Table 4.6, Figures 4.11, 4.12, 4.13 and 4.14. These results indicated a satisfactory SWAT model performance.

These results were consistent with results by Briones *et al*. (2016) and Anaba *et al*. (2017). Both statistical and graphical results showed a satisfactory performance of the model based on R^2, NSE and RSR. Similarly, Ghaffari *et al.* (2010) observed that the predicted monthly discharge matched the observed values with R^2 and NSE of 0.86 and 0.79 during calibration which compared with 0.80 and 0.79 respectively during validation. Beyene *et al.* (2018) results also showed that there was a reasonable agreement between observed and simulated streamflow with R^2 and NSE values of 0.86 and 0.77 during calibration and 0.84 and 0.76 during validation.

4.3.4 Effects of land use/land cover change on the quantity of river discharge

An increase in built-up areas, perennial and annual crops by 1.83%, 10.9% and 15.05% respectively and a decline in forestland, shrubland and grassland by 10.06%, 11.92% and 6.21% respectively between 1984 and 2017 led to a change on the quantity of river discharge components of River Ruiru watershed. SWAT model results indicated that surface runoff greatly increased from 30.25mm/yr to 181.25mm/yr between 1984 and 2017. This increase could have been attributed to the reduction of the forest cover, grassland and shrubland and increase in built-up areas in the area leading to reduced infiltration and high surface runoff while the slight increase in LATQ and GWQ could have been attributed probably by the increase in perennial farming which have comparatively similar characteristics of the forest.

Similar results to the findings of the current study were reported by Githui *et al.* (2009) in their study on the impact of land cover change on runoff in the Nzoia catchment who concluded that land use and in particular agricultural land use had a strong effect on hydrological regime of the Nzoia catchment in Kenya. They observed that changes in LULC over the period of 1973 and 2001 were significant and led to a great increase in runoff. Kavian *et al.* (2017) in their study on flow simulation based on land use change simulations concluded that overall, the model outcomes indicated that land use changes contributed to increase in the average runoff in their study area . Similarly, Setyorini *et al.* (2017) simulated the impact of land use/land cover change in the upper Brantas Basin in Indonesia and observed that land use/land cover change had significant impact on the watershed hydrology by affecting the magnitude and pattern of surface runoff, groundwater and soil moisture content. Katana *et al.* (2013a) in their study on the hydrological impacts of land cover changes in upper Athi catchment also observed that transformations in land use/land cover led to a general increase in runoff depths and peak flows associated to increase in agricultural and built-up areas.

Similar to the findings of the current study, Aduah *et al.* (2017) assessed the impacts of land use changes on the hydrology of a lowland rainforest catchment in Ghana and observed that peak and dry season streamflow between 1990 and 2011 increased by 21% and 37% respectively under the current land use in comparison with the baseline due to a decrease in evergreen and secondary forests by 18% and 39%. Similarly, Ng'eno (2016) in a study on the impact of land use and land cover change on streamflow in Nyangores sub-catchment of Mara River observed that a decline in tree plantation by 9.4% and forest by 1.2% and an increase in farmland by 8.7% and shrubland by 1.2% led to an increase of streamflow by 3%. Akpoti *et al.* (2016) in a study on the impact of rainfall variability and land use/land cover change on streamflow of the Black Volta Basin in West Africa observed that land use trends between the year 2000 and 2013 showed that bare lands, urban areas, water bodies, agricultural lands, deciduous forests and evergreen forests increased respectively by 67.06%, 33.22%, 7.62%, 29.66%, 60.18% and 38.38% while only grassland decreased by 44.54% within that period. This land use/land cover change led to an increase in surface runoff and lateral runoff by 27% and 19% respectively while ground water recharge decreased by 6%. Lang'at *et al.* (2019) concluded that in a catchment where agriculture has gradually increased overtime, coupled with depletion of forest and grassland, high and low flow can increase leading towards overall increase in the total volume of water yield in a river.

Comparatively, Anaba *et al. (*2017) in their study in the Muchison Bay in Uganda, noted that surface runoff increased from 101mm/yr to 128mm/yr (26.7% increase) when the forestland declined from 31.15% to 13.91% and built-up areas increased from 26.53% to 39.09%. Alibuyog *et al.* (2009) while simulating land use change scenarios using SWAT model indicated that runoff volume increased by 3% and 14% when 50% of pasture and grasslands were converted to agriculture and increased by 15% and 32% when the entire sub-watershed was converted to agricultural land. From their modelling, Siriwardena *et al.* (2006) in their study on the impact of land use change on catchment hydrology concluded that clearing of forests generated an increase in runoff to approximately 40%. Other researchers have also observed that a reduction in forest cover and rangeland resulted to an increase in surface runoff (Baker & Miller, 2013; Briones *et al.*, 2016; Pokhrel, 2018; Chotpantarat & Boonkaewwan, 2018).

Similar observations were made by Sukwimolseree & Kosa (2014) in their study on the relationship between land use change and runoff who concluded that land use change especially agricultural area affects runoff. They observed that from 1980 to 2008, forest area declined from 28.01% to 17.94% while agricultural area, urban area and water resources increased from 63.92%, 7.47% and 0.61% to 69.72%, 10.14% and 2.19% respectively. Other results by Sahour *et al.* (2014) showed that urban area increased during the last 11 years (2002-2013) resulting to 5-40% increase in surface runoff. Land use/land cover analysis by Letha *et al.*(2011) revealed that there was considerable increase in the built-up area and barren lands at the expense of forest and other dense vegetation, leading to an increasing pattern of peak flow and decreasing pattern of low flow values. Similarly, since 1980’s, land use in the Dongjiang basin experienced significant change with a prominent increase in urban areas, a moderate increase in farmlands and a great decrease in forest area overall. Research findings equally indicate that runoff change was contributed half and half by climate change and human activities respectively, in which 20%-30% change was contributed by land use change (He *et al.*, 2013).

Likewise, Pan *et al.* (2011) observed that land use change resulted in the decrease of $4\times10^6 m^3$ of yearly groundwater recharge in their study area, with a spatially averaged rate of 100.48mm/yr and 98.41 mm/yr in 1980 and 2005 respectively while Mishra & Kumar (2015) observed that increase of settlement directly led to decrease in groundwater level. Sajikumar & Remya (2015) in their study assessed the effects of land use/land cover on runoff characteristics of two watersheds in Kerara, India and found a reduction in forest area amounted to 60% and 32%. Changes in the surface runoff of these watersheds were not comparable with the changes but were within 20%. Maximum (peak) value of runoff increased by 15% and this could be due to the fact that forest had been converted to agricultural purpose with major proportions of plantations which had comparatively similar characteristics of the forest.

Equally, Mwangi (2016) in his findings from a study on the impact of land use change and climate variability on watershed hydrology in the Mara River Basin concluded that land use change was the major cause of change in streamflow leading to about 97.5% of the change. Deforestation and conversion to cropland agriculture led to an increase in streamflow caused by reduced water use of crops as compared to forests. Abe *et al.* (2018) while modelling the effects of historical and future land cover changes on the hydrology of the Amazonian Basin concluded that increased deforestation intensified floods and low flow events.

On the contrary, a study by Wang *et al.* (2017) observed that two-thirds of the annual streamflow declined and the change in streamflow differed among different types of land use. Overall, 30-year averages of the streamflow reduced on agricultural land but increased in forest areas. Guzha *et al.* (2018) in a trend analysis study on the impacts of land use and land cover change on surface runoff, discharge and low flows in East Africa observed that in spite of forest cover loss, 63% of the watersheds showed non-significant changes in annual discharges while 31% showed increasing trends.

4.3.5 Effects of land use/land cover change on water quality

Findings from the study indicated that the land use/land cover changes experienced in River Ruiru for the last 33 years (1984-2017) led to change in water quality. SWAT model results indicated an increase in nitrates in the surface runoff (NO_3SURQ), nitrates in the lateral runoff (NO_3LATQ), organic nitrogen (N.ORG) and organic phosphorus (P.ORG) from 0.05kgN/ha/yr, 0.06kgN/ha/yr, 5.77kgN/ha/yr and 0.87kgP/ha/yr respectively in the year 1984 to 1.47kgN/ha/yr, 0.19kgN/ha/yr, 70.60kgN/ha/yr and 8.86kgP/ha/yr respectively in the year 2017. This could have been attributed to the expansion of agricultural areas both annual and perennial crops and increased use of inorganic fertilizers rich in nitrates and phosphorus and surface runoff from the cultivated lands.

Similar observations were reported by Matshakeni (2016) in a study on the effects of land use change on water quality in Eerste River in South Africa who observed that from the year 1985 to 2015, the forest cover decreased from about 15% to about 10% and from about 8% to 2% between 2010 to 2015, while settlements increased from 38% to 55% from 1985 to 2015. Bareland decreased from 8% to 3%. This study indicated a significant correlation ($p<0.05$) between water quality and land use changes. Calijuri *et al.* (2015) in their study on the impact of land use/land cover changes on water quality and hydrological behaviour observed that the changes that occurred in land use/land cover for the development of current agriculture significantly impacted the hydrological behaviour in the Alto Paraguacu watershed. Similarly, Hossain (2017) evaluated the relationship between land use change and water quality and found that stream water quality changed with land use practices and expansion of agricultural land is one of the major cause of stream water pollution.

Equally, Huang *et al.* (2013) while studying the relationship between the proportion of land use types and water quality in the Chaohu lake basin indicated that built-up land was largely positively correlated to the indicators of water quality and the forest land, grassland and water areas were negatively related with water quality variables. The built-up areas were positively related to total phosphorus and total nitrogen. Similarly, research results by Mello *et al.* (2018) in a study on the effects of land use/land cover on water quality of low stream order in Southeastern Brazil indicated that forest cover played a significant role in keeping water clean, while agriculture and urban areas led to water quality degradation. Salajeghe *et al.* (2011) found that land use changes had important effects on reducing water quality of Karkheh River in their period of study. Chotpantarat & Boonkaewwan (2018) in their study on the impacts of land use/cover change on watershed discharge and water quality in Thailand concluded that changed land use was closely associated with the quantity of NO^{3}-N and PO_4^{3-}.

Likewise, Namugize *et al.* (2018) in their study on the effects of land use /land cover change on water quality in the uMngeni river catchment in South Africa observed that natural vegetation, forest plantation and cultivated areas occupied 85% of their study catchment. While cultivated areas, built-up areas and degraded areas increased by 6%, 4.5% and 3% respectively, they coincided with a decrease in natural vegetation by 17%. This led to variability in the concentration of water quality parameters from 1994-2011 and an overall decline in water quality was observed. Li *et al.* (2015) observed that during 2006-2013, corn and soybean cultivation in the basin area increased by 62% and 18% whereas cultivation of spring wheat, forest and pasture decreased by 30%, 18% and 50%. These changes in cultivation increased total phosphorus by 14.1%, nitrate by 5.9% and total nitrogen by 9.1%. Similarly, Permatasari *et al.* (2018) in a study on the effects of land use change on water quality in Celiwung watershed concluded that land use change had great impact on water quality and the rising urban land from agricultural land had a positive correlation with increasing concentration of pollutants in the river.

Similarly, Peterson *et al.* (2017) in their study on the effects of land use change on streamwater quality of a coastal catchment demonstrated the link between land cover/land use and water quality in Touws and Duiwe river catchments. Agriculture intensified rapidly in the Duiwe river catchment making concentrations of nutrients and electrical conductivity to be higher than in the more natural Touws river catchment. Zamani *et al.* (2013) in their spatial analysis showed that within four decades about 980 hectares of forests in Ziarat catchment in Iran were converted to other classes of land cover/land use-about 67% to croplands, 8.5% to residential, 13% to bare lands and 11.5% to roads. The results of the research showed that land use/land cover change was one of the key factors causing water quality changes in the study area. Chattopadhyay *et al.* (2005) in a study on water quality variations as linked to land use patterns in Chalakudy river basin observed that correlation analysis of various parameters indicated seasonality in physico-chemical characteristics of river water which was linked to fluctuations of drainage discharge and changes in land use pattern.

4.3.6 Effects of temporal rainfall variability on the quantity of river discharge

Findings from the study indicated that 94.4% of variations in the quantity of river discharge in River Ruiru watershed are caused by temporal rainfall variability. An association of 0.972 was established indicating a strong positive linear relationship between temporal rainfall variability and the quantity of river discharge. The results also indicated that this relationship was significant (p=0.000). This is because heavy rainfall event leads to the generation of runoff during the wet season. Similarly, Zhang *et al.* (2014) in a study on analysis of streamflow variations in the Heihe River Basin in northwest China found that increasing temperature and precipitation were the main cause to explain the increase in streamflow while Xiaoying *et al.* (2016) in their study on the impacts of climate variability and human activities on runoff of Minjiang River Basin concluded that an increase of precipitation and decrease of potential evaporation were the major reasons for increase in runoff. Young (2003) also examined the impact of rainfall simulations on stramflow response in south-west Western Australia using the lumped conceptual hydrological model LASCAM and found that significant reductions in runoff were recorded in response to moderate declines in simulated rainfall. The main factors governing runoff production included both meteorological and hydrological factors. Hackett and Bierman (2009) spectral analysis of precipitation, discharge and lake level data established that discharge was mainly affected by precipitation, anthropogenic changing climate and changing land use over the past 70 years.

Similarly, Njogy & Kitheka (2017) assessed the influence of rainfall and river discharge on sediment yield in upper Tana Catchment and revealed a strong relationship between rainfall and streamflow with r-value of 0.9 which was significant at p=0.05. Kitheka *et al. (*2019) concluded that though the relationship between rainfall and river discharge in the catchment was complex, there was indication of an increase in the frequency of occurrence of above normal rainfall and discharges. On the contrary, conclusion from a study by Guzha *et al.* (2013) who investigated discharge and rainfall variability in an Amazonian watershed noted that annual mean precipitation totals indicated no statistically significant evidence of an increasing streamflow trend. They observed that the increasing trend in streamflow is mostly likely influenced by other factors in the water besides the precipitation pattern.

4.3.7 Effects of temporal rainfall variability on water quality

Findings from this study indicated that temporal rainfall variability was strongly correlated to SWAT generated NO_3, N.ORG and P.ORG concentration. This could be due to the fact that rainfall event acts as a carrier for non-point source pollutants into a river. These study results were consistent with the findings by Rostani *et al. (*2018) in a study on riverline water quality response to precipitation and its change. Their results indicated a significant dependence of most water quality parameters and river flow on the cumulative antecedent precipitation.

The results from the current study also indicated that pH, turbidity, DO, thermal conductivity and TDS had a higher mean during wet season than in dry season. The study findings also indicated that the observed difference between dry and wet season was significant. This implies that temporal rainfall variability significantly affected the pH, turbidity, DO, electrical conductivity and TDS of River Ruiru.

Similar studies on spatial and temporal variations of water quality observed seasonal difference in the physicochemical composition of water during dry and wet season (Fan *et al.*, 2012; Tlili-Zrelli *et al.*, 2018). Ojok *et al.* (2017) observed that colour, turbidity, TSS, TDS, pH, BOD and DO values were higher during rainy season due to erosion discharge of domestic and industrial waste. Similarly, a study by Shi *et al.* (2016) on the influence of land use and land cover patterns on seasonal water quality at multi-spatial scales showed that stream water quality variables displayed highly temporal variations with electrical conductivity (EC), ammonia nitrogen

($NH4+$-N, nitrate nitrogen (NO_3-N) and TSS generally displaying higher levels in the wet season while there were higher concentrations of BOD and DO in the dry season.

Findings from the current study indicated that River Ruiru was highly turbid both during the dry and wet season except for the site at Ruiru dam. This could be due to the fact that Ruiru dam sampling site is within a forest zone hence reduced runoff. High turbidity during wet season could be due to high rainfall leading to increased surface runoff from agricultural lands and built-up areas. This is due to the fact that surface runoff is a carrier of other components such as sediments, nutrients, pesticides, bacteria and agricultural wastes that undesirably affect water quality. According to Edokpayi *et al.* (2014) high turbidity values indicate possible presence of micro-organisms, silts and other suspended solids which cause the water to appear cloudy. The pH was also above WHO/NEMA recommendations during the wet season except for Ruiru dam area. High pH levels during the wet season could have been due to dilution while low pH during the dry season could be due to high concentration of acidic substances as a result of evaporation. High thermal conductivity was observed during the wet season which could be due to increased concentration of salts, organic and inorganic materials during the rainy season.

The BOD values were found to be within NEMA limits in all sampling sites though above WHO limits both seasons except at Kwa Maiko where they were within the limit during the dry season. Higher BOD at Jacaranda and downstream Ruiru treatment plant can be attributed to domestic effluent into the river, organic waste and use of chemical fertilizers. On the contrary, Mbui *et al.* (2016) observed that BOD was slightly higher in dry season compared to wet season due to dilution of water during wet season and sedimentation process during the dry season. In addition, the values of BOD for both seasons were below NEMA limit for effluent discharge into natural water courses and above the WHO limit for drinking water. The DO profile may also be attributed to the relatively higher BOD levels during the dry season compared to the wet season. The higher the BOD level, the more rapidly oxygen is depleted resulting to low DO levels. The TSS values for River Ruiru watershed were above the recommended WHO/NEMA values at the site downstream Ruiru sewerage treatment plant. This could have been attributed to increased level of sediments due to the construction of the sewerage treatment plant which was taking place near the river.

In addition, total coliforms and *Escherichia coli* were found to be very high and above WHO/NEMA recommended values in all the sampling sites. This could have been attributed to discharge of raw sewerage from industries and wastes washed from agricultural, residential and urban areas as shown in Plates 4.2, 4.3 and 4.4. These results are comparable to those by Edokpayi *et al.* (2015) who observed that microbiological parameters of Mvudi River in South Africa exceeded the established guidelines. The level of total coliforms and *E. coli* in River Ruiru watershed was contrary to WHO (2003) drinking water guidelines in which the minimum microbiological quality of water was set as an absence of faecal indicator bacteria such as *Escherichia coli* and *Salmonella typhi.*). Faecal coliforms get into the water through untreated sewerage, poorly maintained septic systems, un-scooped pet waste and farm animals with access to streams and non-point agricultural pollution (McQuaig *et al.,* 2006; Du Plessis, 2014). High faecal coliforms counts have been positively correlated to urban development, agriculture and the amount of erodible soils. The presence of *E. coli* in water indicates potentially dangerous contamination requiring immediate attention (WHO, 1993; UNICEF, 2008).

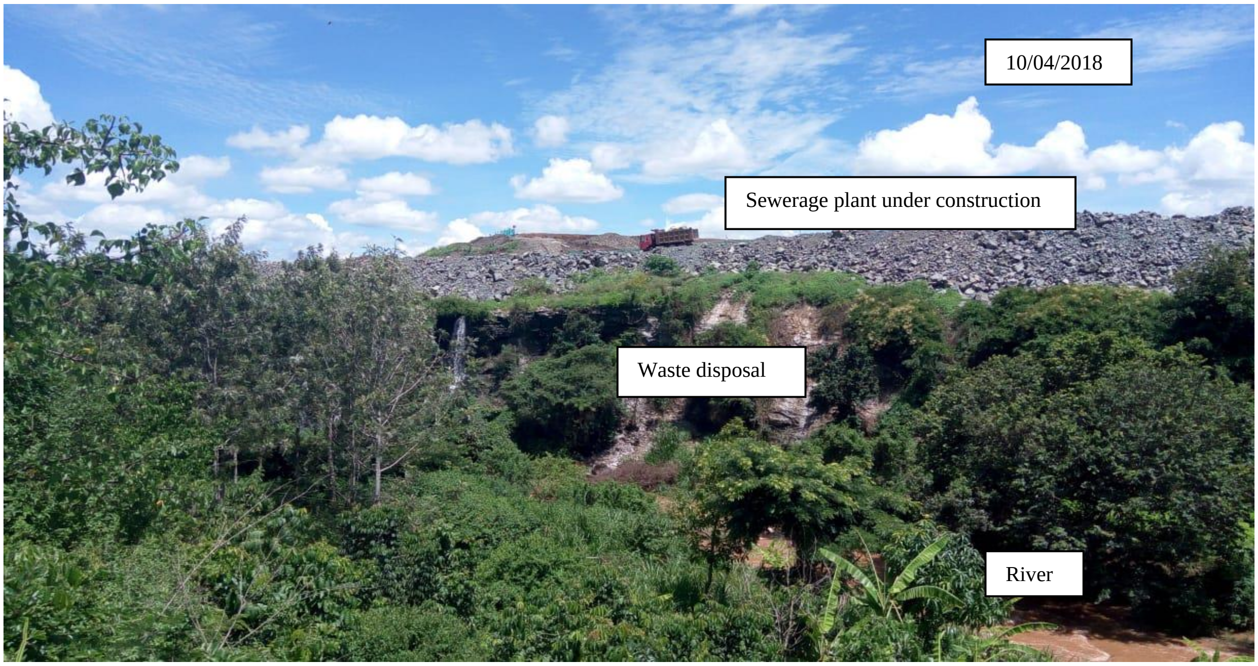

Plate 4.2: Untreated waste disposal from a sewerage plant into River Ruiru (37°02'E, 1°10'S)

Plate 4.3: Car wash and domestic activities (36°51'E, 1°04'S)

Plate 4.4: Grazing and farm activities along River Ruiru (37°01’E, 1°10’S)

Appendix 6 presents cases of waterborne diseases treated in River Ruiru watershed in 2018. This data was collected from Record and Information Departments from Ruiru, Githunguri and Lari Sub-county hospitals. Findings indicated that cases of water-related diarrhoea and amoebiosis were high in the watershed both in dry and wet seasons. Six cases of cholera were recorded in Ruiru sub-county hospital in the months of April and November 2018. Eight cases of dysentery were recorded in Githunguri health centre in May, July, October and December 2018 while four cases of dysentery were recorded in Ruiru sub-county hospital in September and November 2018. Rop (2012) in his study also concluded that faecal contamination of water sources is a serious threat to the quality of water with a negative impact on the integrity of aquatic ecosystems and therefore a risk to the health of the community water from such sources.

Moreover, findings of the current study indicated that DO, TDS, total phosphorus and total nitrogen levels were within WHO/NEMA guidelines. However, higher levels of DO and TDS were observed during the wet season. High DO during the wet season than dry season was probably due to increased current flow that allows diffusion and mixing of atmospheric oxygen into water. The decline in DO during the dry season was probably due to increased input of organic load such as leaf litter into the water whose decomposition increases oxygen depletion and river stagnation. Low DO during the dry season could also be due to high temperature which lowers oxygen solubility.

High TDS values during the wet season can be attributed to large amounts of sediment load transported from the watershed during the rainy season. The trend for TDS values was similar to that of observed electrical conductivity. This was expected since most dissolved solids in water are ionic species which tend to increase electrical conductivity. Ontumbi (2015) found that the water quality parameters with high quantities included *E. coli*, turbidity and TSS while pH, nitrates and phosphorus were within WHO/NEMA standards. Rostani *et al.* (2018) concluded that some water quality parameters such as turbidity and total phosphorus would increase, whereas other parameters would decrease or show no appreciable change under the projected increase of precipitation under the median climate change scenario for the river basin.

Similar to the findings of the current study, Tornevi *et al.* (2014) in their study which aimed to determine how daily rainfall causes variation in indicators of pathogen loads observed that rainfall was associated with exponential increases in concentrations of indicator bacteria while the effect on turbidity attenuated with very heavy rainfall. Likewise, Manyatshe *et al.* (2016) observed elevated concentration of parameters were mainly predominant in wet season, which may be due to washout of contaminants from polluting sources into surface water. During the wet season, the water was impaired by the non-point sources which originated from the upstream of the water.

Contrary to the current study, Makwe & Chup (2013) in a study on seasonal variations in physico-chemical properties of groundwater around Karu abattoir observed that all the parameters had higher concentration in the dry season. However most of the parameters in this study had their mean values within the WHO standards in both seasons except for TSS, *E. coli* and faecal streptococci which were higher than guideline provisions. Similarly, Saifulla *et al.* (2012) while investigating some water quality parameters of Buriaganga River observed higher BOD, EC and TDS in dry season compared to wet season. In addition, Razelan *et al.* (2018) noted that the point sources were dominating the pollution of the Segamat River during the dry season as opposed to the wet season.

Furthermore, findings from the current study indicated insignificant differences in water quality across different sampling sites. This showed that all land use/land cover types in River Ruiru watershed equally contributed to water quality deterioration. This is contrary to the findings by Ngwenya (2006) in a study on water quality trends in the Eeste River, Western Cape from 1990-2005 and Singh and Kumar (2011) in a study on the application of statistical methods to analyse groundwater quality who concluded that major trends in water quality were more spatial than temporal. It is also contrary to the findings by Megersa & Tullu (2018) whose study results indicated significant differences among land use/land cover types in deteriorating water quality. In their study, agricultural dominated surface water was greater in total nitrogen and TSS due to the use of inorganic fertilizer and runoff from cultivated land while urban dominated surface water was greater in TDS due to dissolved solids runoff to the downstream.

4.4 Conclusions

From the aforementioned results of the study, it can be concluded that River Ruiru watershed has undergone land use/land cover changes in the last four decades. These changes have had effects on the quantity of river discharge and water quality. In addition, the results of this study also indicate that temporal rainfall variability in the watershed has equally affected the quantity of river discharge and water quality.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents a summary of the study findings as well as the conclusion and the policy implications of the study on the effects of land use/land cover change and temporal rainfall variability on hydrological characteristics of River Ruiru watershed. It also highlights recommendations for further researches.

5.2 Summary of the findings

5.2.1 Land use/land cover changes in River Ruiru watershed from 1976 to 2017

Land use/land cover change analysis done using ArcGIS 10.4.1 functions based on 1976, 1995 and 2017 landsat images indicated that River Ruiru watershed has experienced land use/land cover changes for the last 41 years from 1976 to 2017. Built-up areas, annual crops and perennial farming (Tea and coffee) increased by 3.07%, 35.85% and 11.49% respectively. However, between 1995 and 2017 perennial farming declined by 1.94%. Water bodies slightly increased in the area by 0.1%. In the same period, forestland declined by 29.79% while grasslands and shrublands declined by 7.48% and 13.25% respectively.

The increase in built-up areas, annual crops and perennial land use/land cover types could be due to population increase in the area and expansion of agricultural land. The decline in perennial farming between 1995 and 2017 could have been contributed by the conversion of coffee estates into residential and commercial lands and conversion into annual crops. This conversion is associated with low coffee prices in the international market. The decline in forestland, shrubland and grassland could have been attributed to increased demand for residential, commercial and agricultural land concomitant to the increasing population in the watershed.

5.2.2 Effects of land use/land cover change on the quantity of river discharge

The effects of land use/land cover change on the quantity of river discharge was modelled in ArcSWATv2012.10.1.18 model based on 1984 and 2017 land use/land cover maps generated using ArcGIS 10.4.1. It was observed that an increase in the built-up areas, annual crops and perennial farming by 1.83%, 15.05% and 10.90% respectively and a decline of the grassland, shrubland and forestland by 6.21%, 11.92% and 10.06% respectively between 1984 and 2017 led to an increase in surface runoff (SURQ) from 30.25mm/yr in 1984 to 181.25mm/yr in 2017. Results also indicated a slight increase in lateral runoff (LATQ) and groundwater contribution to discharge (GWQ) from 8.48mm/yr and 9.95mm/yr in 1984 to 11.44mm/yr and 10.66mm/yr respectively in 2017. The increase in the surface runoff (SURQ) could have been attributed to the reduction of the forest cover, grassland and shrubland and increase in built-up areas in the area leading to reduced infiltration and generation of high surface runoff.

The most sensitive parameter to discharge in River Ruiru watershed was found to be CN2 (SCS runoff curve number). This indicated that the generation of surface runoff is important for discharge to occur. Moreover, the model was able to bracket 67% of observed data and a large uncertainty band (r-factor=1.12) during calibration and 96% of the observed data with a slightly larger uncertainty band(r-factor=1.33) during validation. Calibration and validation outputs for the period 2007-2009 and 2012-2013 showed a good correlation between observed and simulated discharge values with NSE=0.86, PBIAS=19.4, R^2=0.93 and RSR=0.37 during calibration and NSE=0.99, PBIAS=2.0, RSR=0.08 and R^2=0.99 during validation. These results indicated that SWAT model calibration and uncertainty analysis were satisfactory.

5.2.3 Effects of land use/land cover changes on water quality

SWAT model results indicated that land use/land cover change has led to change in water quality of River Ruiru watershed. There was an increase in nitrates in the surface runoff (NO_3SURQ), nitrates in the lateral runoff (NO_3LATQ), organic nitrogen (N.ORG) and organic phosphorus (P.ORG) from 0.05kgN/ha/yr, 0.06kgN/ha/yr, 5.77kgN/ha/yr and 0.87kgP/ha/yr in 1984 to 1.47kgN/ha/yr, 0.19kgN/ha/yr, 70.60kgN/ha/yr and 8.86kgP/ha/yr respectively in 2017. This could have been attributed to the expansion of agricultural areas both annual and perennial crops and increased use of inorganic fertilizers rich in nitrates and phosphorus.

5.2.4 Effects of temporal rainfall variability on the quantity of river discharge

The correlation between the observed and predicted value of dependent variable showed a very good association of 0.972 between temporal rainfall variability and the quantity of river discharge. The coefficient of determination (R^2) indicated 94.4% of variance or correlation between dependent and independent variable. This implied that 94.4% of variations or changes in the quantity of river discharge were caused by temporal rainfall variability indicating a strong positive linear relationship between the parameters. The ANOVA statistics, F (1, 36) = 608.85, $p<0.001$ showed the regression model significance. An F-significance value of p = 0.000 was established showing a probability of 0.0% of the regression model presenting false information. Therefore, the model was very significant. This is because heavy rainfall event leads to the generation of runoff during the wet season.

5.2.5 Effects of temporal rainfall variability on water quality

Temporal rainfall variability in River Ruiru watershed was strongly and positively correlated to NO_3, N.ORG and P.ORG, (R=.695, p<.001; R=.781, p<.001 and R=-.780, p<.001 respectively).

The relationship was significant in each case and showed a strong linear relationship between temporal rainfall variability and water quality parameters. This could be due to the fact that rainfall event acts as a carrier for non-point source pollutants into a river. Moreover, pH, turbidity, DO, conductivity and TDS had higher mean during wet season than in dry season with the observed difference being significant. These findings indicated that temporal rainfall variability significantly affected these water quality parameters in River Ruiru.

Ruiru River was highly turbid in both seasons except for the area around Ruiru dam. This could have been caused by increased surface runoff from agricultural lands and storm water from the built-up areas. The pH was higher than the WHO/NEMA recommended values during the wet season at Kwa Maiko, Jacaranda Coffee Research Centre and the area downstream the sewerage plant. High pH levels during the wet season could have been due to dilution while low pH during the dry season could be due to high concentration of acidic substances as a result of evaporation. High electrical conductivity was observed during the wet season which could be due to increased concentration of salts, organic and inorganic materials during the rainy season.

The BOD values were found to be within NEMA (2006) limits in all sampling sites though above WHO (2011) limits both seasons except at Kwa Maiko where they were within the limit during the dry season. The results for the total coliforms and *E. coli* also indicated that River Ruiru was highly polluted. This could have been attributed discharge of raw sewerage from industries and wastes washed residential and urban areas. Though DO, TDS, electrical conductivity, total phosphorus and total nitrogen values were within WHO/NEMA recommended values higher levels of DO and TDS were observed during the wet season. High DO during the wet season than dry season was probably due to increased current flow that allows diffusion and mixing of atmospheric oxygen into water. The DO declined during the dry season probably due to increased input of organic load such as leaf litter into the water whose decomposition increases oxygen depletion and river stagnation. Low DO during the dry season could also be due to high temperature which lowers oxygen solubility. High TDS values during the wet season can be attributed to large amounts of sediment load transported from the watershed during the rainy season. The trend for TDS values was similar to that of observed electrical conductivity. This was expected since most dissolved solids in water are ionic species which tend to increase electrical conductivity. However, findings from Chi-Square test indicated insignificant differences across different sampling stations.

5.3 Conclusions

River Ruiru watershed has experienced land use/land cover changes for the last 41 years due to agricultural and urban development concomitant to the increasing population in the area. These changes have led to a great increase in Surface runoff (SURQ) and a slight increase in lateral runoff (LATQ) and groundwater contribution to discharge (GWQ). This is due to decline in forest cover, grassland and shrubland and an increase in built-up areas leading to reduced infiltration and high surface runoff. Land use and land cover changes in the watershed have also led to increase in the nitrates in the surface runoff (NO_3SURQ), nitrates in the lateral runoff (NO_3LATQ), organic nitrogen (N.ORG) and organic phosphorus (P.ORG). This could have been attributed to the expansion of agricultural areas both annual and perennial crops and increased use of inorganic fertilizers rich in nitrates and phosphorus.

Results also indicate a very good association between temporal rainfall variability and the quantity of river discharge. Temporal rainfall variability in River Ruiru watershed was strongly and positively correlated to NO_3, N.ORG and P.ORG. The relationship was significant and showed a strong linear relationship between temporal rainfall variability and water quality parameters. Findings from the study indicated that River Ruiru is highly contaminated with faecal organisms hence unsuitable for domestic purposes without proper treatment. Equally, the watershed and its water resources are highly compromised which may inhibit important ecological processes.

5.4 Policy implications from the research findings

Findings from the study indicate that land use and land cover changes and temporal rainfall variability have affected the quantity of river discharge and water quality in River Ruiru watershed. As such, remedial actions to address the hydrological effects of land use/land cover change and temporal rainfall variability both by the national and county governments are required. These may include strategies for sustainable water and environmental resource management such as best management practices (BMPs) in agricultural areas in an effort to control surface runoff. For instance the use of filter strips, cover crops, conservation tillage, contouring and forest or grass buffers. There is need to encourage and support afforestation and reforestation programmes in order to increase forest cover. This will help improve water retention capacity in the watershed as well as providing multi-benefits.

Furthermore, water and land use planners need to deliberate on a comprehensive policy implementation regarding integrated water and land use management. This may include site selection for different activities such as agriculture, urban, industrial and residential and commercial development. Development activities must be integrated with water resource considerations and watershed protection.

There is need for proper sewerage treatment and waste disposal management to mitigate the threat it poses to public health. There is also an urgent need to protect the watershed so as to maintain its ecological integrity by controlling anthropogenic activities.

The national and county governments should ensure increased public education and awareness with regard to environmental conservation. This can be achieved by strengthening and giving financial support to Water Resource User Associations (WRUAs) in the watershed and strengthening all the stakeholders.

To enable policy implementation regarding water resource management, the national government and county governments should provide necessary support to the Water Resource Authority (WRA) to ensure continuous availability of hydrological data. This may include robust management of data inventory for both water quality and quantity. For instance, there is need to develop data collection and distribution in near real time for improved forecasting and water resources management. Consequently, this will strengthen spatial and temporal hydro-meteorological database for the watershed to ensure improved modelling.

5.5 Recommendations for further research

The following are the recommendations for further research;

i. Further researches need to be conducted to assess the effects of water quality pollution on human health.
ii. Further researches need to be conducted to simulate groundwater flow and contaminant transport.

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APPENDICES

Appendix 1: Approved applications for change of use in River Ruiru watershed (Physical planning office, Kiambu County)

No	Service Code	Form Name	Estate/Locality/Area	Acreage(Ha)	Current Land Use	Proposed Use
132	PPA1	ADMINISTRATIVE CHANGE OF USE	Githunguri	0.15	Agricultural	To Commercial
3059	PPA1	CHANGE OF USE	Githunguri	0.048	Agricultural	To Residential above 1ha
2994	PPA1	CHANGE OF USE	GITHUNGURI TOWN	0.8	Agricultural	To Institutional Public above 1ha
590	PPA1	CHANGE OF USE	GITHUNGURI TOWN	0.0221	Residential	To Commercial BCR others below 1ha
2332	PPA1	CHANGE OF USE	GITHUNGURI	0.1012	Agricultural	To Industrial Light below 1ha
2255	PPA1	CHANGE OF USE	GITHUNGURI	0.135	Agricultural	To Residential others below 1ha
2231	PPA1	CHANGE OF USE	GITHUNGURI TOWN	0.0647497	Agricultural	To Residential Urban below 1ha
2152	PPA1	CHANGE OF USE	Githunguri	0.044	Agricultural	To Residential Peri-Urban below 1ha
1874	PPA1	CHANGE OF USE	GITHUNGURI	0.46	Agricultural	To Residential others below 1ha
1924	PPA1	CHANGE OF USE	NYAGA	0.076	Agricultural	To Residential above 1ha
1608	PPA1	CHANGE OF USE	GITHUNGURI TOWN	0.033	Agricultural	To Residential others below 1ha
1653	PPA1	CHANGE OF USE	Githunguri	0.162	Agricultural	To Residential others below 1ha
1684	PPA1	CHANGE OF USE	Githunguri	0.046	Agricultural	To Residential others below 1ha
1654	PPA1	CHANGE OF USE	Ngemwa area in Githunguri sub-County	0.336	Agricultural	To Institutional Public Religious below 1ha
1632	PPA1	CHANGE OF USE	Githunguri	0.072	Agricultural	To Residential others below 1ha
1578	PPA1	CHANGE OF USE	Githunguri	0.072	Agricultural	To Residential Peri-Urban below 1ha
1534	PPA1	CHANGE OF USE	Githunguri	0.061	Agricultural	To Residential Peri-Urban below 1ha
1478	PPA1	CHANGE OF USE	Githunguri	0.085	Agricultural	To Residential Peri-Urban below 1ha
1451	PPA1	CHANGE OF USE	Githunguri	0.011	Agricultural	To Commercial BCR Peri-urban below 1ha
1211	PPA1	CHANGE OF USE	NGEWA AREA	0.42	Agricultural	To Commercial BCR others below 1ha
1240	PPA1	CHANGE OF USE	Githunguri	0.0764	Agricultural	To Commercial BCR others below 1ha
1094	PPA1	CHANGE OF USE	Githunguri	0.0464	Agricultural	To Residential Peri-Urban below 1ha
917	PPA1	CHANGE OF USE	GITHUNGIRI	0.0158	Booster Transmission Station (BTS) Brown Field	To Institutional Educational Pre-Primary

986	PPA1	CHANGE OF USE	Kwa Maiko	0.1	Agricultural	To Institutional Educational Tertiary
840	PPA1	CHANGE OF USE	GIATHIEKO	0.2024	-	For Booster Transmission Station (BTS) Brown Field
943	PPA1	CHANGE OF USE	GITHIGA	0.0405	Agricultural	To Commercial Urban below 1ha
849	PPA1	CHANGE OF USE	Githunguri AREA	0.0575	Agricultural	To Residential others below 1ha
336	PPA1	CHANGE OF USE	GITHUNGURI	0.048	Booster Transmission Station (BTS) Green Field	For Booster Transmission Station (BTS) Brown Field
315	PPA1	CHANGE OF USE	GITHUNGURI TOWN	0.405	Agricultural	To Industrial above 1ha
183	PPA1	CHANGE OF USE	GITHUNGURI	0.093	Agricultural	To Agricultural
106	PPA1	CHANGE OF USE	GITHUNGURI TOWN	0.1133	Agricultural	To Commercial Others below 1ha
2309	PPA1	REGULARIZATION FOR CHANGE OF USE	Githunguri	0.02	Agricultural	To Commercial
1398	PPA1	REGULARIZATION FOR CHANGE OF USE	Githunguri	0.0243	Agricultural	To Residential
22	PPA1	REGULARIZATION FOR CHANGE OF USE	Githunguri AREA	0.0971	Agricultural	To Residential
395	PPA1	RENEWAL FOR CHANGE OF USE	GITHUNGURI	0.06	Agricultural	To Residential
83	PPA1	RENEWAL FOR CHANGE OF USE	GITHUNGURI	0.048	Agricultural	To Residential
2147	PPA1	CHANGE OF USE	GITHUNGURI	0.0275	Residential	To Residential Peri-Urban below 1ha
2148	PPA1	CHANGE OF USE	GITHUNGURI	0.0275	Residential	To Residential Peri-Urban below 1ha
2149	PPA1	CHANGE OF USE	GITHUNGURI	0.042	Residential	To Residential Peri-Urban below 1ha
2491	PPA1	CHANGE OF USE	LARI	0.214	Agricultural	To Industrial above 1ha
2392	PPA1	CHANGE OF USE	LARI	0.0374	Residential	To Residential others below 1ha
1952	PPA1	CHANGE OF USE	LARI	0.051	Agricultural	To Residential Peri-Urban below 1ha
1969	PPA1	CHANGE OF USE	LARI	0.082	Agricultural	To Residential others below 1ha
1309	PPA1	CHANGE OF USE	LARI	1.956	Agricultural	To Industrial Light below 1ha
1310	PPA1	CHANGE OF USE	LARI	0.96	Agricultural	To Industrial Light below 1ha
1311	PPA1	CHANGE OF USE	LARI	1.685	Agricultural	To Industrial Light below 1ha
1312	PPA1	CHANGE OF USE	LARI	3.52	Agricultural	To Industrial Light below 1ha
1313	PPA1	CHANGE OF USE	LARI	0.8	Agricultural	To Industrial Light below 1ha
1441	PPA1	CHANGE OF USE	LARI	0.101	Agricultural	To Institutional Public Religious below 1ha
1153	PPA1	CHANGE OF USE	Lari	0.046	Booster Transmission Station (BTS) Brown Field	To Commercial BCR Peri-urban below 1ha

1157	PPA1	CHANGE OF USE	LARI	0.58	Agricultural	To Institutional Power Distribution Station
334	PPA1	CHANGE OF USE	LARI	0.044	Agricultural	To Residential above 1ha
2990	PPA1	EXTENSION OF USE	LARI	0.1052	-	To Commercial Peri-Urban below 1ha
2136	PPA1	EXTENSION OF USE	LARI	0.128	-	For Booster Transmission Station (BTS) Green Field
2268	PPA1	REGULARIZATION FOR CHANGE OF USE	LARI	5.78	Agricultural	To Industrial
3136	PPA1	ADMINISTRATIVE CHANGE OF USE	Ruiru Constituency, Biashara Ward	0.0312	Residential	To Commercial
1546	PPA1	ADMINISTRATIVE CHANGE OF USE	GATONGORA	0.058	Agricultural	To Commercial
767	PPA1	ADMINISTRATIVE CHANGE OF USE	Ruiru	0.05	Agricultural	To Commercial
2897	PPA1	AMALGAMATION	RUIRU	0.54	-	-
2902	PPA1	AMALGAMATION	KIU	0.068	-	-
2807	PPA1	AMALGAMATION	RUIRU TOWNSHIP ESTATE	0.0117HA EACH	-	-
2794	PPA1	AMALGAMATION	Ruiru	0.2	-	-
2647	PPA1	AMALGAMATION	RUIRU	0.1098	-	-
2644	PPA1	AMALGAMATION	Ruiru	0.068	-	-
1959	PPA1	AMALGAMATION	Ruiru	0.082	-	-
2122	PPA1	AMALGAMATION	Ruiru	0.0822	-	-
2210	PPA1	AMALGAMATION	Ruiru	2.2347	-	-
2097	PPA1	AMALGAMATION	RUIRU TOWNSHIP	0.54	-	-
2014	PPA1	AMALGAMATION	GATONGORA	0.034	-	-
1759	PPA1	AMALGAMATION	RUIRU TOWN	0.0993	-	-
1550	PPA1	AMALGAMATION	Ruiru	0.1735	-	-
991	PPA1	AMALGAMATION	Ruiru Township	1.3133	-	-
379	PPA1	AMALGAMATION	RUIRU HOSPITAL	0.02	-	-
115	PPA1	AMALGAMATION	Ruiru	0.136	-	-
27	PPA1	AMALGAMATION	ruiru town	0.0227	-	-
3184	PPA1	CHANGE OF USE	RUIRU AREA	0.0511	Residential	To Residential above 1ha
3183	PPA1	CHANGE OF USE	Ruiru	0.0861	Agricultural	To Commercial above 1ha
3170	PPA1	CHANGE OF USE	RUIRU TOWN	0.0562	Residential	To Residential above 1ha
3176	PPA1	CHANGE OF USE	Ruiru	0.105	Agricultural	To Residential above 1ha
3166	PPA1	CHANGE OF USE	Gatong'ora	0.106	Agricultural	To Commercial above 1ha
3139	PPA1	CHANGE OF USE	Gatong'ra	0.042	Residential	To Residential above 1ha
3160	PPA1	CHANGE OF USE	Gatong'ora	0.0216	Agricultural	To Residential above 1ha
3158	PPA1	CHANGE OF USE	RUIRU	0.042	Agricultural	To Residential above 1ha
2610	PPA1	CHANGE OF USE	Gatong'ora	0.099	Residential	To Residential above 1ha

3075	PPA1	CHANGE OF USE	Gatong'ora	0.057	Agricultural	To Residential above 1ha
3067	PPA1	CHANGE OF USE	RUIRU WATAALAM	0.0562 Hectares	Residential	To Residential above 1ha
2982	PPA1	CHANGE OF USE	WATAALAM	0.0511	Residential	To Residential above 1ha
3084	PPA1	CHANGE OF USE	Wataalam	0.036	Agricultural	To Commercial above 1ha
3131	PPA1	CHANGE OF USE	RUIRU	0.0511	Agricultural	To Residential above 1ha
2814	PPA1	CHANGE OF USE	Ruiru	0.034	Agricultural	To Residential above 1ha
3093	PPA1	CHANGE OF USE	Gitothua Ward.	0.0409	Residential	To Residential above 1ha
3078	PPA1	CHANGE OF USE	Gitothua	0.0537	Residential	To Residential above 1ha
2385	PPA1	CHANGE OF USE	Ruiru	0.039	Agricultural	To Residential above 1ha
3082	PPA1	CHANGE OF USE	RUIRU	0.099	Residential	To Residential above 1ha
3026	PPA1	CHANGE OF USE	Ruiru	0.029Ha	Agricultural	To Residential above 1ha
3037	PPA1	CHANGE OF USE	RUIRU	0.041	Residential	To Residential above 1ha
3052	PPA1	CHANGE OF USE	Gitothua	0.05	Agricultural	To Residential above 1ha
2995	PPA1	CHANGE OF USE	GITOTHUA	0.0511	Residential	To Residential above 1ha
3063	PPA1	CHANGE OF USE	Ruiru	0.0441	Residential	To Residential above 1ha
3029	PPA1	CHANGE OF USE	Ruiru	0.0542	Residential	To Residential above 1ha
3057	PPA1	CHANGE OF USE	Gitothua	0.0511	Residential	To Residential above 1ha
3050	PPA1	CHANGE OF USE	Gitothua	0.094	Residential	To Residential above 1ha
3021	PPA1	CHANGE OF USE	Ruiru Sunrise Estate	0.1011	Agricultural	To Residential above 1ha
2976	PPA1	CHANGE OF USE	Gathongora	0.0714	Agricultural	To Residential above 1ha
2956	PPA1	CHANGE OF USE	Ruiru	0.1587	Agricultural	To Residential above 1ha
3019	PPA1	CHANGE OF USE	RUIRU SUB COUNTY ALONG RUIRU KAMITI ROAD	0.0409	Residential	To Residential above 1ha
2949	PPA1	CHANGE OF USE	Ruiru	0.3572	Agricultural	To Institutional Educational Pre-Primary
2968	PPA1	CHANGE OF USE	Ruiru	0.045	Agricultural	To Residential above 1ha
2992	PPA1	CHANGE OF USE	Ruiru	0.045	Residential	To Residential above 1ha
2953	PPA1	CHANGE OF USE	Ruiru	0.098	Residential	To Residential above 1ha
2977	PPA1	CHANGE OF USE	GATONGORA	0.072	Agricultural	To Residential above 1ha
2980	PPA1	CHANGE OF USE	Gatong'ora	0.086	Agricultural	To Residential above 1ha
1880	PPA1	CHANGE OF USE	NEAR RUIRU HOSPITAL	0.0593	Residential	To Residential above 1ha
2988	PPA1	CHANGE OF USE	Ruiru	0.0978	Agricultural	To Residential above 1ha
2984	PPA1	CHANGE OF USE	Gatong'ora	0.0536	Residential	To Residential above 1ha
2978	PPA1	CHANGE OF USE	RUIRU	0.4142	Agricultural	To Residential above 1ha

2969	PPA1	CHANGE OF USE	SUNRISE ESTATE, RUIRU	0.064	Agricultural	To Residential above 1ha
2662	PPA1	CHANGE OF USE	Gatongora	0.1032	Residential	To Institutional Educational Pre-Primary
2951	PPA1	CHANGE OF USE	Gatong'ora	0.0511	Residential	To Residential above 1ha
2839	PPA1	CHANGE OF USE	Ruiru	0.65	Agricultural	To Commercial above 1ha
2932	PPA1	CHANGE OF USE	RUIRU	0.064	Residential	To Residential above 1ha
2906	PPA1	CHANGE OF USE	Ruiru	0.35	Agricultural	To Residential above 1ha
2845	PPA1	CHANGE OF USE	GATONGORA_KAMAKIS AREA	0.0349	Agricultural	To Residential above 1ha
2886	PPA1	CHANGE OF USE	Ruiru	0.056	Agricultural	To Residential above 1ha
2875	PPA1	CHANGE OF USE	Ruiru	0.05	Agricultural	To Residential above 1ha
2874	PPA1	CHANGE OF USE	Ruiru	0.0752	Agricultural	To Residential above 1ha
2796	PPA1	CHANGE OF USE	RUIRU TOWNSHIP	0.0511	Agricultural	To Residential above 1ha
2822	PPA1	CHANGE OF USE	Ruiru	0.0511	Residential	To Commercial above 1ha
2542	PPA1	CHANGE OF USE	Ruiru	0.044	Agricultural	To Residential above 1ha
2557	PPA1	CHANGE OF USE	Near Rainbow Restaurant	0.0425	Residential	To Residential above 1ha
2793	PPA1	CHANGE OF USE	GATONGORA	0.045	Agricultural	To Residential above 1ha
2781	PPA1	CHANGE OF USE	NEAR RAINBOW RUIRU RESORT	0.048	Agricultural	To Residential above 1ha
2640	PPA1	CHANGE OF USE	Ruiru	80.93	Agricultural	To Residential above 1ha
2775	PPA1	CHANGE OF USE	Githunguri	0.044	Agricultural	To Residential above 1ha
2609	PPA1	CHANGE OF USE	Githunguri	0.0524	Residential	To Residential above 1ha
2547	PPA1	CHANGE OF USE	RUIRU	0.0422	Agricultural	To Residential above 1ha
2772	PPA1	CHANGE OF USE	RUIRU	0.25	Agricultural	To Residential above 1ha
2446	PPA1	CHANGE OF USE	Opposite Shell Service Station, and approximately 600 metres past Quick Mart supermarket toward Ruiru	0.04	Agricultural	To Residential Urban below 1ha
2576	PPA1	CHANGE OF USE	NEAR VIOLA QUALITY ACADEMY	0.042	Agricultural	To Residential above 1ha
2768	PPA1	CHANGE OF USE	NEAR LILY ACADEMY, MWIHOKO	0.033	Residential	To Residential above 1ha
2762	PPA1	CHANGE OF USE	Rainbow Resort	0.042	Agricultural	To Residential above 1ha
2761	PPA1	CHANGE OF USE	RUIRU SUNRISE ESTATE	0.0505	Agricultural	To Residential above 1ha
2760	PPA1	CHANGE OF USE	Ruiru	0.105	Agricultural	To Residential above 1ha
2749	PPA1	CHANGE OF USE	Bypass-Ruiru	0.0434	Agricultural	To Residential above 1ha
2706	PPA1	CHANGE OF USE	RUIRU	0.1152	Agricultural	To Residential above 1ha
2752	PPA1	CHANGE OF USE	GITOTHUA	0.0264	Agricultural	To Residential above 1ha
606	PPA1	CHANGE OF USE	KIU	0.0185	Agricultural	To Residential above 1ha
2746	PPA1	CHANGE OF USE	KIU	0.0638	Agricultural	To Residential above 1ha

2720	PPA1	CHANGE OF USE	Ruiru Bypass	0.061	Agricultural	To Residential above 1ha
2718	PPA1	CHANGE OF USE	RUIRU	0.0945	Residential	To Residential above 1ha
2714	PPA1	CHANGE OF USE	NEAR ZETECH UNIVERSITY	0.042	Agricultural	To Residential Urban below 1ha
2883	PPA1	CHANGE OF USE	RUIRU	0.07	Agricultural	To Residential others below 1ha
925	PPA1	CHANGE OF USE	RUIRU	0.0929	Commercial	To Institutional Public Health Facility below 1ha
2517	PPA1	CHANGE OF USE	RUIRU	0.0508	Agricultural	To Residential others below 1ha
2654	PPA1	CHANGE OF USE	RUIRU	0.5	Agricultural	To Industrial Light below 1ha
2420	PPA1	CHANGE OF USE	RUIRU	0.1	Agricultural	To Residential Peri-Urban below 1ha
2698	PPA1	CHANGE OF USE	RUIRU	0.1	Agricultural	To Residential Peri-Urban below 1ha
2638	PPA1	CHANGE OF USE	Ruiru	0.2627	Residential	To Industrial Light below 1ha
2693	PPA1	CHANGE OF USE	RUIRU	0.0454	Agricultural	To Residential Peri-Urban below 1ha
2681	PPA1	CHANGE OF USE	ruiru	0.0435	Agricultural	To Residential others below 1ha
2443	PPA1	CHANGE OF USE	Ruiru	0.4992	Agricultural	To Institutional Educational Pre-Primary
2701	PPA1	CHANGE OF USE	Ruiru	0.3989	Agricultural	To Residential Peri-Urban below 1ha
2633	PPA1	CHANGE OF USE	MEMBLEY	0.6667	Residential	To Residential Peri-Urban below 1ha
2650	PPA1	CHANGE OF USE	GITOTHUA	0.0562	Residential	To Residential Peri-Urban below 1ha
2632	PPA1	CHANGE OF USE	ABOUT 30MTS FRON ST. TRIZA HIGH SCHOOL	0.062	Residential	To Residential Urban below 1ha
2492	PPA1	CHANGE OF USE	GATONG’ORA	0.0662	Agricultural	To Institutional Public Health Facility below 1ha
2328	PPA1	CHANGE OF USE	GATONGORA	0.039	Agricultural	To Commercial BCR Urban below 1ha
2536	PPA1	CHANGE OF USE	GATONGORA	0.0542	Agricultural	To Residential others below 1ha
1623	PPA1	CHANGE OF USE	GATONGORA	0.034	Agricultural	To Residential Peri-Urban below 1ha
2467	PPA1	CHANGE OF USE	GITAMBAYA/GITOTHUA	0.0511	Agricultural	To Residential Peri-Urban below 1ha
2460	PPA1	CHANGE OF USE	GITOTHUA	0.0423	Residential	To Residential others below 1ha
2574	PPA1	CHANGE OF USE	ABOUT 500 METRES FROM THIKA SUPERHIGHWAY, EASTERN BYPASS ROUNDABOUT TOWARDS OJ AREA	0.0511	Residential	To Residential others below 1ha
2570	PPA1	CHANGE OF USE	RUIRU - WATAALAM AREA	0.0411	Residential	To Residential others below 1ha

2469	PPA1	CHANGE OF USE	Kamakis, Ruiru	0.725	Agricultural	To Commercial Peri-Urban below 1ha
2665	PPA1	CHANGE OF USE	Kamakis-Ruiru	0.052	Agricultural	To Residential Peri-Urban below 1ha
1887	PPA1	CHANGE OF USE	OPPOSITE MEMBLEY BUS STOP	0.0511	Agricultural	To Residential others below 1ha
2559	PPA1	CHANGE OF USE	RUIRU	0.0555	Agricultural	To Residential Urban below 1ha
1951	PPA1	CHANGE OF USE	RUIRU	0.4307	Agricultural	To Residential others below 1ha
2471	PPA1	CHANGE OF USE	RUIRU	0.049	Residential	To Residential others below 1ha
2472	PPA1	CHANGE OF USE	RUIRU	0.049	Residential	To Residential others below 1ha
2546	PPA1	CHANGE OF USE	RUIRU	0.049	Residential	To Residential others below 1ha
2545	PPA1	CHANGE OF USE	RUIRU	0.049	Residential	To Residential others below 1ha
2453	PPA1	CHANGE OF USE	RUIRU	0.036	Agricultural	To Residential Peri-Urban below 1ha
2539	PPA1	CHANGE OF USE	RUIRU	0.0513	Agricultural	To Residential Peri-Urban below 1ha
2189	PPA1	CHANGE OF USE	RUIRU	0.044	Agricultural	To Residential Peri-Urban below 1ha
2514	PPA1	CHANGE OF USE	KIHUNGURO AREA	0.076	Agricultural	To Residential Peri-Urban below 1ha
2509	PPA1	CHANGE OF USE	GITOTHUA	0.0511	Agricultural	To Residential Peri-Urban below 1ha
2462	PPA1	CHANGE OF USE	KIHUNGURO AREA	0.038	Agricultural	To Residential Peri-Urban below 1ha
2507	PPA1	CHANGE OF USE	RUIRU	0.5	Agricultural	To Industrial Light below 1ha
2267	PPA1	CHANGE OF USE	RUIRU	0.7275	Agricultural	To Industrial Light below 1ha
2501	PPA1	CHANGE OF USE	Ruiru	0.525	Agricultural	To Residential others below 1ha
2457	PPA1	CHANGE OF USE	Gitothua	0.0409	Agricultural	To Residential Peri-Urban below 1ha
2477	PPA1	CHANGE OF USE	Gatong'ora	0.068	Agricultural	To Residential Peri-Urban below 1ha
2454	PPA1	CHANGE OF USE	RUIRU TOWN NEAR LITTLE KIDS ACADEMY	0.042	Agricultural	To Residential Urban below 1ha
2480	PPA1	CHANGE OF USE	Ruiru town	0.1	Agricultural	To Residential Peri-Urban below 1ha
2451	PPA1	CHANGE OF USE	Ruiru Town	0.045	Residential	To Residential Urban below 1ha
1979	PPA1	CHANGE OF USE	RUIRU	0.0297	Residential	To Residential others below 1ha
2174	PPA1	CHANGE OF USE	RUIRU	0.0297	Residential	To Residential others below 1ha
1596	PPA1	CHANGE OF USE	Gatong’ora	0.035	Agricultural	To Residential Peri-Urban below 1ha
2170	PPA1	CHANGE OF USE	Ruiru	0.0259	Residential	To Residential Peri-Urban below 1ha

2171	PPA1	CHANGE OF USE	Ruiru	0.0313	Residential	To Residential Peri-Urban below 1ha
2133	PPA1	CHANGE OF USE	Ruiru	297	Residential	To Residential Peri-Urban below 1ha
2175	PPA1	CHANGE OF USE	RUIRU	0.0297	Residential	To Commercial BCR Peri-urban below 1ha
2176	PPA1	CHANGE OF USE	RUIRU	0.0297	Residential	To Commercial BCR others below 1ha
2172	PPA1	CHANGE OF USE	RUIRU	0.0297	Residential	To Residential Peri-Urban below 1ha
1758	PPA1	CHANGE OF USE	RUIRU	0.068	Agricultural	To Residential Peri-Urban below 1ha
1916	PPA1	CHANGE OF USE	RUIRU	0.044	Agricultural	To Commercial Peri-Urban below 1ha
2088	PPA1	CHANGE OF USE	Ruiru	0.047	Agricultural	To Residential Peri-Urban below 1ha
2439	PPA1	CHANGE OF USE	KIU	0.1	Residential	To Residential Urban below 1ha
2438	PPA1	CHANGE OF USE	NEAR PRISONS, RUIRU	0.045	Residential	To Residential Peri-Urban below 1ha
2425	PPA1	CHANGE OF USE	RUIRU, GATONGORA AREA	0.1043	Agricultural	To Residential Peri-Urban below 1ha
2421	PPA1	CHANGE OF USE	GATONGORA	0.047	Agricultural	To Residential Peri-Urban below 1ha
2422	PPA1	CHANGE OF USE	GATONGORA	0.047	Agricultural	To Residential Peri-Urban below 1ha
2423	PPA1	CHANGE OF USE	GATONGORA	0.047	Agricultural	To Residential Peri-Urban below 1ha
2431	PPA1	CHANGE OF USE	GITOTHUA	0.0562	Agricultural	To Residential Peri-Urban below 1ha
2430	PPA1	CHANGE OF USE	GITOTHUA	0.0409	Agricultural	To Residential Peri-Urban below 1ha
2360	PPA1	CHANGE OF USE	GITOTHUA	0.0405	Agricultural	To Residential Peri-Urban below 1ha
2411	PPA1	CHANGE OF USE	GITOTHUA	0.0405	Agricultural	To Residential Peri-Urban below 1ha
2329	PPA1	CHANGE OF USE	RUIRU	0.0437	Residential	To Commercial Urban below 1ha
2402	PPA1	CHANGE OF USE	RUIRU TOWN	0.064	Agricultural	To Commercial Peri-Urban below 1ha
2372	PPA1	CHANGE OF USE	RAINBOW AREA	0.149	Agricultural	To Residential Peri-Urban below 1ha
2382	PPA1	CHANGE OF USE	RUIRU	0.0679	Agricultural	To Residential Peri-Urban below 1ha
2381	PPA1	CHANGE OF USE	Ruiru	0.88	Agricultural	To Institutional Public Religious below 1ha
2177	PPA1	CHANGE OF USE	Sunrise Estate-Ruiru	0.35	Agricultural	To Residential Urban below 1ha
2178	PPA1	CHANGE OF USE	RUIRU	0.06	Agricultural	To Residential Peri-Urban below 1ha
2179	PPA1	CHANGE OF USE	RUIRU	0.061	Agricultural	To Residential Peri-Urban below 1ha

2365	PPA1	CHANGE OF USE	RUIRU	0.047	Residential	To Residential Peri-Urban below 1ha
2150	PPA1	CHANGE OF USE	RUIRU	0.0297	Residential	To Residential others below 1ha
2337	PPA1	CHANGE OF USE	GATONGORA	0.0352	Agricultural	To Residential Peri-Urban below 1ha
2338	PPA1	CHANGE OF USE	GATONGORA	0.0351	Agricultural	To Residential Peri-Urban below 1ha
2350	PPA1	CHANGE OF USE	RUIRU	0.034	Agricultural	To Residential Peri-Urban below 1ha
2347	PPA1	CHANGE OF USE	RUIRU	0.034	Agricultural	To Residential Peri-Urban below 1ha
1682	PPA1	CHANGE OF USE	The proposed site is adjacent to Pinky Supermarket Homes and is located approx. 50m from Ruiru Central High School	0.0409	Residential	To Residential Urban below 1ha
2339	PPA1	CHANGE OF USE	GITOTHUA	0.511	Residential	To Residential others below 1ha
2330	PPA1	CHANGE OF USE	RUIRU	0.065	Agricultural	To Residential Peri-Urban below 1ha
2323	PPA1	CHANGE OF USE	RUIRU TOWN	0.0319	Agricultural	To Residential Peri-Urban below 1ha
2321	PPA1	CHANGE OF USE	RUIRU	0.0511	Agricultural	To Residential Peri-Urban below 1ha
2311	PPA1	CHANGE OF USE	RUIRU	0.0586	Agricultural	To Residential Peri-Urban below 1ha
2256	PPA1	CHANGE OF USE	RUIRU	0.034	Agricultural	To Residential Urban below 1ha
2307	PPA1	CHANGE OF USE	Ruiru,near Zetech	0.04	Agricultural	To Residential others below 1ha
2306	PPA1	CHANGE OF USE	RUIRU	0.0547	Agricultural	To Residential Peri-Urban below 1ha
2254	PPA1	CHANGE OF USE	RUIRU	0.4235	Residential	To Residential Peri-Urban below 1ha
2294	PPA1	CHANGE OF USE	OJ CONNECTION	0.0455	Agricultural	To Residential Peri-Urban below 1ha
2302	PPA1	CHANGE OF USE	RUIRU	0.0573	Agricultural	To Residential others below 1ha
2287	PPA1	CHANGE OF USE	RUIRU	0.041	Agricultural	To Residential Peri-Urban below 1ha
2295	PPA1	CHANGE OF USE	RUIRU	0.021	Agricultural	To Residential Urban below 1ha
2241	PPA1	CHANGE OF USE	RUIRU	0.0562	Agricultural	To Residential Urban below 1ha
1669	PPA1	CHANGE OF USE	RUIRU	0.045	Agricultural	To Residential Urban below 1ha
2252	PPA1	CHANGE OF USE	RUIRU TOWN	0.0674	Agricultural	To Residential Peri-Urban below 1ha
2058	PPA1	CHANGE OF USE	Githurai Kimbo	0.022	Agricultural	To Residential others below 1ha
2245	PPA1	CHANGE OF USE	RUIRU NEAR GITAMBAYA ESTATE	0.0459	Residential	To Residential Peri-Urban below 1ha

2244	PPA1	CHANGE OF USE	RUIRU NEAR GITAMBAYA ESTATE	0.045	Residential	To Residential Peri-Urban below 1ha
1960	PPA1	CHANGE OF USE	Ruiru	0.045	Agricultural	To Commercial BCR Peri-urban below 1ha
1303	PPA1	CHANGE OF USE	RUIRU	0.0475	Residential	To Commercial BCR others below 1ha
2215	PPA1	CHANGE OF USE	RUIRU	0.45	Residential	To Residential Urban below 1ha
2181	PPA1	CHANGE OF USE	GATONGORA	0.039	Agricultural	To Residential Peri-Urban below 1ha
1087	PPA1	CHANGE OF USE	RUIRU TOWNSHIP	0.2193	Institutional Private	To Commercial BCR Urban below 1ha
2161	PPA1	CHANGE OF USE	KIHUNGURO AREA	0.081	Agricultural	To Residential Peri-Urban below 1ha
2082	PPA1	CHANGE OF USE	GITOTHUA	0.02229673	Agricultural	To Residential Peri-Urban below 1ha
2138	PPA1	CHANGE OF USE	GITOTHUA	0.033	Agricultural	To Commercial BCR others below 1ha
2129	PPA1	CHANGE OF USE	RUIRU GITAMBAYA	0.0511	Residential	To Residential Peri-Urban below 1ha
2084	PPA1	CHANGE OF USE	RUIRU RAINBOW	0.048	Agricultural	To Residential Peri-Urban below 1ha
2116	PPA1	CHANGE OF USE	RUIRU	52.83	Agricultural	To Residential above 1ha
1996	PPA1	CHANGE OF USE	Ruiru	0.02991	Agricultural	To Commercial BCR Peri-urban below 1ha
2112	PPA1	CHANGE OF USE	Ruiru	0.0533	Commercial	To Industrial Light below 1ha
2109	PPA1	CHANGE OF USE	GITOTHUA	0.0409	Agricultural	To Residential Peri-Urban below 1ha
1385	PPA1	CHANGE OF USE	GITOTHUA	0.0216	Residential	To Residential others below 1ha
1384	PPA1	CHANGE OF USE	GITOTHUA	0.0216	Residential	To Residential others below 1ha
1155	PPA1	CHANGE OF USE	GITOTHUA	0.0216	Residential	To Residential Peri-Urban below 1ha
2003	PPA1	CHANGE OF USE	RUIRU TOWNSHIP	0.54	Industrial	To Institutional Public Religious below 1ha
1841	PPA1	CHANGE OF USE	RUIRU	0.045	Residential	To Residential others below 1ha
2076	PPA1	CHANGE OF USE	Ruiru	0.0802	Residential	To Residential Peri-Urban below 1ha
1811	PPA1	CHANGE OF USE	RUIRU	0.0919	Agricultural	To Residential Peri-Urban below 1ha
2068	PPA1	CHANGE OF USE	RUIRU	0.0791	Agricultural	To Residential Peri-Urban below 1ha
2067	PPA1	CHANGE OF USE	RUIR AREA	0.033	Agricultural	To Residential Peri-Urban below 1ha
2056	PPA1	CHANGE OF USE	RUIRU TOWN	0.0704	Agricultural	To Residential Peri-Urban below 1ha
1997	PPA1	CHANGE OF USE	Gatongora	0.045	Commercial	To Residential others below 1ha
1998	PPA1	CHANGE OF USE	Gatongora	0.045	Commercial	To Residential others below 1ha

1999	PPA1	CHANGE OF USE	Gatongora	0.045	Commercial	To Residential others below 1ha
1843	PPA1	CHANGE OF USE	Gatongora	0.1098	Agricultural	To Residential others below 1ha
1964	PPA1	CHANGE OF USE	Mutonya area, Gatongora	0.045	Agricultural	To Commercial Others below 1ha
1978	PPA1	CHANGE OF USE	RUIRU TOWN	0.04	Agricultural	To Residential Peri-Urban below 1ha
2045	PPA1	CHANGE OF USE	RUIRU	0.0636	Agricultural	To Residential Peri-Urban below 1ha
2039	PPA1	CHANGE OF USE	RUIRU	0.051	Agricultural	To Residential Peri-Urban below 1ha
2004	PPA1	CHANGE OF USE	GITOTHUA	0.036	Residential	To Residential Peri-Urban below 1ha
2001	PPA1	CHANGE OF USE	KIHUNGURO AREA	0.1	Agricultural	To Residential Peri-Urban below 1ha
1976	PPA1	CHANGE OF USE	KAGINA	0.039	Agricultural	To Residential Peri-Urban below 1ha
1178	PPA1	CHANGE OF USE	Sunrise -RUIRU	0.0332	Agricultural	To Residential Peri-Urban below 1ha
1986	PPA1	CHANGE OF USE	GITOTHUA	0.0375	Agricultural	To Residential Peri-Urban below 1ha
1834	PPA1	CHANGE OF USE	GITOTHUA	0.0465	Agricultural	To Residential Peri-Urban below 1ha
345	PPA1	CHANGE OF USE	RUIRU SUB-COUNTY	0.0297	Residential	To Residential Peri-Urban below 1ha
1572	PPA1	CHANGE OF USE	RUIRU RAINBOW AREA	0.042	Agricultural	To Residential Peri-Urban below 1ha
1430	PPA1	CHANGE OF USE	RUIRU	0.057	Agricultural	To Residential Peri-Urban below 1ha
1973	PPA1	CHANGE OF USE	RUIRU RAINBOW AREA	0.06	Agricultural	To Residential Peri-Urban below 1ha
1971	PPA1	CHANGE OF USE	GITOTHUA	0.0511	Agricultural	To Residential Peri-Urban below 1ha
1813	PPA1	CHANGE OF USE	ruiru	2.596	Agricultural	To Industrial Light below 1ha
1814	PPA1	CHANGE OF USE	RUIRU	1.267	Agricultural	To Residential others below 1ha
1815	PPA1	CHANGE OF USE	RUIRU	1.214	Agricultural	To Industrial Light below 1ha
1816	PPA1	CHANGE OF USE	RUIRU	1.214	Agricultural	To Industrial Light below 1ha
1835	PPA1	CHANGE OF USE	RUIRU	0.126	Agricultural	To Commercial BCR Peri-urban below 1ha
1958	PPA1	CHANGE OF USE	RUIRU	0.0771	Residential	To Commercial Peri-Urban below 1ha
1955	PPA1	CHANGE OF USE	Gatong'ora	0.031	Agricultural	To Residential others below 1ha
1945	PPA1	CHANGE OF USE	RUIRU	0.057	Agricultural	To Residential Peri-Urban below 1ha
1943	PPA1	CHANGE OF USE	RUIRU GITAMBAYA	0.0511	Residential	To Residential Peri-Urban below 1ha
1670	PPA1	CHANGE OF USE	Gatong'ora	0.0375	Agricultural	To Residential Peri-Urban below 1ha

1926	PPA1	CHANGE OF USE	RUIRU	0.041	Agricultural	To Residential Peri-Urban below 1ha
1918	PPA1	CHANGE OF USE	Ruiru	0.084	Agricultural	To Residential Peri-Urban below 1ha
134	PPA1	CHANGE OF USE	Ruiru	0.0313	Agricultural	To Residential Peri-Urban below 1ha
1911	PPA1	CHANGE OF USE	Ruiru	0.156	Agricultural	To Industrial Light below 1ha
1867	PPA1	CHANGE OF USE	Ruiru	0.0356	Agricultural	To Residential Peri-Urban below 1ha
1865	PPA1	CHANGE OF USE	Ruiru	0.044	Agricultural	To Residential Peri-Urban below 1ha
1649	PPA1	CHANGE OF USE	RUIRU	0.0042	Residential	To Residential others below 1ha
926	PPA1	CHANGE OF USE	RUIRU	0.044	Agricultural	To Residential others below 1ha
1860	PPA1	CHANGE OF USE	GITHUNGURI, RUIRU	0.0545	Agricultural	To Residential Peri-Urban below 1ha
907	PPA1	CHANGE OF USE	GITOTHUA	0.827	Residential	To Institutional Educational Pre-Primary
1582	PPA1	CHANGE OF USE	OJ RUIRU	0.045	Residential	To Residential Peri-Urban below 1ha
1735	PPA1	CHANGE OF USE	Ruiru	0.0223	Residential	To Residential Peri-Urban below 1ha
1214	PPA1	CHANGE OF USE	KIU	0.0269	Residential	To Residential Urban below 1ha
466	PPA1	CHANGE OF USE	KIU	0.099	Residential	To Residential Peri-Urban below 1ha
1090	PPA1	CHANGE OF USE	KIU	0.0212	Residential	To Residential Urban below 1ha
1208	PPA1	CHANGE OF USE	Ruiru area (Approx. 130 M from Zetech University)	0.044	Agricultural	To Residential Peri-Urban below 1ha
1703	PPA1	CHANGE OF USE	Ruiru	0.1068	Residential	To Residential Peri-Urban below 1ha
1740	PPA1	CHANGE OF USE	KIHUNGURO, RUIRU	0.064	Agricultural	To Commercial BCR Peri-urban below 1ha
1836	PPA1	CHANGE OF USE	Ruiru	0.045	Agricultural	To Residential Peri-Urban below 1ha
1668	PPA1	CHANGE OF USE	RUIRU GITAMBAYA	0.0511	Residential	To Residential Peri-Urban below 1ha
1457	PPA1	CHANGE OF USE	Ruiru	0.044	Agricultural	To Residential Peri-Urban below 1ha
1824	PPA1	CHANGE OF USE	RUIRU	1.8495	Agricultural	To Industrial above 1ha
1547	PPA1	CHANGE OF USE	GITOTHUA AREA,	0.6078	Agricultural	To Institutional Educational Pre-Primary
1736	PPA1	CHANGE OF USE	Gitothua	0.0414	Agricultural	To Residential Peri-Urban below 1ha
1719	PPA1	CHANGE OF USE	Ruiru	0.036	Agricultural	To Residential Peri-Urban below 1ha
1733	PPA1	CHANGE OF USE	Ruiru	0.0549	Agricultural	To Residential Peri-Urban below 1ha

1795	PPA1	CHANGE OF USE	RUIRU	0.3601	Agricultural	To Residential Peri-Urban below 1ha
1711	PPA1	CHANGE OF USE	GITothua	0.0511	Agricultural	To Residential Peri-Urban below 1ha
1524	PPA1	CHANGE OF USE	RUIRU	0.058	Agricultural	To Residential Peri-Urban below 1ha
1737	PPA1	CHANGE OF USE	RUIRU	0.0514	Agricultural	To Residential Peri-Urban below 1ha
1501	PPA1	CHANGE OF USE	RUIRU	0.464	Agricultural	To Residential Peri-Urban below 1ha
1619	PPA1	CHANGE OF USE	RUIRU	0.0506	Agricultural	To Residential Urban below 1ha
1774	PPA1	CHANGE OF USE	RUIRU	0.5	Agricultural	To Commercial above 1ha
1657	PPA1	CHANGE OF USE	RUIRU	0.041	Agricultural	To Residential above 1ha
1544	PPA1	CHANGE OF USE	KAMAKIS	0.035	Agricultural	To Residential Peri-Urban below 1ha
1738	PPA1	CHANGE OF USE	RUIRU	0.0613	Residential	To Residential Peri-Urban below 1ha
1549	PPA1	CHANGE OF USE	Ruiru	0.0363	Agricultural	To Commercial BCR Peri-urban below 1ha
1495	PPA1	CHANGE OF USE	RUIRU	0.0293	Residential	To Commercial BCR others below 1ha
1182	PPA1	CHANGE OF USE	RUIRU	0.1	Residential	To Residential others below 1ha
1665	PPA1	CHANGE OF USE	RUIRU	0.0511	Agricultural	To Residential above 1ha
1708	PPA1	CHANGE OF USE	RUIRU	0.4048	Agricultural	To Residential others below 1ha
1694	PPA1	CHANGE OF USE	GITOTHUA	0.045	Agricultural	To Residential Peri-Urban below 1ha
1704	PPA1	CHANGE OF USE	RUIRU	0.3738	Agricultural	To Institutional Public Religious below 1ha
1698	PPA1	CHANGE OF USE	RUIRU	0.0219	Residential	To Residential Peri-Urban below 1ha
1252	PPA1	CHANGE OF USE	GATONGORA	0.0392	Agricultural	To Residential Peri-Urban below 1ha
1692	PPA1	CHANGE OF USE	GATONGORA	0.0392	Agricultural	To Residential Peri-Urban below 1ha
1686	PPA1	CHANGE OF USE	RUIRU	0.182	Residential	To Residential Peri-Urban below 1ha
1673	PPA1	CHANGE OF USE	RUIRU	0.039	Agricultural	To Residential Peri-Urban below 1ha
1511	PPA1	CHANGE OF USE	RUIRU	0.0623	Agricultural	To Residential Peri-Urban below 1ha
1659	PPA1	CHANGE OF USE	Gitothua	0.0511	Agricultural	To Commercial BCR Peri-urban below 1ha
1652	PPA1	CHANGE OF USE	RUIRU	0.1	Agricultural	To Residential Urban below 1ha
1562	PPA1	CHANGE OF USE	RUIRU	0.0909	Residential	To Residential Peri-Urban below 1ha
1548	PPA1	CHANGE OF USE	RUIRU	0.026	Agricultural	To Residential Urban below 1ha

1646	PPA1	CHANGE OF USE	RUIRU	0.0223	Agricultural	To Residential Urban below 1ha
1644	PPA1	CHANGE OF USE	RUIRU	0.114	Agricultural	To Residential others below 1ha
1541	PPA1	CHANGE OF USE	Gatong'ora	0.0223	Agricultural	To Residential Urban below 1ha
1636	PPA1	CHANGE OF USE	GITOTHUA GITAMBAYA AREA	0.0511	Residential	To Residential Peri-Urban below 1ha
1530	PPA1	CHANGE OF USE	RUIRU	0.0576	Residential	To Residential Peri-Urban below 1ha
1245	PPA1	CHANGE OF USE	RUIRU	0.0339	Agricultural	To Residential Peri-Urban below 1ha
1244	PPA1	CHANGE OF USE	RUIRU	0.0339	Agricultural	To Residential others below 1ha
1552	PPA1	CHANGE OF USE	RUIRU TOWN	0.048	Residential	To Residential Urban below 1ha
1583	PPA1	CHANGE OF USE	Gikumari	0.5	Agricultural	To Residential Peri-Urban below 1ha
344	PPA1	CHANGE OF USE	Ruiru	0.0297	Residential	To Residential others below 1ha
1574	PPA1	CHANGE OF USE	Ruiru	0.12	Agricultural	To Residential Peri-Urban below 1ha
1558	PPA1	CHANGE OF USE	Ruiru	0.0565	Agricultural	To Residential Peri-Urban below 1ha
1520	PPA1	CHANGE OF USE	Ruiru	0.0547	Agricultural	To Residential Peri-Urban below 1ha
346	PPA1	CHANGE OF USE	Ruiru	0.0297	Residential	To Residential Peri-Urban below 1ha
1545	PPA1	CHANGE OF USE	Ruiru	0.098	Residential	To Residential Peri-Urban below 1ha
1540	PPA1	CHANGE OF USE	Ruiru	0.038	Agricultural	To Residential Peri-Urban below 1ha
1507	PPA1	CHANGE OF USE	Ruiru	0.0557	Agricultural	To Residential Peri-Urban below 1ha
1479	PPA1	CHANGE OF USE	Gatong'ora	0.1	Agricultural	To Residential Peri-Urban below 1ha
1513	PPA1	CHANGE OF USE	GATONG'ORA AREA, RUIRU	0.5	Agricultural	To Residential Peri-Urban below 1ha
1381	PPA1	CHANGE OF USE	Ruiru	0.0213	Residential	To Residential Peri-Urban below 1ha
619	PPA1	CHANGE OF USE	Ruiru	0.0538	Agricultural	To Residential others below 1ha
1407	PPA1	CHANGE OF USE	Ruiru	0.044	Agricultural	To Residential Peri-Urban below 1ha
1365	PPA1	CHANGE OF USE	RUIRU	0.052	Agricultural	To Residential Peri-Urban below 1ha
354	PPA1	CHANGE OF USE	Ruiru	0.0224	Agricultural	To Residential Peri-Urban below 1ha
1246	PPA1	CHANGE OF USE	Ruiru	0.0954	Residential	To Residential Peri-Urban below 1ha
1397	PPA1	CHANGE OF USE	Ruiru	0.0606	Residential	To Residential Urban below 1ha

1413	PPA1	CHANGE OF USE	Ruiru	0.082	Agricultural	To Industrial Light below 1ha
1357	PPA1	CHANGE OF USE	Ruiru	0.0511	Residential	To Residential Peri-Urban below 1ha
1369	PPA1	CHANGE OF USE	Ruiru	0.0536	Residential	To Residential Peri-Urban below 1ha
1394	PPA1	CHANGE OF USE	Ruiru	0.0447	Agricultural	To Commercial BCR Peri-urban below 1ha
1354	PPA1	CHANGE OF USE	Ruiru	0.03	Residential	To Residential Peri-Urban below 1ha
1373	PPA1	CHANGE OF USE	Ruiru	0.1087	Residential	To Commercial BCR Peri-urban below 1ha
1372	PPA1	CHANGE OF USE	RUIRU	0.0312	Residential	To Commercial BCR Peri-urban below 1ha
1367	PPA1	CHANGE OF USE	Ruiru	0.039	Agricultural	To Residential Peri-Urban below 1ha
1343	PPA1	CHANGE OF USE	Ruiru	0.042	Booster Transmission Station (BTS) Brown Field	For Booster Transmission Station (BTS) Brown Field
1340	PPA1	CHANGE OF USE	RUIRU RAINBOW AREA	0.05	Agricultural	To Industrial Heavy below 1ha
1325	PPA1	CHANGE OF USE	GITOTHUA	0.0511	Agricultural	To Residential above 1ha
1280	PPA1	CHANGE OF USE	Ruiru	0.055	Agricultural	To Commercial BCR Peri-urban below 1ha
1305	PPA1	CHANGE OF USE	Gatong'ora	0.033	Agricultural	To Residential above 1ha
1203	PPA1	CHANGE OF USE	Gatong'ora	0.033	Agricultural	To Institutional Recreational below 1ha
1088	PPA1	CHANGE OF USE	Ruiru	0.041	Agricultural	To Institutional Educational Primary and Secondary
1039	PPA1	CHANGE OF USE	Ruiru	0.045	Agricultural	To Institutional Educational Primary and Secondary
1301	PPA1	CHANGE OF USE	Ruiru	0.064	Agricultural	To Industrial above 1ha
1298	PPA1	CHANGE OF USE	Ruiru	0.045	Commercial	To Commercial BCR Peri-urban below 1ha
1122	PPA1	CHANGE OF USE	Ruiru	0.033	Agricultural	To Residential Peri-Urban below 1ha
859	PPA1	CHANGE OF USE	Ruiru	0.047	Booster Transmission Station (BTS) Brown Field	To Commercial above 1ha
1295	PPA1	CHANGE OF USE	Ruiru	0.029	Agricultural	For Booster Transmission Station (BTS) Brown Field
1282	PPA1	CHANGE OF USE	GITOTHUA	0.0511	Booster Transmission Station (BTS) Green Field	To Industrial Heavy below 1ha
989	PPA1	CHANGE OF USE	Kimbo	0.0208	Agricultural	To Institutional Power Distribution Station
1277	PPA1	CHANGE OF USE	Gitothua	0.0475	Booster Transmission Station (BTS) Brown Field	To Institutional Educational Pre-Primary
1242	PPA1	CHANGE OF USE	Ruiru	0.421	Booster Transmission Station (BTS) Brown Field	To Commercial above 1ha
1275	PPA1	CHANGE OF USE	Ruiru	0.734	Booster Transmission Station (BTS) Green Field	To Commercial BCR Urban below 1ha

1272	PPA1	CHANGE OF USE	GITOTHUA	0.0366	Booster Transmission Station (BTS) Brown Field	To Agricultural
1271	PPA1	CHANGE OF USE	Ruiru	0.0405	Booster Transmission Station (BTS) Brown Field	To Institutional Educational Primary and Secondary
1266	PPA1	CHANGE OF USE	Ruiru	0.0511	Agricultural	To Industrial Light below 1ha
1265	PPA1	CHANGE OF USE	Ruiru Area	0.043	Agricultural	To Industrial Light below 1ha
1264	PPA1	CHANGE OF USE	Ruiru	0.0409	Agricultural	To Commercial Others below 1ha
1261	PPA1	CHANGE OF USE	Ruiru	0.0988	Booster Transmission Station (BTS) Brown Field	To Agricultural
965	PPA1	CHANGE OF USE	Ruiru	0.3572	Booster Transmission Station (BTS) Brown Field	For Booster Transmission Station (BTS) Green Field
1201	PPA1	CHANGE OF USE	Ruiru	0.0203	-	-
1213	PPA1	CHANGE OF USE	Ruiru	0.056	Commercial	To Industrial Light below 1ha
1027	PPA1	CHANGE OF USE	Ruiru	0.0375	Commercial	To Commercial BCR Urban below 1ha
1257	PPA1	CHANGE OF USE	Ruiru	0.0216	Booster Transmission Station (BTS) Brown Field	To Industrial Medium below 1ha
598	PPA1	CHANGE OF USE	Ruiru	0.044	Institutional Private	To Industrial Medium below 1ha
1205	PPA1	CHANGE OF USE	GITOTHUA	0.0511	Agricultural	To Residential above 1ha
312	PPA1	CHANGE OF USE	GATONGORA	0.044	Agricultural	To Residential above 1ha
1187	PPA1	CHANGE OF USE	Ruiru	0.036	Agricultural	To Residential above 1ha
1206	PPA1	CHANGE OF USE	RUIRU RAINBOW AREA	0.0293	Agricultural	To Residential others below 1ha
745	PPA1	CHANGE OF USE	RUIRU RAINBOW AREA	0.0834	Commercial	To Commercial BCR Peri-urban below 1ha
1181	PPA1	CHANGE OF USE	Ruiru	0.045	Agricultural	For Booster Transmission Station (BTS) Green Field
1197	PPA1	CHANGE OF USE	RUIRU RAINBOW AREA	0.044	Agricultural	To Institutional Transportation below 1ha
1172	PPA1	CHANGE OF USE	Ruiru	0.042	Booster Transmission Station (BTS) Brown Field	To Industrial Heavy below 1ha
1169	PPA1	CHANGE OF USE	Ruiru	0.0216	Agricultural	To Residential others below 1ha
1073	PPA1	CHANGE OF USE	Ruiru	0.03	Booster Transmission Station (BTS) Green Field	To Industrial above 1ha
1116	PPA1	CHANGE OF USE	Ruiru	0.1	Agricultural	To Residential Peri-Urban below 1ha
1114	PPA1	CHANGE OF USE	Ruiru	0.0216	Agricultural	To Institutional Recreational below 1ha
610	PPA1	CHANGE OF USE	Ruiru	0.08	Agricultural	To Commercial BCR Peri-urban below 1ha
1111	PPA1	CHANGE OF USE	WATAALAM	0.0511	Booster Transmission Station (BTS) Brown Field	To Industrial above 1ha

1105	PPA1	CHANGE OF USE	GITOTHUA	0.033	Industrial	To Commercial BCR Urban below 1ha
990	PPA1	CHANGE OF USE	GITOTHUA	0.0409	Booster Transmission Station (BTS) Brown Field	To Institutional Educational Pre-Primary
1049	PPA1	CHANGE OF USE	Ruiru	0.0234	Booster Transmission Station (BTS) Brown Field	To Industrial Medium below 1ha
946	PPA1	CHANGE OF USE	WATAALAM	0.0511	Agricultural	To Industrial Medium below 1ha
1007	PPA1	CHANGE OF USE	Near Prisons	0.045	Agricultural	To Residential Peri-Urban below 1ha
1078	PPA1	CHANGE OF USE	RUIRU AREA	0.0267	Booster Transmission Station (BTS) Brown Field	To Institutional Educational Pre-Primary
1069	PPA1	CHANGE OF USE	RUIRU AREA	0.046	Agricultural	To Institutional Public Others below 1ha
1037	PPA1	CHANGE OF USE	RUIRU	4	Agricultural	To Institutional Educational Primary and Secondary
788	PPA1	CHANGE OF USE	RUIRU HOSPITAL	0.033	Agricultural	To Industrial Medium below 1ha
787	PPA1	CHANGE OF USE	RUIRU HOSPITAL	0.033	Booster Transmission Station (BTS) Green Field	To Commercial Others below 1ha
786	PPA1	CHANGE OF USE	RUIRU HOSPITAL	0.033	Agricultural	To Commercial above 1ha
1062	PPA1	CHANGE OF USE	Ruiru	0.0223	Booster Transmission Station (BTS) Brown Field	To Industrial Light below 1ha
1052	PPA1	CHANGE OF USE	Ruiru	0.07	Institutional Private	To Industrial Medium below 1ha
1046	PPA1	CHANGE OF USE	Ruiru	0.0216	Booster Transmission Station (BTS) Brown Field	To Institutional Educational Primary and Secondary
836	PPA1	CHANGE OF USE	Ruiru	0.1	Agricultural	To Residential Peri-Urban below 1ha
1032	PPA1	CHANGE OF USE	Ruiru	0.0366	Agricultural	To Institutional Public Religious below 1ha
1024	PPA1	CHANGE OF USE	Ruiru Rainbow Area	0.046	Agricultural	For Booster Transmission Station (BTS) Green Field
930	PPA1	CHANGE OF USE	Ruiru	0.116	Agricultural	To Institutional Power Distribution Station
303	PPA1	CHANGE OF USE	GATONGORA	0.035 hA	-	-
1015	PPA1	CHANGE OF USE	GATONG'ORA	0.035 hA	-	-
1013	PPA1	CHANGE OF USE	GITOTHUA	0.0511	Booster Transmission Station (BTS) Green Field	To Institutional Power Distribution Station
982	PPA1	CHANGE OF USE	Ruiru	0.1	Agricultural	To Institutional Educational Tertiary
967	PPA1	CHANGE OF USE	GITOTHUA GITAMBAYA AREA	0.051	Commercial	To Commercial above 1ha
705	PPA1	CHANGE OF USE	Ruiru	0.3697	Commercial	To Commercial above 1ha
954	PPA1	CHANGE OF USE	Ruiru	0.1	Booster Transmission Station (BTS) Brown Field	To Industrial Heavy below 1ha
476	PPA1	CHANGE OF USE	GATONG'ORA	0.05	Booster Transmission Station (BTS) Green	To Commercial Others below 1ha

					Field	
939	PPA1	CHANGE OF USE	GATONG’ORA	0.0405	Booster Transmission Station (BTS) Brown Field	To Agricultural
918	PPA1	CHANGE OF USE	RAINBOW AREA	0.03	Agricultural	To Institutional Public Others below 1ha
897	PPA1	CHANGE OF USE	RUIRU	0.1	Agricultural	For Booster Transmission Station (BTS) Green Field
892	PPA1	CHANGE OF USE	RUIRU	0.103	Booster Transmission Station (BTS) Brown Field	To Agricultural
887	PPA1	CHANGE OF USE	RUIRU	0.0511	Booster Transmission Station (BTS) Brown Field	To Institutional Educational Primary and Secondary
885	PPA1	CHANGE OF USE	Gitothua	0.03	Agricultural	To Agricultural
883	PPA1	CHANGE OF USE	Ruiru	0.038	Commercial	To Institutional Educational Pre-Primary
879	PPA1	CHANGE OF USE	GITHUNGURI RUIRU	0.0511	Booster Transmission Station (BTS) Brown Field	To Commercial Others below 1ha
725	PPA1	CHANGE OF USE	RUIRU	0.06	Agricultural	To Institutional Public above 1ha
714	PPA1	CHANGE OF USE	GATONG'ORA	0.0297	Booster Transmission Station (BTS) Brown Field	To Industrial Medium below 1ha
877	PPA1	CHANGE OF USE	RUIRU	0.0471	Booster Transmission Station (BTS) Green Field	-
471	PPA1	CHANGE OF USE	RUIRU HOSPITAL	0.045	Booster Transmission Station (BTS) Green Field	To Commercial BCR Peri-urban below 1ha
872	PPA1	CHANGE OF USE	RUIRU	0.0436	Agricultural	To Institutional Recreational below 1ha
423	PPA1	CHANGE OF USE	RUIRU	0.018	Booster Transmission Station (BTS) Brown Field	To Commercial BCR others below 1ha
766	PPA1	CHANGE OF USE	RAINBOW	0.04	Agricultural	To Institutional Educational Pre-Primary
850	PPA1	CHANGE OF USE	RUIRU	0.036	Institutional Public	To Industrial above 1ha
732	PPA1	CHANGE OF USE	Gitothua	0.0524	Agricultural	To Institutional Educational Primary and Secondary
834	PPA1	CHANGE OF USE	GITOTHUA	0.0955	Agricultural	To Institutional Public Religious below 1ha
831	PPA1	CHANGE OF USE	GATONG’ORA	0.1	Agricultural	To Institutional Public above 1ha
807	PPA1	CHANGE OF USE	GITOTHUA	0.0511	Booster Transmission Station (BTS) Green Field	To Commercial above 1ha
805	PPA1	CHANGE OF USE	RUIRU	0.044	Booster Transmission Station (BTS) Brown Field	To Institutional Educational Pre-Primary
795	PPA1	CHANGE OF USE	RUIRU	0.0288	Booster Transmission Station (BTS) Brown Field	To Institutional Educational Pre-Primary
691	PPA1	CHANGE OF USE	RUIRU	0.0507	Agricultural	For Booster Transmission Station (BTS) Green Field

686	PPA1	CHANGE OF USE	RUIRU	0.033	Agricultural	For Booster Transmission Station (BTS) Green Field
679	PPA1	CHANGE OF USE	GITOTHUA	0.0409	Agricultural	To Institutional Public below 1ha
677	PPA1	CHANGE OF USE	GITOTHUA	0.033	Booster Transmission Station (BTS) Brown Field	To Commercial Peri-Urban below 1ha
601	PPA1	CHANGE OF USE	Rainbow Resort area	0.045	Booster Transmission Station (BTS) Brown Field	For Booster Transmission Station (BTS) Brown Field
670	PPA1	CHANGE OF USE	GITOTHUA	0.0536	Agricultural	For Booster Transmission Station (BTS) Green Field
635	PPA1	CHANGE OF USE	RUIRU	0.045	Booster Transmission Station (BTS) Brown Field	To Commercial above 1ha
524	PPA1	CHANGE OF USE	RUIRU	0.036	Agricultural	To Commercial BCR others below 1ha
605	PPA1	CHANGE OF USE	RUIRU AREA	0.045	Agricultural	To Institutional Educational Tertiary
543	PPA1	CHANGE OF USE	RUIRU RAINBOW AREA	0.045	Agricultural	To Commercial above 1ha
387	PPA1	CHANGE OF USE	RUIRU RAINBOW AREA	0.041	Booster Transmission Station (BTS) Green Field	To Commercial BCR Peri-urban below 1ha
386	PPA1	CHANGE OF USE	RUIRU RAINBOW AREA	0.041	Booster Transmission Station (BTS) Brown Field	To Commercial BCR others below 1ha
600	PPA1	CHANGE OF USE	RUIRU AREA	0.06	Agricultural	To Institutional Educational Tertiary
501	PPA1	CHANGE OF USE	NEAR ZETECH UNIVERSITY	0.05	Institutional Private	To Industrial Medium below 1ha
594	PPA1	CHANGE OF USE	GATONGORA AREA	0.1	Agricultural	To Institutional Public above 1ha
557	PPA1	CHANGE OF USE	RUIRU	0.045	Booster Transmission Station (BTS) Green Field	For Booster Transmission Station (BTS) Brown Field
558	PPA1	CHANGE OF USE	RUIRU	0.045	Booster Transmission Station (BTS) Green Field	To Industrial Light below 1ha
591	PPA1	CHANGE OF USE	RUIRU	0.045	Booster Transmission Station (BTS) Brown Field	For Booster Transmission Station (BTS) Green Field
584	PPA1	CHANGE OF USE	RUIRU	0.1061	Agricultural	For Booster Transmission Station (BTS) Green Field
575	PPA1	CHANGE OF USE	RUIRU	0.4213	Booster Transmission Station (BTS) Green Field	To Commercial above 1ha
567	PPA1	CHANGE OF USE	RUIRU	0.015	Institutional Public	To Institutional Power Distribution Station
546	PPA1	CHANGE OF USE	RUIRU	0.0767	Agricultural	For Booster Transmission Station (BTS) Brown Field
422	PPA1	CHANGE OF USE	GATONG'ORA	0.05	Booster Transmission Station (BTS) Brown Field	To Institutional Educational Primary and Secondary
339	PPA1	CHANGE OF USE	RUIRU	0.0288	Booster Transmission Station (BTS) Brown Field	To Industrial Heavy below 1ha
544	PPA1	CHANGE OF USE	RUIRU	0.09	Booster Transmission Station (BTS) Brown	To Agricultural

					Field	
547	PPA1	CHANGE OF USE	RUIRU	0.0405	Booster Transmission Station (BTS) Brown Field	To Agricultural
392	PPA1	CHANGE OF USE	RUIRU	0.015	Agricultural	For Booster Transmission Station (BTS) Green Field
329	PPA1	CHANGE OF USE	Ruiru	0.0599	Booster Transmission Station (BTS) Brown Field	For Booster Transmission Station (BTS) Brown Field
421	PPA1	CHANGE OF USE	NEXT TO REDEEMED GOSPEL CHURCH RUIRU	0.0511	Institutional Private	To Industrial Light below 1ha
536	PPA1	CHANGE OF USE	RUIRU	0.0416	Agricultural	For Booster Transmission Station (BTS) Brown Field
304	PPA1	CHANGE OF USE	RUIRU	0.039	Agricultural	To Agricultural
479	PPA1	CHANGE OF USE	GATONG'ORA-KAMAKIS AREA	0.041	Agricultural	To Commercial above 1ha
525	PPA1	CHANGE OF USE	RUIRU	0.5	Booster Transmission Station (BTS) Brown Field	To Agricultural
391	PPA1	CHANGE OF USE	RUIRU AREA	0.0998	Booster Transmission Station (BTS) Brown Field	To Commercial BCR Peri-urban below 1ha
511	PPA1	CHANGE OF USE	RUIRU	0.055	Agricultural	For Booster Transmission Station (BTS) Green Field
522	PPA1	CHANGE OF USE	RUIRU	0.1068	Booster Transmission Station (BTS) Brown Field	To Agricultural
521	PPA1	CHANGE OF USE	RUIRU	0.0198	Booster Transmission Station (BTS) Brown Field	To Agricultural
512	PPA1	CHANGE OF USE	RUIRU	0.0549	Booster Transmission Station (BTS) Green Field	To Commercial Peri-Urban below 1ha
390	PPA1	CHANGE OF USE	RUIRU	0.0288	Industrial	To Agricultural
261	PPA1	CHANGE OF USE	Gitothua	0.037	Booster Transmission Station (BTS) Brown Field	For Booster Transmission Station (BTS) Brown Field
378	PPA1	CHANGE OF USE	RUIRU TOWN	0.0188	Booster Transmission Station (BTS) Brown Field	To Commercial above 1ha
494	PPA1	CHANGE OF USE	RUIRU	0.0511	Booster Transmission Station (BTS) Brown Field	To Agricultural
502	PPA1	CHANGE OF USE	Sunrise area-Ruiru	0.047	Agricultural	For Booster Transmission Station (BTS) Green Field
498	PPA1	CHANGE OF USE	Gitothua	0.0383	Agricultural	To Industrial Medium below 1ha
377	PPA1	CHANGE OF USE	RUIRU	0.0216	Commercial	-
400	PPA1	CHANGE OF USE	RUIRU	0.024	Agricultural	To Commercial above 1ha
407	PPA1	CHANGE OF USE	RUIRU	0.033	Booster Transmission Station (BTS) Green Field	To Commercial BCR others below 1ha
366	PPA1	CHANGE OF USE	RUIRU	0.0409	Institutional Public	To Industrial Medium below 1ha
430	PPA1	CHANGE OF USE	RUIRU	0.1	Commercial	To Commercial Peri-Urban below 1ha

431	PPA1	CHANGE OF USE	RUIRU	0.027	Booster Transmission Station (BTS) Green Field	To Commercial BCR others below 1ha
459	PPA1	CHANGE OF USE	RUIRU	0.047	Agricultural	To Institutional Power Distribution Station
458	PPA1	CHANGE OF USE	RUIRU	0.5	Agricultural	To Institutional Educational Primary and Secondary
439	PPA1	CHANGE OF USE	RUIRU	0.0218	Booster Transmission Station (BTS) Brown Field	For Booster Transmission Station (BTS) Green Field
317	PPA1	CHANGE OF USE	RUIRU	0.0297	Institutional Public	To Industrial Medium below 1ha
213	PPA1	CHANGE OF USE	RUIRU	0.0234	Booster Transmission Station (BTS) Brown Field	To Commercial Urban below 1ha
432	PPA1	CHANGE OF USE	RUIRU	0.064	Commercial	To Commercial BCR Peri-urban below 1ha
425	PPA1	CHANGE OF USE	GITOTHUA	0.0409	Agricultural	To Institutional Power Distribution Station
365	PPA1	CHANGE OF USE	GITOTHUA	0.045	Booster Transmission Station (BTS) Green Field	To Agricultural
404	PPA1	CHANGE OF USE	GITOTHUA	0.036	Agricultural	To Institutional Power Distribution Station
371	PPA1	CHANGE OF USE	Gitothua	0.056	Booster Transmission Station (BTS) Brown Field	For Booster Transmission Station (BTS) Brown Field
393	PPA1	CHANGE OF USE	RUIRU	0.032	Agricultural	To Industrial Heavy below 1ha
388	PPA1	CHANGE OF USE	RUIRU	0.033	Institutional Private	To Residential above 1ha
357	PPA1	CHANGE OF USE	Ruiru	0.04	Agricultural	To Industrial Heavy below 1ha
372	PPA1	CHANGE OF USE	RUIRU	0.051	Agricultural	For Booster Transmission Station (BTS) Green Field
353	PPA1	CHANGE OF USE	RUIRU	0.0398	Booster Transmission Station (BTS) Brown Field	To Agricultural
352	PPA1	CHANGE OF USE	RUIRU	0.0288	Booster Transmission Station (BTS) Green Field	To Commercial BCR Peri-urban below 1ha
347	PPA1	CHANGE OF USE	RUIRU	0.0312	Institutional Public	To Institutional Educational Pre-Primary
340	PPA1	CHANGE OF USE	RUIRU	0.04	Agricultural	For Booster Transmission Station (BTS) Green Field
338	PPA1	CHANGE OF USE	RUIRU	0.04	Booster Transmission Station (BTS) Brown Field	To Agricultural
305	PPA1	CHANGE OF USE	Ruiru	0.051	Agricultural	To Industrial Medium below 1ha
287	PPA1	CHANGE OF USE	Ruiru South, Prison area	0.05	Booster Transmission Station (BTS) Brown Field	To Institutional Public Health Facility below 1ha
295	PPA1	CHANGE OF USE	Ruiru South, Prison area	0.0983	Institutional Public	To Institutional Educational Tertiary
265	PPA1	CHANGE OF USE	Ruiru Area	0.0511	Booster Transmission Station (BTS) Brown Field	To Agricultural

294	PPA1	CHANGE OF USE	GATONG'ORA	0.116	Booster Transmission Station (BTS) Green Field	To Institutional Educational Pre-Primary
51	PPA1	CHANGE OF USE	Gatong'ora	0.0542	Booster Transmission Station (BTS) Brown Field	To Industrial Light below 1ha
212	PPA1	CHANGE OF USE	NEAR ZETECH UNIVERSITY	0.041	Agricultural	To Commercial BCR others below 1ha
144	PPA1	CHANGE OF USE	RUIRU	0.041	Booster Transmission Station (BTS) Green Field	To Industrial Heavy below 1ha
286	PPA1	CHANGE OF USE	Ruiru South, Prison area	0.05	Institutional Public	To Institutional Power Distribution Station
279	PPA1	CHANGE OF USE	near Chiefs camp, Gatongora Area	0.05	Booster Transmission Station (BTS) Brown Field	For Booster Transmission Station (BTS) Green Field
276	PPA1	CHANGE OF USE	Rainbow Resort	0.0432	Booster Transmission Station (BTS) Green Field	To Institutional Educational Tertiary
263	PPA1	CHANGE OF USE	RUIRU	0.1002	Agricultural	To Institutional Educational Tertiary
259	PPA1	CHANGE OF USE	Sunrise area-Ruiru	0.033	Agricultural	For Booster Transmission Station (BTS) Green Field
39	PPA1	CHANGE OF USE	RUIRU	0.0223	Agricultural	To Commercial BCR Urban below 1ha
243	PPA1	CHANGE OF USE	RUIRU AREA	0.09	Agricultural	To Institutional Educational Tertiary
206	PPA1	CHANGE OF USE	RUIRU	0.0711	-	To Commercial BCR Urban below 1ha
192	PPA1	CHANGE OF USE	RUIRU	0.047	Agricultural	To Industrial above 1ha
187	PPA1	CHANGE OF USE	RUIRU	0.03	Booster Transmission Station (BTS) Brown Field	-
191	PPA1	CHANGE OF USE	RUIRU	0.0216	Booster Transmission Station (BTS) Brown Field	For Booster Transmission Station (BTS) Green Field
189	PPA1	CHANGE OF USE	Sunrise area-Ruiru	0.0505	Agricultural	For Booster Transmission Station (BTS) Green Field
186	PPA1	CHANGE OF USE	RUIRU	0.034	Booster Transmission Station (BTS) Brown Field	For Booster Transmission Station (BTS) Green Field
185	PPA1	CHANGE OF USE	RUIRU	0.07	Booster Transmission Station (BTS) Brown Field	For Booster Transmission Station (BTS) Green Field
176	PPA1	CHANGE OF USE	RUIRU	0.0223	Booster Transmission Station (BTS) Brown Field	For Booster Transmission Station (BTS) Green Field
153	PPA1	CHANGE OF USE	Gatong'ora	0.048	Institutional Public	To Institutional Educational Pre-Primary
152	PPA1	CHANGE OF USE	RUIRU AREA	0.079	Agricultural	To Industrial Light below 1ha
145	PPA1	CHANGE OF USE	Ruiru	0.022	Booster Transmission Station (BTS) Brown Field	To Commercial above 1ha
142	PPA1	CHANGE OF USE	RUIRU	0.035	Institutional Private	To Institutional Educational Primary and Secondary
110	PPA1	CHANGE OF USE	RUIRU	0.0511	Agricultural	To Institutional Educational Pre-Primary

105	PPA1	CHANGE OF USE	RUIRU	0.0537	Institutional Public	To Industrial Medium below 1ha
42	PPA1	CHANGE OF USE	RUIRU	0.0515	Commercial	To Institutional Educational Pre-Primary
104	PPA1	CHANGE OF USE	RUIRU AREA	0.0511	Booster Transmission Station (BTS) Green Field	To Industrial Medium below 1ha
103	PPA1	CHANGE OF USE	RUIRU AREA	0.0511	Agricultural	To Commercial BCR others below 1ha
102	PPA1	CHANGE OF USE	RUIRU	0.02	Booster Transmission Station (BTS) Brown Field	To Agricultural
95	PPA1	CHANGE OF USE	RUIRU	0.4992	Agricultural	To Industrial above 1ha
76	PPA1	CHANGE OF USE	RUIRU	0.045	Booster Transmission Station (BTS) Green Field	For Booster Transmission Station (BTS) Green Field
75	PPA1	CHANGE OF USE	GiTOTHUA	0.0511	Agricultural	To Agricultural
6	PPA1	CHANGE OF USE	GITOTHUA	0.0216	Agricultural	For Booster Transmission Station (BTS) Brown Field
7	PPA1	CHANGE OF USE	Ruiru	0.033	Booster Transmission Station (BTS) Brown Field	To Commercial BCR Urban below 1ha
67	PPA1	CHANGE OF USE	RUIRU	0.04	Booster Transmission Station (BTS) Brown Field	For Booster Transmission Station (BTS) Green Field
64	PPA1	CHANGE OF USE	Ruiru	0.0511	Industrial	To Agricultural
26	PPA1	CHANGE OF USE	RUIRU AREA	0.04	Agricultural	To Institutional Educational Primary and Secondary
24	PPA1	CHANGE OF USE	Ruiru	0.081	Booster Transmission Station (BTS) Green Field	To Agricultural
3024	PPA1	EXTENSION OF USE	RUIRU	0.1	-	To Commercial Urban below 1ha
2967	PPA1	EXTENSION OF USE	RUIRU	0.08	-	To Commercial Peri-Urban below 1ha
2649	PPA1	EXTENSION OF USE	Ruiru	0.0511	-	For Booster Transmission Station (BTS) Green Field
2590	PPA1	EXTENSION OF USE	OPPOSITE SPINNERS AND SPINNERS TEXTILES COMPANY	1.575	-	To Commercial above 1ha
2585	PPA1	EXTENSION OF USE	RUIRU	0.015	-	For Booster Transmission Station (BTS) Green Field
2582	PPA1	EXTENSION OF USE	RUIRU	0.044	-	For Booster Transmission Station (BTS) Green Field
2429	PPA1	EXTENSION OF USE	RUIRU	0.062	-	For Booster Transmission Station (BTS) Brown Field
1705	PPA1	EXTENSION OF USE	GITOTHUA	0.0161	-	For Booster Transmission Station (BTS) Green Field
1818	PPA1	EXTENSION OF USE	RUIRU	0.0896	-	For Booster Transmission Station (BTS) Green Field
1514	PPA1	EXTENSION OF USE	RUIRU	0.0375	-	For Booster Transmission Station (BTS) Green Field

1512	PPA1	EXTENSION OF USE	RUIRU	0.15	-	For Booster Transmission Station (BTS) Green Field
1086	PPA1	EXTENSION OF USE	RUIRU	0.15	-	For Booster Transmission Station (BTS) Green Field
1235	PPA1	EXTENSION OF USE	RUIRU	0.046	-	For Booster Transmission Station (BTS) Green Field
1332	PPA1	EXTENSION OF USE	RUIRU	0.0216	-	For Booster Transmission Station (BTS) Brown Field
1028	PPA1	EXTENSION OF USE	RUIRU	0.0682	-	For Booster Transmission Station (BTS) Brown Field
488	PPA1	EXTENSION OF USE	RUIRU	0.0409	-	For Booster Transmission Station (BTS) Green Field
389	PPA1	EXTENSION OF USE	RUIRU	0.022	-	For Booster Transmission Station (BTS) Brown Field
2445	PPA1	EXTENSION OF USE FOR BTS	RUIRU	0.525	-	For Booster Transmission Station (BTS) Green Field
238	PPA1	EXTENSION OF USE FOR BTS	RUIRU	0.0829	-	For Booster Transmission Station (BTS) Brown Field
2595	PPA1	REGULARIZATION FOR CHANGE OF USE	RUIRU	0.41	Agricultural	To Residential
2908	PPA1	REGULARIZATION FOR CHANGE OF USE	RUIRU	0.09	Residential	To Institutional Private
3060	PPA1	REGULARIZATION FOR CHANGE OF USE	Ruiru Town	0.0396	Residential	To Residential
2965	PPA1	REGULARIZATION FOR CHANGE OF USE	Ruiru	4	Residential	To Commercial
2461	PPA1	REGULARIZATION FOR CHANGE OF USE	Ruiru	0.026	Agricultural	To Commercial
2419	PPA1	REGULARIZATION FOR CHANGE OF USE	Ruiru	0.1	Residential	To Residential
1983	PPA1	REGULARIZATION FOR CHANGE OF USE	GATONGORA	0.0566	Agricultural	To Commercial
2124	PPA1	REGULARIZATION FOR CHANGE OF USE	GATONG'ORA	0.036	Agricultural	To Residential
2017	PPA1	REGULARIZATION FOR CHANGE OF USE	GATONG'ORA	2.481	Agricultural	To Institutional Private
1946	PPA1	REGULARIZATION FOR CHANGE OF USE	GATONG'ORA	0.071	Residential	To Residential
1939	PPA1	REGULARIZATION FOR CHANGE OF USE	GITAMBAYA	0.045	Agricultural	To Residential
1732	PPA1	REGULARIZATION FOR CHANGE OF USE	GATONG'ORA	0.0269	Agricultural	To Residential
1883	PPA1	REGULARIZATION FOR CHANGE OF USE	GATONG'ORA	0.045	Agricultural	To Residential

1573	PPA1	REGULARIZATION FOR CHANGE OF USE	GATONG'ORA	0.0336	Agricultural	To Residential
1671	PPA1	REGULARIZATION FOR CHANGE OF USE	GATONGORA	0.0511	Agricultural	To Commercial
678	PPA1	REGULARIZATION FOR CHANGE OF USE	RUIRU	0.071	Agricultural	To Residential
1724	PPA1	REGULARIZATION FOR CHANGE OF USE	GATONG'ORA	0.0533	Agricultural	To Residential
1734	PPA1	REGULARIZATION FOR CHANGE OF USE	Ruiru	0.032	Agricultural	To Residential
1662	PPA1	REGULARIZATION FOR CHANGE OF USE	Wells area, Ruiru	0.045	Agricultural	To Residential
1577	PPA1	REGULARIZATION FOR CHANGE OF USE	RUIRU	0.0835	Agricultural	To Residential
1353	PPA1	REGULARIZATION FOR CHANGE OF USE	GITOTHUA	0.0511	Residential	To Residential
1569	PPA1	REGULARIZATION FOR CHANGE OF USE	GATONG'ORA	0.1413	Agricultural	To Residential
822	PPA1	REGULARIZATION FOR CHANGE OF USE	GATONG'ORA	0.022	Residential	To Residential
1551	PPA1	REGULARIZATION FOR CHANGE OF USE	GATONG'ORA	0.0546	Agricultural	To Residential
1527	PPA1	REGULARIZATION FOR CHANGE OF USE	RUIRU	0.06	Agricultural	To Residential
1348	PPA1	REGULARIZATION FOR CHANGE OF USE	RUIRU	0.3702	Agricultural	To Residential
1419	PPA1	REGULARIZATION FOR CHANGE OF USE	Ruiru Area	0.045	Agricultural	To Residential
478	PPA1	REGULARIZATION FOR CHANGE OF USE	GITOTHUA;GITAMBAYA AREA	0.0511	Agricultural	To Residential
944	PPA1	REGULARIZATION FOR CHANGE OF USE	RUIRU	0.1239	Residential	To Industrial
770	PPA1	REGULARIZATION FOR CHANGE OF USE	RUIRU	0.0534	Agricultural	To Residential
863	PPA1	REGULARIZATION FOR CHANGE OF USE	Ruiru Area	0.037	Agricultural	To Residential
826	PPA1	REGULARIZATION FOR CHANGE OF USE	GATONG'ORA	0.0983	Residential	To Residential
2778	PPA1	RENEWAL FOR ADMINISTRATIVE CHANGE OF USE	GATONG'ORA	0.033	Residential	To Residential
2227	PPA1	RENEWAL FOR CHANGE OF USE	GITOTHUA	1.855	Agricultural	To Industrial
1766	PPA1	RENEWAL FOR CHANGE OF USE	RUIRU	0.0229	Agricultural	To Residential

1599	PPA1	RENEWAL FOR CHANGE OF USE	RUIRU	0.0924	Agricultural	To Residential
1416	PPA1	RENEWAL FOR CHANGE OF USE	RUIRU	0.04	Agricultural	To Residential
642	PPA1	RENEWAL FOR CHANGE OF USE	RUIRU	0.04	Agricultural	To Residential
794	PPA1	RENEWAL FOR CHANGE OF USE	GITHUNGURI	0.0335	Agricultural	To Commercial

Appendix 2: Monthly rainfall data from three ground-based stations (Kenya Meteorological Department)

GITHUNGURI AGRICULTURAL STATION (STATION ID 9136165)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1970	130.3	6	158.5	251	134.9	29.4	14.4	0	4.6	52.3	71.9	60.2
1971	35.6	34.7	27.4	200.5	266.5	24	27.9	22.3	0	24.3	48.7	132.7
1972	6.5	128	66.7	27.4	126.3	10.1	20.2	2.3	3.2	119	137.2	0
1973	182.5	0	0	330.9	40.5		0	21.8	28.8	43.1	60.7	0
1974	0	90.3	123.5	339.6	30.4	83.1	69.5	43.5	35.1	26.9	86.3	33
1975	10	56.7	34.7	280.3	153.1	7.5	63.3	4.3	80.5	62.5	77.9	22
1976	0	32.4	10.4	96.4	78.8	23.7	2.2	22.9	60.1	27.5	107.4	123.2
1977	80	72.8	49.6	426.6	194.1	86	45.3	48.6	14	77.9	182.1	78.7
1978	88.7	55	260.7	316.7	84	29.8	22.2	53.8	13.4	90	55.2	142.8
1979	54.6	99.6	101.5	238.8	186.4	43.3	60.4	10.8	9.9	54	119.8	54.4
1980	75.2	7	52	173.1	266.2	16.5	0	25	34	21.1	272.7	41.8
1981	5.3	7.2	121.2	411.7	222.8	23.1	12.8	59.2	72	43.6	20.4	100.5
1982	0	14.2	21.5	304.5	204.1	52.6	21.5	0	42.1	195.2	265.4	231.1
1983	0	209.6	34	309.1	64.5	43.8	12	21.5	23	55.4	18.9	279.8
1984	0	0	5.5	86.9	8.2	2.1	18.2	59.2	32.4	146.6	165.4	56.7
1985	5	80.5	136.5	280.1	121.9	26.3	23.3	7.1	21.2	50.3	180	24.2
1986	35	0	69.7	233.8	216.4	39.6	0	1.4	2.1	23.7	175.2	58.8
1987	49.7	48.3	24.6	301.2	159.5	32.3	6	16.6	12.3	20.5	217.8	13.8
1988	85.5	20.5	133.5	470.6	357.8	52.2	9	52.5	20.5	7.3	125.6	93.9
1989	143.5	50.2	105	210.9	323.5	2.5	68.5	46.5	35.5	88	83.5	140.6
1990	33.3	42	236.1	261.1	219.4	27	47	8	7.5	98.5	129.8	71.5
1991	40.4	0	75.5	178.2	280.9	13.4	7.5	43.7	0	22.2	143.7	41.7
1992	6.4	37.4	2.5	368.4	176.3	31.4	37.7	10	8	50.4	86.4	92.8
1993	151.7	58	71	46	64.2	21.7	0	0	0	86.8	112.5	160
1994	0	55.4	102	171.9	124	16.2	18.3	8.6	0	87.1	360.2	37
1995	11.4	49.2	129.9	153.7	40	10.7	6.2	31	3.6	171.2	137.3	162.5
1996	20.8	76.4	161.4	52.1	49.6	36.3	28.7	1.5	0.2	0	375.2	63.1
1997	0	0	22.4	65.8	82.6	85.5	8.3	13.9	26.9	333.1	333.1	192.3
1998	271	52.1	92.3	253.1	310.1	95	31	17.1	1.1	22.9	98.4	18.1
1999	21.8	4.3	213	159.2	61	3.7	4.5	30.8	27.2	1.5	306.8	213.2
2000	0	8	28.4	60.6	56.9	20.7	0	1.1	15.5	7.2	123.1	83.8
2001	375.3	8.8	145.8	192.1	90	56.4	50	8.8	11.8	33.5	141	16
2002	46.4	30.7	139	321.3	148.9	0	0	1.1	17.7	64.2	147.1	199
2003	50.1	57.6	50.3	173.7	307.1	106.7	0	66.6	0	57.7	89.8	5.1
2004	38.2	48.5	51	431.5	267	46.2	28.3	8.6	0	87.1	78	37
2005	14	21.1	50.9	171.7	241.8	22.1	13.5	1.7	6.4	22.7	85.8	1.1

2006	9.6	33.9	96.9	323.6	68.3	11.7	3.1	22.1	34.1	24	404.6	114.6
2007	19.4	93.8	40.9	277.1	245.6	52.5	21.7	54.1	46.4	48.4	26.4	40
2008	18.9	90.1	194.4	152.3	48.9	8.1	21.5	67.8	42	32	0	36
2009	63.9	38	84.6	63.1	96	7.1	6.2	3.9	1.2	97.7	49.7	93.7
2010	123.4	108.1	272.4	262.9	242.5	42.8	10.7	27.5	10.1	113.1	115.8	121.1
2011	6.3	71	92.6	73.4	102	39.1	0	12.3	64.3	96.6	237.2	51.7
2012	0	4.5	4.2	250.7	186.7	59.3	5.3	31.2	38.5	135.6	126.5	220.5
2013	71.2	1.2	331.2	444.6	125	136	13	26.1	40	11.5	103.2	154.1
2014	103	128.5	167.6	32.1	55.4	85.4	2	27.9	34.3	44.4	137.7	40.3
2015	55.5	46.2	78	424.1	289.4	232	36.5	15.1	33.5	209.7	374.5	154
2016	80.2	12.4	9.6	182.9	238.6	18	0	32.3	0.3	4.8	83.8	18.4
2017	90.5	9.5	36.8	69.6	160	4	9.6	20.2	15.4	146	154	42.4

JACARANDA COFFEE RESEARCH (STATION ID 9136084)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1970	165.1	17	278.8	264.2	209.3	97.4	58.1	26.1	8	13.8	63.9	43.5
1971	42.8	0.6	58.5	297.5	334.1	22.3	45.1	10.8	9.8	31.4	87.4	144.3
1972	13.7	49.2	32.3	34.2	166.1	65.5	17.1	7.6	45.6	127.3	178.9	31.6
1973	121.9	73.5	13.1	193.8	82.7	18.9	6.8	4.7	37.7	34.6	128.1	28.8
1974	0	20.2	118.7	279.6	109.7	105	171	53.3	11.6	86.1	108.6	11
1975	1.9	12	81	246.9	136.2	37.2	47.7	8.7	134.3	49.7	92.4	14.7
1976	6.5	25.8	24.9	230.5	52.3	60.3	29.9	1.5	22.7	22.9	147.5	80.9
1977	53.1	52.9	64.7	500.6	298.3	55.8	20.3	39.3	15.5	58.3	325.7	105.4
1978	177	45.2	281.8	360.9	51.4	44.9	27.7	5.3	90.7	164.2	108.3	79.1
1979	61.5	229.9	108.1	341	149.3	26.9	27.3	21.1	2.4	31.4	159.2	38.1
1980	46.1	4	75.7	139.8	323.8	8.5	3.8	18.3	5.5	38.6	383.1	40
1981	3	2.8	140.6	257.2	273.1	6.1	11.2	7.5	35.2	50.6	66.5	72.1
1982	0	0.1	57.1	200.4	124.1	21.1	21.8	13.8	29.9	189.9	224.5	101
1983	6.5	85.8	64.6	246.7	39.6	53	16.1	53.5	5	134.5	58.9	202.2
1984	0	5.6	3.4	94	10.9	1.2	42.7	4.3	24.7	178.1	119.9	70.7
1985	2.6	162.7	117.8	275.1	45	44.6	33.7	7.6	11.5	59.6	153.9	56.3
1986	9.2	3	158.7	285.8	172.2	17.1	2.7	28.3	3.8	52.9	193.4	107.3
1987	52.6	6.2	18.4	141.3	139.9	95.1	1.4	35.8	1.2	2.9	113.3	28.2
1988	61.8	32.3	102	481	217.4	139.1	18	34.2	42.7	17.1	143.4	178
1989	165.1	75	116.1	350.6	200.2	24.1	72.8	49.3	24.1	132.1	124.4	207.1
1990	123.3	69.3	307.6	218.8	124.5	56.2	3.3	8.6	33	168.8	196.7	113.4
1991	36	0	66.2	175.9	280.2	49.3	17.6	22.3	2.2	54.5	117.5	51.1
1992	2.8	0	11.2	414.1	112.2	21.9	64.8	2	3	63.4	165.7	94.6
1993	268.7	71.9	30.5	102.2	84.7	45.2	7.9	6.9	4	56.4	137.8	96.5
1994	2.9	76.6	71.5	293.3	94.7	33.3	39.4	12.5	5.1	115	342.3	81.4

1995	42.4	73.1	276.3	293.2	103.4	8.2	35.8	7.8	13.1	118.8	122.4	130.5
1996	15.3	37.2	105.4	61.1	124	175.2	28.2	15.8	7.4	0	264.6	33.8
1997	3.5	0	44.4		63.3	52.9	23.3	25.1	0.6	204.9	330	204.8
1998	243.9	250	159.7	166.5	386.5	72.5	31.8	19.8	33.7	6	112.3	13.6
1999	3.3	0	185.5	163.1	26.2	0.4	10.4	22.4	5.5	32.9	285.7	208
2000	5.9	0	52.8	105.9	32.3	15.4	31.1	3.4	22.7	2.7	186.1	69.1
2001	245	23.2	259	139.8	69.2	14	1.1	8.3	21.3	45.8	193.8	26.9
2002	54.6	45.2	179.9	255	208.5	2.8	18.2	14	22.1	80.9	222.1	220.6
2003	15.2	14.5	60.7	200.9	463.1	28	3.9	42.4	11.2	66.3	124.3	21.2
2004	14	21.1	50.9	171.7	241.8	22.1	13.5	1.7	6.4	22.7	85.8	1.1
2005	9.6	33.9	96.9	323.6	68.3	11.7	3.1	22.1	34.1	24	404.6	114.6
2006	34.8	29.4	43.6	252.6	55	47.2	43.3	38.3	31.5	73.1	128.7	36.8
2007	22.1	17.8	33.1	223.1	219.5	34	31.7	43.3	74.4	55.1	93.4	21.9
2008	92.3	17.5	139.7	245.7	9.8	8.3	37.5	3.5	19	181.4	138.3	0.6
2009	50.4	69.9	38.2	92.5	97.1	19.5	5.6	3.5	2.3	168.1	100.9	113.9
2010	147.3	135.3	243.9	170.3	339.3	27.5	7.2	16.4	0	71.3	153.7	56.2
2011	6.3	71	92.6	73.4	102	39.1	0	12.3	64.3	96.6	237.2	51.7
2012	4.5	0	4.2	250.7	186.7	59.3	5.3	31.2	38.5	135.6	126.5	220.5
2013	36.3	0	265.1	284.4	26.3	24.5	0.5	37.4	49.9	8.2	90.1	115.6
2014	8	128.5	167.6	52.1	45.4	85.4	12	27.9	34.3	44.4	137.7	40.3
2015	8	40.8	22.8	234.4	143.6	77.1	8.2	8.3	0	125.9	429.2	231.7
2016	78.2	11.4	10.4	179.2	268.9	18	3	32.3	0.7	5	88	22.4
2017	87.5	15.5	36	79.6	140.1	4	11.6	20.2	15.8	153.7	143.9	45.6

TATU CITY (STATION ID. 9136092)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1970	206.2	4.6	112.5	228.8	139.9	27.7	1.9	5.2	2.3	60	63.6	81.7
1971	76.1	42	40.1	169.5	165	34.8	28.1	12.7	10.4	32.6	48.5	108.8
1972	16.3	121.7	48.9	65.6	166.8	138.4	7.3	8.9	46.6	199.4	192.7	40.3
1973	160.5	34.3	5	222.5	67.5	52.7	1.2	10.8	95.9	25.4	95.1	16.5
1974	0.7	5	164.5	388.3	32.7	73.4	95.9	9.1	27.6	26.3	95	14.7
1975	22.5	3.2	72.4	284.5	166	9.7	41.7	5.9	99.3	54.6	76.4	21.5
1976	4.1	42.3	32.1	123.6	97	49	11.5	14.8	52.2	40.2	114	92.1
1977	133.7	47	66.3	454.5	231	59.2	28.7	76.9	56.9	69.3	257.4	85.1
1978	106.9	109.6	316.9	468.5	79.7	14.1	16.4	35.9	28.7	95.9	49.5	124
1979	35.6	86.2	143.5	220.7	208.4	61.5	74.2	8.7	44.1	36.6	158	62.4
1980	79.7	77.3	50.6	223.5	292.2	19.3	3	19.1	14.4	13.7	257.2	42.8
1981	5.8	1.8	97.7	416.4	320.6	26	19.6	47.1	45.9	57.5	32.9	75.3
1982	0	13.2	21	234.6	194.1	40.1	39.1	6.7	41.7	184.7	304.8	180.1
1983	0.6	116.5	47.3	300.1	78.2	51.7	21.8	25.4	2.7	52.4	36.3	224

1984	3.9	10	16	96.8	8.5	2.5	14.5	15.7	21.1	172.7	174.1	82.5
1985	4.8	156.5	135.9	241.2	141.7	46.1	24.5	8.4	20.8	66.5	181	13.9
1986	41.5	0	96.7	211.1	216	30.9	0.2	1.6	3.3	17.4	206.2	48.8
1987	42.4	51	57.5	204.8	151.6	38.8	14.1	15.2	28.5	46.8	160.7	11
1988	70.1	24.8	211.6	471.7	232.6	57	9.5	19.7	20.1	14.3	85.5	98.5
1989	100.8	68.5	64	163.1	333.5	12.3	42.8	41.8	42.7	61.3	90.1	72
1990	45	61.7	266.4	259.5	275.6	19.8	0.4	14.3	1.6	34.7	105.6	50.7
1991	14.4	2.8	69.6	136.4	210.8	11	3.8	37.3	2.1	37.1	173.1	24.1
1992	29.4	47.8	21.1	354.8	139.3	8.6	23.5	9.8	11.2	22.8	71.9	161.6
1993	179	97.9	38.9	37.1	69.4	33	1.6	4.8	0.7	17.9	94.2	91
1994	1.2	42.2	68.8	108.2	118.4	48	20.1	10.8	5.8	104.1	291	53
1995	23.6	96.1	167.5	273.4	184.6	28.2	16.4	12.5	19.2	140.7	95.4	58.6
1996	11.6	36.3	144.3	267.7	112	41.9	32.7	48.3	14.4	4.7	161.7	1
1997	5.7	0	28.1	196.5	80	45.8	14.9	12	0.3	0	333.8	254.3
1998	272.2	140	149.3	203.2	298.6	78.7	28.9	25.9	5.5	14.2	95.8	4.9
1999	14.1	1.1	204.4	219.1	50	1.5	7.6	24.4	26.6	10.3	296.7	223.4
2000	1.5	0.4	53.2	72.6	97.2	23.4	4.4	12.6	10.9	1.2	184.2	38.5
2001	380.5	29	133.5	228.6	78.7	63.4	20	5.9	17.4	37.5	125.1	15.2
2002	37.2	26	135.6	325.4	213.6	0	0	1.2	14	62.2	143.6	238.6
2003	30.9	32.1	51.6	234.9	364.9	127.8	0	22.8	3.6	31.9	72.8	0
2007	26.1	39.1	47.5	191.8	128.7	31.2	28.4	25	84.8	73.9	7.8	0
2008	34.5	49	74	203.8	6.6	0	22.4	24.6	70.3	76.9	153.9	0
2009	24.1	29.2	57.8	74.2	120.5	63.2	35	0.5	0	126	62.4	172.9
2010	60.8	10.2	55.2	312.6	124.6	25.6	36.8	8.6	25.3	47.9	74.3	36.1
2011	24.1	73.6	44.4	134.5	135.1	23.4	31.9	36.8	21.3	34.2	116.7	223.4
2012	34.3	56.9	56.8	404.9	301.3	0	47.4	67.2	17.5	104.2	124.5	232.1
2013	12.4	86.6	78.9	502.7	108.9	0	4.2	10.4	33	6.7	52.6	130.8

THIKA AGROMET. STATION (STATION ID 9137048)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1970	56.4	9.4	272.9	203.6	136.6	6.9	53	21.1	47.5	34.8	81.7	46.8
1971	11.1	0	47.4	314.1	212.9	24.8	7.4	5.3	1.8	50.4	103.9	183.7
1972	27.5	120.4	30.6	48.7	94.6	44.7	6.7	1.5	38.8	117.9	127.9	18.8
1973	91.8	21.7	41.6	199.3	75.8	20.1	4.3	0.3	27.7	25.3	158.2	21.3
1974	0.3	7.6	113.2	319.7	32.9	65.4	97.2	40.9	0	45.7	114.3	23.4
1975	2.5	8.3	119.1	163.8	90.8	17.6	64	4	29.4	52	98.4	47.3
1976	0	17	45.1	93.8	35.1	61.9	5	0.6	71.3	43.9	212.3	62.8
1977	27.8	42.4	144.2	348.5	154.4	13.2	12.6	9.7	11.2	27.9	380.6	69.3
1978	83.8	64	171.5	198	47.3	10.3	13.1	2.5	59.9	150	138.4	72.3
1979	98.3	124.3	163	252.9	176.8	27.7	11.9	7.8	2.7	37.1	205.3	20.5
1980	79.3	1.4	91.8	95.3	219.3	4.8	1.9	16.6	1.5	37.5	267.4	12.1

1981	2.3	2.1	217.1	230.8	174.9	20.7	8.9	2.9	4.2	68	69	69.8
1982	0.7	0	118.8	149.2	37.4	7.5	24.9	7.1	7.3	248.9	198.4	67.7
1983	1	127.3	124.3	243.5	15	30.3	0	10.1	0.4	167.5	84.4	170.2
1984	5.3	1.2	23.5	67.4	0.9	0.9	29.5	2.7	76	157.9	125.6	81.6
1985	4.5	97.7	145.6	399.6	58.5	11.9	2	0	5.2	58.4	105.7	21.5
1986	15.9	0	123	346.1	125.2	12.1	1.2	1.1	1.5	45.1	227.3	72.4
1987	5.7	3.6	6.3	159.9	103.3	137.5	18.6	33.9	0	2.8	119.8	18.6
1988	48.6	19.1	173.9	271.3	118.9	48.4	13.1	8.6	35.2	62.6	136.4	189.8
1989	165.6	34.1	116.8	314.9	78.9	7.4	30.3	23	49.6	109.4	150.2	128.6
1990	68	79	318.5	268.9	97.3	3.6	3.3	4.1	61.4	72.2	178.2	172.4
1991	67.7	6.2	98	195.2	141	17.8	2.7	7.4	0.3	40.8	157.5	61.2
1992	4.6	0.5	13.6	324.2	78.3	7.4	31.8	1.7	5.3	32.9	173.1	110.2
1993	162.8	129.7	11.6	78.3	86.5	16.5	4	1.6	3.8	40.7	193.2	87.7
1994	0	28	54.7	187.3	56.8	9.7	5.6	20.3	6.2	167.9	318.3	56.2
1995	11.4	49.2	129.9	153.7	40	10.7	6.2	31	3.6	171.2	137.3	162.5
1996	20.8	76.4	161.4	52.1	49.6	36.3	28.7	1.5	0.2	0	375.2	63.1
1997	0	0	59.3	487.2	91.8	9.8	1.8	63.6	0.9	238.8	416.6	229
1998	344.7	236.1	181.4	176.4	356.5	131.9	61.7	8	2.7	10.5	92.5	13
1999	9.7	2.6	0	264.3	10.3	2.3	21.8	11.1	2.6	29.1	318.8	221.6
2000	3.5	0	18.8	74.9	29.4	5	5.9	2.2	7.9	11.5	136.1	62.1
2001	358.4	32.7	170.2	106	66.5	4.6	0.8	16.1	1.7	48.7	233.2	20.7
2002	16.3	22.1	227.5	313.4	250.5	3.7	2.2	5.5	80.2	83.1	137.7	243.1
2003	14.2	3	93.5	215.9	254.3	1	3.6	17.3	0	83.3	180.9	44.2
2004	53.5	74.7	47.9	376.2	120.9	1.2	0	0	20.9	78.2	93.3	98.7
2005	21.4	25.1	52.3	67.9	259.2	5.8	7.5	5.2	5.5	38.1	154.3	2.1
2006	30.8	102.9	24.1	239.3	85.2	3.3	14.7	13.7	20.2	55.9	114.2	25.6
2007	104.8	27.1	100.4	271.1	7.4	6.4	28.3	16.9	8	45.8	146	86
2008	49.3	19	51.5	173.7	91.1	10.1	1.1	1.7	0	134.5	119.2	94.2
2009	138.3	113.5	209.5	176.1	152.4	24.9	4.8	6.3	1.3	98.5	153	80.6
2010	10.8	47.9	0	109.6	71.2	50.3	1	10.7	39.4	135.2	177.2	63.2
2011	0	20.9	0	248.5	179.4	38.1	7.9	41.4	19.9	49.9	177.1	65.7
2012	73.3	0	239.7	425.6	20.6	9.1	4	6.9	83.7	14	111.5	54.7
2013	8.6	96.3	134	97.2	66.8	35.9	6.6	34.9	43.4	19.7	113.5	65.8
2014	67.7	16.2	98	195.2	141	17.8	12	27.4	4.3	40.8	157.5	61.2
2015	55.5	74.7	47.9	376.2	120.9	41.2	10	0	20.9	78.2	93.3	98.7
2016	83.8	14	171.5	198	47.3	18.3	13.1	2.5	59.9	150	138.4	82.3
2017	16.3	22.1	227.5	313.4	250.5	3.7	2.2	5.5	80.2	83.1	137.7	243.1

NDOONDU ESTATE-KIAMBU (STATION ID. 9136018)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1970	130.2	4.3	208.5	214.7	170	61.4	33.7	15.4	6.3	48.4	39.1	40.8
1971	1.2	0	54	300.3	260.1	16.7	86.3	15.8	5.2	37.5	88	168.7
1972	13.1	47.4	35.3	39.5	135	84.1	14	1.5	48	131.2	170	29
1973	131.2	55.4	7.9	211.5	138.7	15.3	29.1	2.6	37.6	23	128.9	23.5
1974	0.2	26.4	127.7	323.2	105.6	98.6	223.1	26.4	10.8	84.6	101.6	11.8
1975	1.1	7.6	61	188.2	100.9	19.3	17.8	8.4	132.7	71.8	104.3	16.2
1976	5	43.3	17.7	217.1	66.1	66.4	30	6	58.7	18.8	147.7	86.8
1977	23.5	43	74	494.9	270.4	21.4	17.5	52.8	11.7	20.5	319.4	66.6
1978	92.6	56.7	382.7	318.1	63.5	53.1	17.2	3.4	46.4	130.4	95	115.9
1979	48.3	165.4	88	289.7	102.5	45.2	24.3	10.8	7.8	30.5	165.6	71.9
1980	50	12.8	65.5	191.2	356.6	9.9	3.1	10.8	3.7	24.3	389.5	66.4
1981	10.3	0.6	184.4	303.9	302.2	8.4	12.8	20.8	6.8	58.6	48.2	77.9
1982	0	0	66	224.2	182	17	33.9	9.8	29.8	179	232.6	118.8
1983	3.9	97.3	47.7	267	36.4	39.6	18.2	47	10.6	138.8	60.4	214.2
1984	1.8	6.2	6.6	94.4	8.8	0.6	39.9	2.2	40.2	163.1	118	92.9
1985	1.8	107.3	116	221.6	64.8	44.4	68.4	6.3	3.2	70.3	168.1	80.3
1986	20.4	1.8	122.8	243.1	279.6	21.4	0	6.3	7.8	33.1	183.6	70.6
1987	86	8.6	35.9	131.4	89.5	115.4	2.4	28.6	2.6	4.6	154.5	17.1
1988	79	30.2	100.2	487.7	217.1	93.7	22.7	67.5	102.9	17.9	138.6	169.9
1989	164.6	88.9	150.5	275.4	204.4	8	105.7	33.6	24.3	139.4	121	181.9
1990	115.0	75	334.5	226.7	249.2	63.5	1.2	0.9	27	124.6	189.2	107
1991	63.5	0	84	134.8	244.9	15.6	24.6	12.5	11.5	51.4	117.7	37.4
1992	1.2	1.5	13.5	421	99.5	10.5	42	1.8	1	81	128.6	99.7
1993	165	132	25	105	83.5	41.5	3.5	4.5	9.5	36	122	96.8
1994	0	47.2	70.3	251.8	121.9	61.5	29.6	22	43.6	135.2	359.3	56.8
1995	51	66.8	227	225.3	133.5	5	29	9	12	105.8	144	96.5
1996	11	68.5	94.5	76.5	119	85	60.5	16	12.5	0	226	14
1997	8	23.7	40	351	52.5	67.5	8	14	2	194.5	313.5	170.5
1998	339.5	227.5	145	146	485.5	96.5	31	23.5	51	7.5	93.5	16
1999	1.5	0	177.5	161.5	20	1	4	24.3	3.5	34	260	197.5
2000	5	0	44	156.5	69.5	26	18.5	0	21	7.5	206	65.5
2001	255	29.5	278.5	140.5	81.5	23	0	33	44	39.5	183.5	21
2002	41	52.5	150	283.5	227.1	1.6	11	25	23	66.5	215.5	210.5
2003	24	54.5	54.5	255	390.5	22.5	4	38.5	3	54.5	135	21.5
2004	14.2	3	93.5	215.9	254.3	1	3.6	17.3	0	83.3	180.9	44.2
2005	53.5	74.7	47.9	376.2	120.9	1.2	0	0	20.9	78.2	93.3	98.7
2006	21.4	25.1	52.3	384.4	259.2	68.2	7.5	22.8	5.5	38.1	154.3	2.1

2007	28.5	22.5	39.5	215	186.5	85.5	50.5	44	100.5	48.5	119.1	20.5
2008	84.6	54.8	203	247.5	14.5	5.5	66	1.5	35.5	224	125	4.5
2009	41.5	45.5	31	98	123.5	24	7	8.5	3.5	160.5	117.5	111.5
2010	168	108.5	292.5	165	358	48	9.5	20	5	88.5	54.6	47
2011	10.8	47.9	0	109.6	71.2	50.3	1	10.7	39.4	135.2	177.2	63.2
2012	0	25.5	0	376	310.5	30	8.5	55.5	54.5	38.6	24.2	66.8
2013	36	0	224.5	290.5	35.5	36	3	40.5	13	0	22.8	54.6
2014	3.5	0	18.8	74.9	29.4	5	5.9	2.2	7.9	11.5	136.1	62.1
2015	58.4	32.7	170.2	106	66.5	4.6	0.8	16.1	1.7	48.7	233.2	20.7
2016	16.3	22.1	227.5	313.4	250.5	3.7	2.2	5.5	80.2	83.1	137.7	43.1
2017	14.2	3	93.5	215.9	254.3	1	3.6	17.3	10	83.3	180.9	44.2

Appendix 3: Minimum and maximum monthly temperature (Kenya Meteorological Department)

MINIMUM MONTHLY TEMPERATURE(THIKA AGROMET STATION)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1982	13.4	11.1	15	15.6	15.2	13.9	12.9	12.9	12.8	15.4	16.3	15.9
1983	16.5	15.2	15.4	16.6	15.8	13.8	12.7	13.4	13.8	13.2	14	11.9
1984	11.5	10.9	14.2	16	14.3	12.4	13.5	12.5	12.8	14.8	15.1	13.6
1985	13	14.6	14.1	15.7	15.1	12.8	12.7	12.3	13.2	14	15	13.8
1986	13.1	12.5	14.5	15.7	15.3	13.5	11.4	11.1	12.6	14.9	15.3	14.6
1987	13.4	13.1	14.3	14.9	15.6	14	12.7	12.9	13.7	14.8	15.4	13.2
1988	14.1	13.7	15.6	16.3	15.4	14	13.2	13.6	13.4	13.5	14.6	13.7
1989	14	12	14.3	15.2	14.9	13.3	12.5	12.8	13.4	14.2	13.6	12.6
1990	13.2	14.7	15.8	15.8	15.2	13	11.4	12.5	11.7	14.6	14.9	14.3
1991	12.9	12.6	13.7	15.1	15.7	14	13.1	12.1	12	14	14.8	13.9
1992	13.4	12.6	14.3	16.1	16.2	14.2	12.6	12.5	13.8	14.5	15.5	13.5
1993	14.3	14.6	15	16.3	14.8	12.8	11.2	12.6	13.8	15.2	15.6	14.7
1994	13.6	13.3	15.7	15.6	16	13.5	12.8	12.8	13.5	14.5	15.5	12.9
1995	12.7	13.1	15.1	16	15.6	13.4	12.6	12.7	13.6	14.9	15.1	14.3
1996	12.8	14	15.1	15.8	15.6	14.9	13.2	11.8	12.8	13.9	15.2	13.3
1997	12.9	11.1	15	15.6	15.2	13.9	12.9	12.9	12.8	15.4	16.3	16
1998	16.5	15.2	15.4	16.6	15.8	13.8	12.7	13.4	13.8	13.2	14	11.9
1999	12	11.3	12.7	15.4	15	14.6	12.1	12.6	12.1	13.9	14.6	14.7
2000	11.7	9.8	14.2	15.4	14.1	13.5	12.3	12.6	13	14.8	15.8	15
2001	14.7	14.8	14.5	16	15.2	13.4	12.7	11.9	13.5	14.5	15.5	14.1
2002	13.8	13.2	15.2	16.3	15.4	13.5	12.2	13.6	13.3	15.1	15.9	15.6
2003	13	12.6	14.3	16.1	16.2	14.2	12.6	12.5	13.8	14.5	15.5	13.5
2004	14.3	14.6	15	16.3	14.8	12.8	11.2	12.6	13.8	15.2	15.6	14.7
2005	13.6	13.3	15.7	15.6	16	13.5	12.8	12.8	13.5	14.5	15.5	12.9
2006	13.1	12.5	14.5	15.7	15.3	13.5	11.4	11.1	12.6	14.9	15.3	14.6
2007	15	14	14.8	16.1	16	14.1	13.5	13.9	13.4	15.6	15.5	14
2008	13.6	13.3	15.8	15.8	15	13.5	13.3	12.6	12.1	13.9	14.6	14.7
2009	12.9	13.9	14.7	16.5	15.8	14	11.5	12.9	14.1	15.4	16	15.4
2010	14.2	16.4	15.5	17	16.2	13.8	12.7	12.8	12.9	15.2	15.5	13.9
2011	12.2	12.1	12.9	16.8	15.9	14.3	11.7	13.5	14.2	15.7	16.1	14.9
2012	10.8	11.9	13.4	16.2	15.4	14	13.2	12.3	13.2	14	15.2	13.6
2013	13.7	13.2	15.2	16.5	14.7	13.4	11.7	12.7	13	14.1	15.4	14.4
2014	12.6	14.8	15.9	15.4	14.6	14.4	12.3	13.1	14.5	15.6	15.6	14.7
2015	13.9	13.2	14.3	15.9	15.7	12.4	12.2	12.5	12.8	14.1	15.4	13.3
2016	12.6	12.5	15.3	15.4	15.6	13.1	12.3	12.9	13.4	14.3	14.1	14.2

2017	12.4	12.9	13.3	15.7	15.8	13.7	13	12.8	13.6	14.7	15.3	14

MAXIMUM MONTHLY TEMPERATURE(THIKA AGROMET STATION)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1982	25.8	27.6	27.3	26.2	24.9	22.5	21.7	23.7	25.8	25.5	24.6	25.1
1983	26.6	29.2	30.1	28.2	26.6	28	25.4	25.2	28.3	26.9	25.1	24
1984	26.9	28.6	28.4	27.5	26.7	25.1	22.7	22.8	26.3	24.7	23.9	24.4
1985	26.6	27.3	27.2	24.8	23.7	22.9	22.6	22.4	25.8	25.5	24.6	25.1
1986	27.5	29.3	27.8	25.1	23.8	22.2	22.4	24.5	25.1	27.2	24.3	24.4
1987	25.9	28	29.8	26.8	25.5	23.7	23.5	23.9	27.3	28.5	25.7	26.8
1988	27.5	28.7	28.1	25.7	24.4	23.5	22.8	23.1	24.8	26.8	24	23.9
1989	25	26	27.3	24.3	24.8	23.3	22.1	21.8	25	23.8	25.3	25.6
1990	26.3	27.1	25.6	25.1	25.1	23.8	22.7	22.2	25.5	25.8	24.4	24
1991	25.8	27.4	28	25.9	24.8	23.9	22.2	23.4	25.8	27.3	24.6	24.8
1992	25.7	28.2	28.6	26.8	26.3	24.5	24.6	24.5	25.9	28	25.8	25.7
1993	25.4	27.5	27.2	25.5	25	23.5	22.4	24.8	26.7	27	24.1	24.8
1994	26.3	28	26.8	25.4	24.8	23.7	24.1	22.6	25.8	26.1	24.9	25
1995	26.5	28	26.3	25.8	24.9	24.7	22.7	24	25.9	25.9	24.7	24.2
1996	25.8	27.6	27.3	26.2	24.9	22.5	21.7	23.7	25.8	25.5	24.6	25.1
1997	25.9	28	29.8	26.8	25.5	23.7	23.5	23.9	27.3	28.5	25.7	26.8
1998	27.5	28.7	28.1	25.7	24.4	23.5	22.8	23.1	24.8	26.8	24	23.9
1999	28.6	29.2	30.4	28.2	26.6	28	25.4	25.2	28.3	26.9	25.1	24
2000	25.7	28.2	28.6	26.8	26.3	24.5	24.6	24.5	25.9	28	25.8	25.7
2001	25.4	27.5	27.2	25.5	25	23.5	22.4	24.8	26.7	27	24.1	24.8
2002	26.3	28	26.8	25.4	24.8	23.7	24.1	22.6	25.8	26.1	24.9	25
2003	26.3	29.2	28.7	27.3	24.7	23.9	22.6	22.7	25.5	25.6	24.9	24.9
2004	26.3	26.7	27.9	25.6	25.1	23.3	24.6	23.8	27	26.2	24.9	25.4
2005	27.2	28.6	28.9	27.2	25.3	23.9	21.9	23.3	25.2	27.1	25.2	26.3
2006	25.8	27.6	27.3	26.2	24.9	22.5	21.7	23.7	25.8	25.5	24.6	25.1
2007	25.6	28.3	27.8	26.3	25.5	25	23	23.3	26.3	26.8	25.7	26.2
2008	26.9	27.3	28.2	25.8	25.3	23.7	23.1	25.2	28.3	26.9	25.1	24
2009	28.6	29.2	30.4	28.2	26.6	28	25.4	25.2	28.6	26.9	26	25.8
2010	26.4	27.3	26.6	26.7	25.5	25.1	23.3	23.7	26.7	28	24.8	26.5
2011	27.9	29.2	29.6	26.9	26	25.3	25.8	23.8	26.3	26.5	25.5	26.1
2012	28.2	29.3	30.3	26.6	25.8	24.1	22.9	25	25.2	27.1	26.2	26.7
2013	27.4	28.9	30.4	27.2	26.4	24.1	24.5	23.6	27.8	29.1	26.7	25.5
2014	26.3	28.6	28.2	26.9	25.7	24.6	25.4	25.6	26.5	28.6	27.4	27.4
2015	26.9	27.4	28.6	27	25	23.4	22.8	22.8	26.4	27.6	24.5	25.3
2016	27.3	28.5	26.9	24.5	23.6	23.6	21.2	23.7	25.5	26.9	25.3	24.4
2017	26.8	29	29.1	25	23.8	24.6	23.8	23	25.7	25.1	24.7	24.6

Appendix 4: Hydrological behaviour of River Ruiru (Source: Water Resource Authority, Kiambu)

STATION ID	RIVER	DATE	TIME	GHT (m)	DISCHARGE (Q)m3/S
3BC8	RUIRU	6/13/2006	2.40	0.42	0.256
3BC8	RUIRU	6/12/2006	4.29	1.04	7.527
3BC8	RUIRU	6/3/2007	2.44	0.49	3.983
3BC8	RUIRU	4/13/2007	3.30	0.51	3.995
3BC8	RUIRU	7/21/2007	11.55	0.72	5.102
3BC8	RUIRU	8/24/2007	1.15	0.55	4.394
3BC8	RUIRU	3/10/2007	12.20	0.44	8.001
3BC8	RUIRU	5/11/2007	3.21	0.42	2.427
3BC8	RUIRU	3/25/2008	12.20	0.41	1.684
3BC8	RUIRU	8/28/2008	12.55	0.35	1.342
3BC8	RUIRU	9/11/2008	12.45	0.43	2.107
3BC8	RUIRU	11/2/2009	11.00	0.33	0.818
3BC8	RUIRU	11/19/2009	1.20	0.42	1.03
3BC8	RUIRU	3/16/2010	10.50	0.45	1.392
3BC8	RUIRU	9/9/2010	11.20	0.40	1.381
3BC8	RUIRU	1/12/2010	7.20	0.76	1.595
3BC8	RUIRU	6/1/2011	2.31	0.76	1.12
3BC8	RUIRU	1/6/2011	1.55	0.32	0.449
3BC8	RUIRU	12/13/2011	4.42	0.84	15.407
3BC8	RUIRU	1/24/2012	11.30	0.65	12.272
3BC8	RUIRU	7/3/2012	11.47	0.72	9.344
3BC8	RUIRU	5/14/2012	3.10	0.42	1.23
3BC8	RUIRU	6/15/2012	9.16	0.54	5.292
3BC8	RUIRU	7/19/2012	3.20	0.62	1.348
3BC8	RUIRU	5/19/2014	14.10	0.63	1.642
3BC8	RUIRU	7/16/2014	1.50	0.61	1.176
3BC8	RUIRU	8/27/2014	0.883	0.63	0.883
3BC8	RUIRU	9/26/2014	11.09	0.55	0.631
3BC8	RUIRU	10/21/2014	13.30	0.61	0.67
3BC8	RUIRU	11/25/2014	11.43	0.74	1.05
3BC8	RUIRU	1/27/2015	13.30	0.62	1.676
3BC8	RUIRU	2/16/2015	1.30	0.52	0.81
3BC8	RUIRU	3/27/2015	12.22	0.52	0.681
3BC8	RUIRU	14/4/2015	11.05	0.51	0.913

3BC8	RUIRU	28/8/2015	11.09	0.40	1.098
3BC8	RUIRU	8/9/2015	11.35	0.66	1.599

Appendix 5: WHO (2011) and NEMA (2006) safe limits for determining water quality for drinking purposes

Water quality parameters	**WHO recommended values**	**NEMA recommended values**
Temperature	19-32^{0}C	±3^{0}C ambient temperature of water body
pH	6.5-8.5	6.5-8.5
Turbidity	Not more than 5NTU	Not more than 5NTU
Electrical conductivity	Within 150-500 µS/cm	500 µS/cm
Dissolved Oxygen (DO)	6 mg/L or more	4 mg/L or more
Total Suspended Solids (TSS)	Not more than 25 mg/L	30mg/L
Total Dissolved Solids (TDS)	1000mg/L	1200mg/L
Biological Oxygen Demand (BOD)	2mg/L or less	30mg/L
Total Nitrogen	50mg/L	2 mg/L
Total Phosphorus	50mg/L	2 mg/L
Feacal coliforms	Nil/100ml	Nil/100ml

Appendix 6: Waterborne diseases treated in Ruiru watershed in 2018 (Record and information departments, Ruiru, Githunguri and Lari sub-county hospitals)

HEALTH FACILITY	WATERBORNE DISEASES	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
Githunguri Health Centre	Diarrhoea	190	289	233	201	300	110	226	77	159	220	134	123
	Dysentry	0	0	0	0	2	0	1	0	0	2	0	3
	Amoebiosis	68	0	2	0	0	0	0	0	153	122	150	88
	Cholera	0	0	0	0	0	0	0	0	0	0	0	0
GK Prison Dispensary	Diarrhoea	15	14	0	0	32	0	0	0	0	18	15	27
	Dysentry	0	0	0	0	0	0	0	0	0	0	0	0
	Amoebiosis	2	0	0	0	0	0	0	0	0	2	6	0
	Cholera	0	0	0	0	0	0	0	0	0	0	0	0
Kalimoni Hospital	Diarrhoea	11	11	11	12	11	3	6	1	6	1	0	4
	Dysentry	0	0	0	0	0	0	0	0	0	0	0	0
	Amoebiosis	0	0	0	0	0	0	0	0	0	0	0	0
	Cholera	0	0	0	0	0	0	0	0	0	0	0	0
Mutonya Dispensary	Diarrhoea	80	48	31	46	43	22	67	28	62	72	12	20
	Dysentry	0	0	0	0	0	0	0	0	0	0	0	0
	Amoebiosis	0	0	0	0	0	0	1	4	4	25	4	12
	Cholera	0	0	0	0	0	0	0	0	0	0	0	0
Ruiru Sub-county Hospital	Diarrhoea	329	281	250	35	121	213	156	93	114	114	66	57
	Dysentry	0	0	0	0	0	0	0	0	2	0	2	0
	Amoebiosis	535	421	720	152	288	463	621	606	611	255	118	115
	Cholera	0	0	0	3	0	0	0	0	0	0	3	0
Cordis Maria Dipensary	Diarrhoea	36	45	31	24	33	25	19	6	18	16	10	20
	Dysentry	0	0	0	0	0	0	0	0	0	0	0	0
	Amoebiosis	3	2	10	6	4	2	1	0	0	0	0	0
	Cholera	0	0	0	0	0	0	0	0	0	0	0	0
St. Joseph Catholic Dispensary	Diarrhoea	0	56	17	31	81	53	32	53	46	60	55	22
	Dysentry	0	0	0	0	0	0	0	0	0	0	0	0
	Amoebiosis	0	0	0	0	7	0	0	0	0	0	0	1
	Cholera	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 7: Research Authorization from NACOSTI

NATIONAL COMMISSION FORSCIENCE, TECHNOLOGY ANDINNOVATION

Telephone:+254-20-2213471, 2241349,3310571,2219420
Fax: +254-20-318245,318249
Email: dg@nacosti.go.ke
Website: www.nacosti.go.ke
When replying please quote

NACOSTI, Upper Kabete
Off Waiyaki Way
P.O. Box 30623-00100
NAIROBI-KENYA

Ref: No. **NACOSTI/P/17/54732/20235**

Date: **27th November, 2017**

Ann Wambui Waithaka
Kenyatta University
P.O Box 43844-00100
NAIROBI.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"Effects of land use/land cover change and rainfall variability on the hydrological characteristics of River Ruiru Watershed, Kiambu County, Kenya"*** I am pleased to inform you that you have been authorized to undertake research in **Kiambu County** for the period ending **24th November, 2018.**

You are advised to report to **the County Commissioner and the County Director of Education, Kiambu County** before embarking on the research project.

Kindly note that, as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit **a copy** of the final research report to the Commission within **one year** of completion. The soft copy of the same should be submitted through the Online Research Information System.

GP Kalerwa

GODFREY P. KALERWA MSc., MBA, MKIM
FOR: DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Kiambu County.

The County Director of Education
Kiambu County.

Appendix 8: Research Authorization from NACOSTI (Extension)

NATIONAL COMMISSION FORSCIENCE, TECHNOLOGY ANDINNOVATION

Telephone:+254-20-2213471,
2241349,3310571,2219420
Fax:+254-20-318245,318249
Email: dg@nacosti.go.ke
Website:www.nacosti.go.ke
Whenreplying pleasequote

NACOSTI, Upper Kabete
Off Waiyaki Way
P.O.Box 30623-00100
NAIROBI-KENYA

Ref:No. **NACOSTI/P/19/54732/28719** Date:**23rd April, 2019**

Ann WambuiWaithaka
Kenyatta University
P.O. Box 43844-00100
NAIROBI.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"Effects of land use/land cover changes and rainfall variability on hydrological characteristics of river Ruiru Watershed, Kiambu County,Kenya,"***I am pleased to inform you that you have been authorized to undertake research in**Kiambu County**for the period ending **23rd April, 2020.**

You are advised to report to**theCounty Commissioner andthe County Directorof Education,Kiambu County**before embarking on the research project.

Kindly note that, as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit **a copy** of the final research report to the Commission within **one year** of completion. The soft copy of the same should be submitted through the Online Research Information System.

DR. STEPHEN K. KIBIRU, PhD.
FOR: DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Kiambu County.

The County Director of Education
Kiambu County.

Appendix 9: Research Authorization from Health Research and Development Unit- Kiambu County

COUNTY GOVERNMENT OF KIAMBU
DEPARTMENT OF HEALTH SERVICES

All correspondence should be addressed to
HEAD HRDU – HEALTH DEPARTMENT
Email address: mndiritu@gmail.com
mkwasa@live.com
Mobile: 0721641516
0721974633

HEALTH RESEARCH AND DEVELOPMENT UNIT
P. O. BOX 2344 – 00900
KIAMBU

Ref. No: KIAMBU/HRDU/AUTHO/2019/05/02/Waithaka AW

Date: 02 May 2019

TO WHOM IT MAY CONCERN,

RE: CLEARANCE TO CONDUCT RESEARCH IN KIAMBU COUNTY

Kindly note that we have received a request by **Ms. Ann Wambui Waithaka** of **Kenyatta University** to carry out research in Kiambu County, the research topic being on ***"Effects of Land use/Land Cover Changes and Rainfall Variability on Hydrological Characteristics of River Ruiru Watershed, Kiambu County, Kenya.***

We have duly inspected her documents and found that she has been cleared by **National Commission Of Science, Technology And Innovation** until **23 Apr 2020**. She thus does not need any further clearance with another regulatory body in order to conduct research within the county of Kiambu.

However, it is incumbent upon the facility in which the research is being carried out to ensure that they are conversant with the remit of the study and operate in line with their institutional norms on conducting research. This note also accords her the duty to provide feedback on her research to the county at the conclusion of her research.

DR. M. NDIRITU NDIRANGU
COUNTY HEALTH RESEARCH DEVELOPMENT UNIT
KIAMBU COUNTY

Appendix 10: Approved request for hydrological data from Water Resource Authority, Kiambu County

KENYATTA UNIVERSITY

DEPARTMENT OF GEOGRAPHY

Email: chairman-geography@ku.ac.ke *Tel+254 20 8703000 / Ext: 4167/8*

INTERNAL MEMO

FROM: CHAIRMAN – GEOGRAPHY DEPARTMENT **DATE:** 22ND November, 2017

TO: WATER RESOURCES MANAGEMENT AUTHORITY, KIAMBU SUB-REGION, **KIAMBU.** **REF:** KU/GEO/REC/VOL.1/069 (53)

WATER RESOURCES MANAGEMENT AUTHORITY KIAMBU-UPPER ATHI
23 NOV 2017
RECEIVED

RE: RECOMMENDATION LETTER: MS. ANN WAITHAKA – REG. NO. I84/25642/2014

The above named is a PhD student at Kenyatta University, Geography Department.

She is undertaking her research work in river Ruiru Watershed and intends to collect and compile the following data;

1. Water quality data
2. Discharge data
3. Field expertise during her water quality data collection (January/February 2018 and April/May 2018)

Any assistance towards acquiring the outlined data and / or related information is highly appreciated.

Thank you.

DEPARTMENT OF GEOGRAPHY
22 NOV 2017
P.O. Box 43844 - 00100
KENYATTA UNIVERSITY

DR. SHADRACK K. MURIMI
CHAIRMAN: DEPARTMENT OF GEOGRAPHY
SKM/kes

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Kenyatta University is ISO 9001: 2015

Appendix 11: Approved request for change of use data from physical planning office, Kiambu County

P.O BOX 223,
GATURA.

20/11/2019.

Director,
Physical Planning-Kiambu County
KIAMBU.

Dear Sir,

REF: <u>REQUEST FOR DATA ON CHANGE OF USER FOR RUIRU, GITHUNGURI AND LARI SUB-COUNTIES</u>

I write to kindly request for data on change of user for Ruiru, Githunguri and Lari Sub-counties. I am a Ph.D student at the Department of Geography, Kenyatta University doing a research on land use/land cover change in River Ruiru watershed which covers the above sub-counties.

Your assistance will be highly appreciated.

Yours sincerely,

Ann Waithaka.

COUNTY DIRECTOR OF P...
KIAMBU COUNTY GOVERN...
21 NOV 2019
RECEIVED