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DECLARATION AND RECOMMENDATION

DECLARATION

I declare that this thesis is my original work, and that it has not been wholly or in part presented for an award of any degree in any University known to me.

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This thesis is the candidate's original work and has been prepared with our guidance and assistance. It is presented for examination with our approval as official University Supervisors.

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ABSTRACT

River basins are vital water resources that provide sustainable fresh water for anthropogenic activities. Land use and land cover changes (LULC) in Katonga River basin have had a negative impact on the fresh water resources leading to the reduction on the quantity and flow characteristics of water. The objective of this study was to predict and model the impact of land use/cover change on streamflow in Katonga River basin using HBV model. The study examined land use change impacts on the hydrology and hence produce the potential results based on the historical changes and the future scenarios of the river basin. The use of HBV model coupled with ArcGIS for digital processing of data was applied to study the catchment characteristics and its response to hydrological changes by understanding the effect on the stream flow changes of the river. The modelling of the basin focused on hydro-meteorological for a period 1990-2018 using HBV and the Eto calculator from FAO. To evaluate the model performance calibration and validation was performed using periods (1991-1995) and (2006-2010) respectively. The Coefficient of Efficiency/ determination (R^2), model efficiency/Nash-Sutcliffe Efficiency (NSE), Kling Gupta Efficiency (KGE) were parameters considered for calibration and validation criterion. The values obtained for the Model efficiency/NSE is 0.43, Criterion coefficient R^2 0.57 and KGE 0.477 for the calibration period and 0.39, 0.41, and 0.54 respectively for the validation period. The model performance was rated satisfactory according to the NSE-criterion from the obtained calibration values for different simulations. It was concluded that streamflow trend of the basin was greatly affected by land use/ cover changes with more negative impacts evident. This study also explains the implications of extensive bad land use policies that affect catchments and therefore different strategies of ecological sound system management, watershed and development strategies are paramount for water resources management and governance.

Key words: Land use, Land Cover, Katonga River basin, Hydrological response,
Hydrological modelling, and HBV model

RÉSUMÉ

Les bassins hydrographiques sont des ressources en eau vitales qui fournissent de l'eau douce durable pour les activités anthropiques. L'utilisation des terres et les changements d'occupation des sols (LULC) dans le bassin du fleuve Katonga ont eu un impact négatif sur les ressources en eau douce, ce qui a entraîné une réduction de la quantité et des caractéristiques de débit de l'eau. L'objectif de cette étude était de prédire et de modéliser l'impact du changement d'utilisation et de couverture des terres sur le débit du bassin du fleuve Katonga en utilisant le modèle HBV, l'étude a examiné les impacts du changement d'utilisation des terres sur l'hydrologie et donc de produire les résultats potentiels basés sur les changements historiques et les scénarios futurs du bassin du fleuve. L'utilisation du modèle HBV couplé à ArcGIS pour le traitement numérique des données a été utilisée pour étudier les caractéristiques du bassin versant et sa réponse aux changements hydrologiques en comprenant les effets sur les changements du débit de la rivière. La modélisation du bassin s'est concentrée sur l'hydrométéorologie pour la période 1990-2018 en utilisant le VHB et le calculateur Eto de l'Organisation pour l'alimentation et l'agriculture. Pour évaluer la performance du modèle, l'étalonnage et la validation ont été effectués par périodes (1991-1995) et (2006-2010) respectivement. Le coefficient d'efficacité/détermination (R2), l'efficacité du modèle/efficacité de Nash Sutcliffe (NSE), l'efficacité de Kling Gupta (KGE) étaient des paramètres considérés pour l'étalonnage et la validation. Les valeurs obtenues pour l'efficacité du modèle/NSE sont 0,43, le coefficient de critère R 2 0,57 et KGE 0,477 pour la période d'étalonnage et 0,39, 0,41 et 0,54 respectivement pour la période de validation. La performance du modèle a été jugée satisfaisante selon le critère NSE à partir des valeurs d'étalonnage obtenues pour différentes simulations. On a conclu que la tendance du débit du bassin a été grandement influencée par les changements dans l'utilisation et la couverture des terres, avec des impacts plus négatifs évidents. Cette étude explique également les implications des mauvaises politiques d'utilisation extensive des terres qui affectent les bassins versants et, par conséquent, les différentes stratégies de gestion écologique rationnelle des systèmes, de gestion des bassins versants et de développement sont primordiales pour la gestion des ressources en eau et la gouvernance.

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Dedication

This thesis research is dedicated to my family, my supervisors, my friends for the continued support and encouragement.

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List of Abbreviations

Abbreviation	**Description**
DEM	Digital Elevation Model
ET	Evapotranspiration
HBV	Hydrologiska Byråns Vattenbalansavdelning
HRU	Hydrologic Response Unit
LULC	Land Use and Land Cover
MIKE SHE	Systeme Hydrologique European
NSE	Nash–Sutcliffe model Efficiency
PET	Potential Evapotranspiration
RMSE	Root Mean Square Error
SPI	Standardized Precipitation Index
SWAT	Soil Water Assessment Tool
SWM	Stanford Watershed Model IV
SWRM	Sustainable Water Resource Management
UNMA	Uganda National Meteorological Authority
VIC	Variable Infiltration Capacity

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CHAPTER ONE

INTRODUCTION

1.1 Background Information

Most African countries have very limited renewable water resources with the continent having about 9%, which translates to 3931 km^3/year of water. Of the continent's renewable water resources, 72 % is concentrated in central Africa and western regions along the Gulf of Guinea, where 34 % of the population lives (McClain, 2013). Sustainable development in Africa is dependent on increasing use of the continent's water resources without significantly degrading ecosystem services that are also fundamental to human wellbeing. The need for greater use of water resources is paramount, as development across much of Africa over the last half century has lagged far behind that of the rest of the world (Arthington *et al*., 2010). Most of the river basins in Africa face serious degradation (Cook *et al.,* 2009). River catchment degradation is of concern in contemporary river basin management in tropical systems (Abell *et al*., 2008). This degradation is driven by increasing population pressure, which place a heavy burden on natural resources (Mosepele *et al*., 2018). The Katonga River basin is a potential water resource for the development of the central region in Uganda. Therefore, there is need to ensure that the water resources of this system is managed effectively to ensure water sustainability in the basin.

According to Refsgaard and Andersen (2007) scarcity and misuse of fresh water resources pose a serious and growing threat to sustainable development and protection of the environment. Human health and welfare, food security, industrial development and the ecosystems on which they depend, are all at risk, unless water and land resources are managed more effectively in the present decade and beyond than they have been in the past (Conway *et al*., 2005) . Water remains the most important natural resource in water stressed countries (less than 1700 m^3/capita per year of water availability) (Parish *et al*., 2012). Its availability and demand have been affected by a number of factors such as high population growth, irregular rainfall, excessive land use change and increasing vulnerability to risks such as drought, desertification and pollution (Hosseini and Ashraf, 2013).

According to Kumar (2012) managing water resources is mostly required at watershed scale given that it forms the basic hydrologic unit which can be studied with the heterogeneity and complexity of processes and interactions linking land surface, climatic factors and human activities. Due to land use and land cover (LULC) changes, different studies have been conducted using various hydrological models in determining parameters for a given sub basin, water shed, catchment and other hydrologic units in a given environments (Devia *et al*., 2015).

According to Gyamfi *et al*. (2016) the limited accessible freshwater, is found mainly in lakes, rivers, wetlands and soil moisture, but this is however under pressure as a result of human-induced activities. Rivers are particularly vulnerable to land use and land cover changes. This is due to the influence of climatic variables such as precipitation, evaporation, subsurface water flow and wind conditions within river basins and the environment. A number of studies have focused on the impacts of LULC on the hydrologic systems in given watersheds (Roosmalen *et al*.,2009; Yan *et al*., 2013; Bosmans *et al*., 2017). Hydrologic modelling and spatial mapping of LULC impacts on hydrology therefore present a useful means of watershed water resources assessment, that will lead to the formulation and hence enhancement of policy directives (Wang *et al*., 2018).

1.2 Statement of the Problem

Uganda has surface fresh water sources such as lakes, rivers and swamps that constitute 41743.2 km^2 of area, with about 16% of the total land area of wetlands, plus the annual water supply of 66 km^3 in form of rain and inflows (Nsubuga *et al*., 2014). Most of the anthropogenic activities in the country depend on the fresh water sources which are supplied from the lakes and rivers in various regions. But due to land use and land cover changes the hydrological cycle has been interrupted greatly because of human activities such as deforestation, increase in built up areas, more cultivated lands and several other land use changes. The changing use of land from sustainable to unscientific agriculture, overgrazing, and unlimited forests exploitation is pointedly shifting the hydrologic characteristics of the Katonga River basin. Katonga River basin is a water sanctuary to several wild life animals and also a survival means for different people living around the basin. Despite several studies both regionally and nationally which have distinctly evaluated the hydrologic responses to anthropogenic activities and related changes across several river basins, very limited interventions have been put in place to predict the streamflow changes in the Katonga River basin. The continued reduction in the river flows will not only affect the wild life but also the productivity of the people involved in different activities around the watershed (Jansen and Di Gregorio, 2003). Through application of hydrological models such as HBV water resources managers, planners and government authorities to be able to monitor and devise means to protect and maintain the watershed for sustainable use by the people. Therefore, understanding the impact of LULC on streamflow within Katonga River basin by predicting the changes of stream flow was to help in finding results for better informed decision making. Thorough understanding of how these hydrological responses under changing LULC within the river basin is very vital for Sustainable Water Resources Management (SWRM).

1.3 Main Objective

The main objective of this study was to predict and model the impact of land use/cover change on streamflow in Katonga River basin using HBV model.

1.3.1 Specific Objectives

The specific objectives were:

i. To identify/investigate the land use and land cover changes within the Katonga River basin from 1990 to 2018.
ii. To determine the impact of LULC on the streamflow trend of the River Katonga from 1990 to 2018 and
iii. To predict streamflow changes of the river basin using future land use and land cover change scenarios derived from HBV model for the period 2020 to 2040.

1.4 Research Questions

i. To what extent has the land use and land cover change occurred in Katonga River basin?

ii. How did the land use and land cover changes impact on the stream flow of River Katonga?
iii. How was the stream flow affected by future continuous land use and land cover changes of the river basin?

1.5 Justification

According to Gyamfi *et al*. (2016) the Land use and land cover (LULC) is an essential component of the terrestrial ecosystem, influencing various fundamental characteristics and processes such as the hydrological cycle, geomorphological processes, land productivity and animal species. These have been degraded by anthropogenic activities and therefore the changes have affected mostly the fresh water resources which are essential to maintaining the hydrological cycle and maintaining the biodiversity of the environment. Since changes in the LULC directly alter the hydrological systems, which also directly influences the interception, evapotranspiration (ET), infiltration, soil moisture, water balance and biogeochemical cycling of carbon, nitrogen and other elements at regional to global scales (Yan *et al*., 2013). This therefore calls upon the water resources managers to formulate mechanism aimed at protecting and nourishing the water resources in order to minimize degradations as a result of land use/land cover changes. According to Kumar (2012) hydrological models, can be used to link model parameters to physically measurable catchment parameters to assess impacts of land use changes on hydrological response of river basins. Models are used to represent the real-world system where robust models give results close to river basins (Johnston and Smakhtin, 2014). Some model even with the use of the least parameters could be used to model complex river basins and still realise the expected results (Devia *et al*., 2015). Application of hydrological models is one the available tools to forecast and predict the quantity and quality of water for planners, decision makers and policy makers (Tessema, 2011). Therefore, this study was established in order to understand how the streamflow of River Katonga basin in Uganda is affected by Land use/cover changes over the years. The study was also about the prediction of the river basin hydrological response based on future land use/cover changes.

1.6 Scope and Limitations

The study was only focusing on the contribution of the LULC to the river streamflow changes in Katonga River basin. Although there is a likelihood of the contribution of the impact of climate change on the streamflow regime, the study was not determining the effect of climate change on streamflow changes. The study was only using one hydrological model in the determination of the impact of land use/cover change on the streamflow. However, the study did not compared results of other hydrological model with other models that may have been used in similar studies. This study focused on precipitation, temperature, discharge evapotranspiration, land use patterns and streamflow of the river basin as the main parameters.

CHAPTER TWO

LITERATURE REVIEW

2.1 Hydrological Response to Land Use/Cover

According to Yang *et al*. (2014) land use and land cover (LULC) changes contribute to changes in energy, hydrological and biogeochemical cycles of the earth's system, thereby leading to climate and ecosystem change, which affects the ability of biological systems to support human needs. Understanding how changes in individual land use types and cover influence the dynamics of streamflow is paramount (Gashaw *et al*., 2018). This is important because these hydrological alterations lead to degradation of forest land which is one of the major contributors to the hydrological cycle modulation. LULC is a key factor that affects runoff, evapotranspiration, streamflow and soil erosion characteristics of a given river basin (Mutua *et al*., 2011; Gyamfi *et al*., 2016). To understand how LULC affects and interacts with global earth systems, information is needed on what changes occur, where and when they occur, the rates at which they occur, and the social and physical forces that drive these changes (Aduah *et al*., 2017).

2.2 Effects of LULC of River Basin Stream Flow

According to Tessema (2011) many factors were compared to the direct effect of precipitation and how land use changes affect hydrologic processes which is explained primarily through two mechanisms: its link with the evapotranspiration regime and the degree and type of ground cover, which has an enormous impact on the initiation of surface streamflow. The provision of water resources is closely related to the hydrological processes, while land use/cover changes are considered as the two major factors that affect the hydrological processes in the basins as stated by Li *et al.* (2015). Many studies have investigated the effects of LULCs' on hydrological processes varies in different geographical regions as described by Bosmans *et al*. (2017) and Wang *et al*. (2018). The study examined the hydrological response of an entire basin, which was based mainly on a hydrological model with a focus on how LULC have affected the streamflow of the rivers within the basin.

2.2.1 Response of Streamflow due to Land Use Changes

One requirement for the evaluation of the impacts of predicted changes in land use/cover on streamflow is application of one land use scenario or more and more physical land descriptions (Mwangi *et al*., 2017). Streamflow levels of a given river in a basin can be greatly influenced by several factors like increased urbanization, agricultural practices, forests and other land use activities. In addition, the natural streamflow of a river can be simulated under the influence of both climate and land use change using the meteorological data of the time period in a particular basin as described by (Shang *et al*., 2019).

2.3 Hydrological Modelling

According to Sorooshian *et al*. (2008) a model is a simplified representation of real-world system. The best model is the one which give results close to reality with the use of least parameters and model complexity. Models are mainly used for predicting system behavior and understanding various hydrological processes (Abdulkareem and Jamil, 2018). A model consists of various parameters that define the characteristics of the particular model. A runoff model can be defined as a set of equations that helps in the estimation of runoff as a function of various parameters used for describing watershed characteristics. Some of the important inputs required for all models are rainfall data and drainage area. Along with these model inputs, watershed characteristics such as soil properties, vegetation cover, watershed topography, soil moisture content, characteristics of ground water aquifer are also considered (Yang *et al*., 2014). Hydrological models are nowadays considered as important and necessary tool for water and environment resources management (Loucks and van Beek, 2017).

2.4 Model Classification

Rainfall-runoff models are classified based on model input and parameters and the extent of physical principles applied in the model. These models can be classified as lumped and distributed models based on their parameters as a function of space and time. Rainfall runoff models can be classified as deterministic and stochastic models.

Deterministic models give same output for a single set of input values whereas in stochastic models, different values of output can be produced for a single set of inputs. According to (Devia *et al*., 2015) in lumped models, the entire river basin is taken as a single unit where spatial variability is disregarded and hence the outputs are generated without considering the spatial processes. On the other hand, a distributed model can make predictions that are distributed in space by dividing the entire catchment in to small units, usually square cells or triangulated irregular network, so that the parameters, inputs and outputs can vary spatially.

Models are classified as static and dynamic models based on time factor. static models present information that does not change with time while the dynamic one change over time. Models can also be classified as event and continuous (Almeida *et al*., 2018). The former one produces output only for specific time periods while the latter produces a continuous output. One of the most important classifications is empirical model, conceptual models and physically based models.

2.4.1 Empirical Models

These are observation-oriented models which take only the information from the existing data without considering the features and processes of hydrological system and hence these models are also called data driven models. It involves mathematical equations derived from concurrent input and output time series and not from the physical processes of the catchment. These models are valid only within the boundaries (Bardossy, 2008). The unit hydrograph is an example of empirical model (Maskey, 2004). Statistically based methods use regression and correlation models and are used to find the functional relationship between inputs and outputs. Artificial neural network and fuzzy regression are some of the machine learning techniques used in hydro informatics methods.

2.4.2 Conceptual Models

The class of models describes all of the components of the hydrological processes. A conceptual model consists of a number of interconnected reservoirs which represents the physical elements in a catchment in which such a catchment is recharged by rainfall, infiltration and percolation and is emptied by evaporation, runoff, drainage and many more. Semi empirical equations are used in this method and the model parameters are assessed not only from field data but also through calibration. A large number of meteorological and hydrological records is required for calibration. The calibration involves curve fitting which makes the interpretation difficult and hence the effect of land use change cannot be predicted with much confidence. Many conceptual models have been developed with varying degree of complexity. Stanford Watershed Model IV (SWM) is the first major conceptual model developed by Crawford and Linsley in 1966 and where between 16 and 20 parameters were used.

2.4.3 Physically Based Models

These are mathematically idealized representations of the real phenomenon. These are also called mechanistic models that include the principles of physical processes. These models use state variables which are measurable and are functions of both time and space. The hydrological processes of water movement are represented by finite difference equations. It does not require extensive hydrological and meteorological data for their calibration but the evaluation of the large number of parameters describing the physical characteristics of the catchment are required (Abbott *et al*., 1986). In this method huge amount of data such as soil moisture content, initial water depth, topography, topology and dimensions of river network are required. Physically based models can overcome many defects of the other two models because of the use of parameters having physical interpretation. The physically based models can provide large amount of information even outside the boundary and can be applied in a wide range of situations. SHE/ MIKE SHE (Systeme Hydrologique European) model is an example (Ma *et al*., 2016).

2.4.4 Deterministic Models

A deterministic model is one in which the values for the dependent variables of the system are completely determined by the parameters of the model. Also (Leenders and Tuszynski, 2013) states that deterministic models have the advantage of often being amenable to mathematical analysis, as in the case of using ordinary differential equations to model the geographic spread of infectious disease within human populations. Simulation of these models through parameter and input adjustment can provide important insights into the quantitative and qualitative features of epidemics. The mathematical clarity offered by deterministic models can, however, come at a cost of decreased realism. Because of this, most of the mathematical modeling done in human geography is stochastic (Devia *et al*., 2015).

2.5 Commonly used Hydrological Models

A hydrological model is a simplified mathematical representation of these processes involved in precipitation-runoff transformation at the catchment scale (Devia *et al*., 2015). The best model is the one which give results close to reality with the use of least parameters and model complexity (Mwangi *et al*., 2017). Models are mainly used for predicting system behaviour and understanding various hydrological processes (Cheng *et al*., 2017). Hydrological models are now a day considered as an important and necessary tool for water and environment resource management.

2.5.1 Soil and Water Assessment Tool (SWAT) Model

The Soil Water Assessment Tool (SWAT) model is a robust and efficient in performing long term simulations (Gashaw *et al*., 2018). The model breaks the entire catchment into sub catchments which are further divided into Hydrologic Response Units (HRU). In addition, the model uses other parameters that include land use, vegetation and soil characteristics as its inputs (Muthuwatta *et al*., 2018). The daily rainfall data, maximum and minimum air temperature, solar radiation, relative air humidity and wind speed are the other inputs used by this model. The model is able to describe water and sediment circulation, vegetation growth and nutrients circulation. Based on the amount of precipitation and mean daily air temperature, the rate of snowfall can be determined. Penman Monteith, Priestly- Taylor and Hargreaves methods are used to estimate evapotranspiration. In addition, in order to obtain accurate forecasting of water, nutrient and sediment circulation, it is necessary to simulate hydrologic cycle which integrates overall water circulation in the catchment area and hence the SWAT model uses the following water balance equation in the catchment (Devi *et al*., 2015).

$$SW_t = SW_o + \sum_{i=1}^{t} \left(Rv - Qs - Wseepage - ET - Qgw \right) \tag{2.1}$$

Where:

SW_t = humidity of the soil

SW_o = base humidity

R_v = rainfall volume in mm water

Q_s = surface runoff

$W_{seepage}$ = water from the soil to underlying layers

ET = Evapotranspiration

Q_{gw} = ground water runoff and t is time in days

2.5.2 MIKE SHE Model (Systeme Hydrologique European)

MIKE SHE is physically based model was developed in 1990 by the Institute of Hydrology (the United Kingdom), SOGREAH (France) and DHI (Denmark). The model thus requires extensive physical parameters as its inputs. The model accounts for various processes of hydrological cycle such as precipitation, evapotranspiration, interception, river flow, saturated ground water flow, and unsaturated ground water flow. It can simulate surface and ground water movement, their interactions, sediment, nutrient and pesticide transport in the model area and various water quality problems and can be applied for large watersheds. The model was first used by Kristensen and Jensen (1975) as a method for estimating evapotranspiration. The full details and manual of MIKE SHE code are given in the user's guide (DHI-WE, 2005). According Storm (1990), they provided the detailed description of the structure and set up of the model. The code involves pre-processing and post processing modules and has various options for displaying results.

2.5.3 TOPMODEL

The TOP model is a semi distributed conceptual rainfall runoff model that takes the advantage of topographic information related to runoff generation. But according to Beven and Kirby (1979), Beven *et al*. (1986), the TOPMODEL is considered as a physically based model as its parameters can be theoretically measured. In other words, it can be defined as a variable contributing area conceptual model. It can be used in single or multiple sub catchments using gridded elevation data for the catchment area. It helps in the prediction of hydrological behavior of basins. The major factors considered in its application include; catchment topography and soil transmissivity. The main aim is to compute storage deficit or water table depth at any location. The storage deficit value is a function of topographic index of the form (a/tanβ) (Beven, 1986).

From the index **a** is the drained area per unit contour length while *tanβ* is the slope of the ground surface at the location. Since the index is based on basin topography, the model gives calculations only for representative values of indices. It is obtained by manual analysis of contour maps. The model uses exponential Green-Ampt method of Beven (1984) for calculating runoff and it is advised to reduce the number of parameters. The output will be in the form of area maps or simulated hydrographs.

2.5.4 Variable Infiltration Capacity (VIC Model).

The Variable Infiltration Capacity (VIC) is a semi distributed grid based hydrological model which uses both energy and water balance equations (Abdulkareem *et al*., 2018). The main inputs are precipitation; minimum and maximum daily temperature and wind speed. The model allows many land covers types within each model grid as part of its inputs. The processes such as infiltration, runoff and base flow are based on various empirical relations. Surface runoff is generated by infiltration excess runoff (Hortonian flow) and saturation excess runoff (Dunne flow). The VIC model simulates saturated excess runoff by considering soil heterogeneity and precipitation. It consists of 3 layers; where the top layer allows quick soil evaporation, middle layer represents dynamic response of soil to rainfall events and the lower layer is used to characterise the behaviour of soil moisture. Improvised VIC model has included both infiltration excess runoff and saturated excess runoff. In addition, it also includes the effects of variability of soil heterogeneity on surface runoff characteristics. It can deal with the dynamics of surface and ground water interactions and calculate ground water table (Ebrahim *et al*., 2019) and can be applied in cold climate. The model is nowadays applied to a number of river basins and helps in predicting climate and land cover changes over the study area.

2.5.5 Hydrologiska Byråns Vattenbalansavdelning (HBV) Model

The HBV model was originally developed at the Swedish Meteorological and Hydrological Institute (SMHI) in Norrköping, Sweden (Bergström, 1992). After twenty years, the HBV model has become a standard tool for runoff simulations in the Nordic countries (Dakhlaou *et al*., 2012), and the number of applications in other countries is growing. According to the study conducted by Yan *et al*. (2013), it was found out many hydrological models have been developed over the recent years to help in simulating the catchment parameters for the desired hydrological output. The HBV model approach has since the early days been approved as flexible and robust model in solving water resource problems and applications especially in hydrological modelling. This method has been widely used in the Nordic countries in Europe and it has proved to produce good results. Hydrological components of the basin are examined and analysed so as to understand their direct impact on the streamflow changes of the river (Hyandye *et al*., 2018).

It is characterised as a conceptual model (Bergström, 1992). The aim of the first operational applications of the HBV model was hydrological forecasting for given watershed or catchment (SMHI., 2015). According to (Bardossy, 2008), the HBV model is a rainfall-runoff model, which includes conceptual numerical descriptions of hydrological processes at the catchment scale. The model is based general water balance given as;

$$P - E - Q = \frac{d}{dt}\left[SP + SM + UZ + LZ + L/R\right] \tag{2.2}$$

Where:

P = precipitation
E = evapotranspiration
Q = runoff
SP = snow pack
SM = soil moisture
UZ = upper groundwater zone
LZ = lower groundwater zone
L/R = Lake volume and River is River volume.

In general, rainfall-runoff models are the standard tools used for investigating hydrological processes. A large number of models with different applications ranges from small catchments to global models have been developed. Each of these models discussed has its own advantages, disadvantages, application, and limitations of use in terms of assessing and analyzing hydrological process.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

The River basin is located in the topography of 1500-2500 metres above sea level in south west side and 1100 metres above sea level towards Lake Victoria. The maximum temperature ranges from 28.6 to 28.7^{0}C and with corresponding minimum temperature of 18.2^{0}C in the River basin while the mean annual rainfall ranges between 900 and 1500 millimeters, with highest amounts around the Lake Victoria region. The River basin is located within the South-western side stretching to the central part of Uganda and it is continuous between Lake George and Lake Victoria.

The Katonga River basin enters into Lake Victoria at position close to Lukaya in the district of Kalungu at geographical coordinates 0°07.3'S 31°54.8'E whereas its western section that empties into Lake George is close to Mpanga in the district of Kamwenge geographical coordinates of 0°02.6'N 30°17.4'E. The river basin has the surrounding wetlands located at approximately 0°13’N 30°39’E close to the Katonga Wildlife Reserve and at a distance of over 120 kilometers from Lake Victoria. Interestingly, the water levels always rise in the marshlands watersheds in the rainy season and sometimes push some waters to flow to the west sides from the watershed before draining into Lake George.This River drains through a number of Districts that include Ibanda, Sembabule, Mpigi, Bukomansimbi, Kalungu, Gomba, Mubende, Kiruhura, kyegegwa and Kamwenge along its main course. The Katonga River basin is directly linked to Lake Victoria which is also connected to River Nile. In case of any streamflow changes in Katonga will automatically affect the levels in the Lake Victoria and hence direct effect on the flow of streamflow of River Nile.

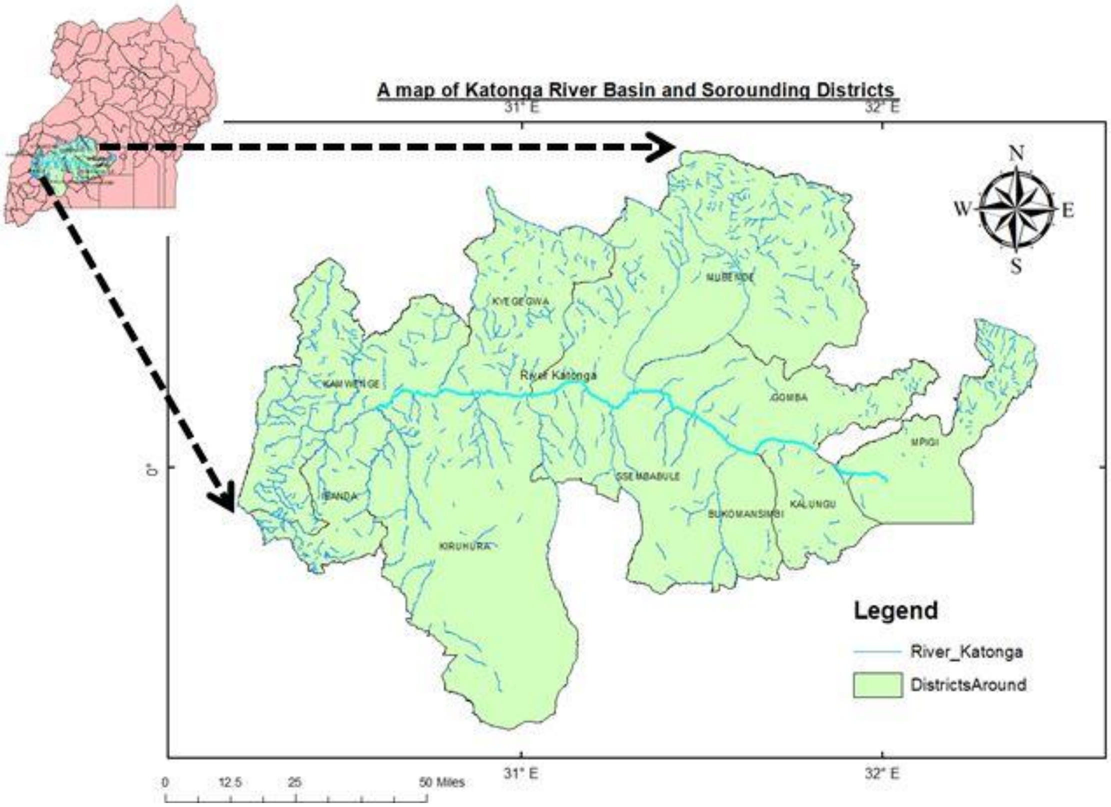

Figure 3.1: A map showing the study area

This magnificent river is known to measure up to 220 kilometers and popular for the phenomenal beauty that surrounds it. The vegetation around River Katonga is characterized by mainly savannah dotted with acacia shrubs and woodlands. The largest part of Katonga Reserve is made up of either seasonal or permanent wetlands. Nonetheless, there are also pockets of Riverine and luxuriant tropical rainforest.

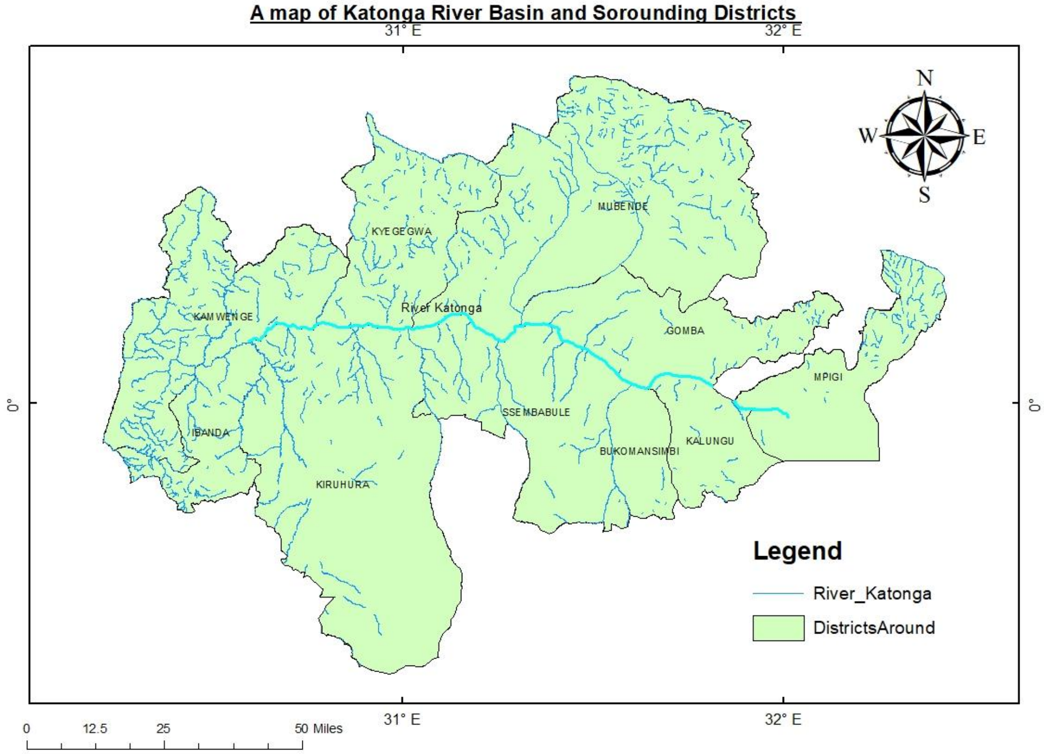

Figure 3.2:A map showing the River Katonga Basin

3.1.1 Data collection

The data used was from the national Uganda National Meteorological Authority (UNMA) which is the Department of Meteorology under Ministry of Water and Environment and it is classified as semi-autonomous government authority for weather and climate services (UNMA Act. 2012) and a focal institution to Inter-Governmental Panel on Climate Change (IPCC), an international body mandated to carryout scientific research on climate change.

The data used was daily recorded precipitation, temperatures and stream flow of the River Katonga from the stations around the area of study. The data used was for 28 years from 1990-2018. The Shuttle Radar Topography Mission (SRTM) 3-second digital elevation model (DEM) was used to represent the topography of the study area. The LULC data was from two Landsat images (Landsat5 TM images (2000) and Landsat 5 TM images (2014)). The LULC data was collected from the department of survey and mappings which is under the Ministry of lands, Housing and Urban development. The department is responsible for the establishment of survey and geodetic controls, quality checks of cadastral jobs, survey of government land and international boundaries, production and printing of topographical maps. The Department is also responsible for producing a National Atlas. The shape files for vegetation types, rivers, watersheds, district boundaries and all other information related to land used/cover was provided by the department.

3.2 Determination of Land Use and Land Cover Change in the Katonga River Basin

The LULC data used was categorized and analyzed as described in the following sections.

3.2.1 Mapping Land Use

The analysis LULC as observed and spread within the river basin emphasizing more on land use and landcover change of the watershed with a view of understanding changing trends during the period from 1990 to 2015. By studying the detailed land use/cover changes in the basin was to help in reclassification and then comparison of past and existing LULC for better assessment. Also studying and mapping the LULC did help in thorough understanding of anthropological factors (reforestation, cultivated land, deforestation, fires, urbanization among others. The main objective of the land use was to link the land use and landcover changes to the flood hydrographs which were used in estimating the river streamflow. ArcGIS software was used for digitization, integration, overlaying and presentation of spatial and non-spatial extent of the LULC.

3.2.2 Land Classification for period 1990-2015

The hybrid DEM Landsat images of previous years (2000 and 2014) of Katonga River basin were got from the depart of surveying and mapping at the ministry of lands, housing and urban planning which were to classify the land use and cover changes of the selected particular years. The land classification was done in the following categories; closed grassland, closed shrub land, dense natural forest, dense woodland, moderate natural forest, moderate woodland, open grassland, open shrub land, perennial commercial cropland, settlement, subsistence cropland, wetland and water body of the river basin.

3.3 Determination of impact of LULC on Streamflow trends

After land classification of the listed periods for both past and future, the analysis of the main river basin parameters was performed for the catchment. The dynamic data required such as precipitation, evapotranspiration, temperature, topography of the areas and then discharge was collected from the Uganda National Meteorology Authority (UNMA). The main static data used was Digital Elevation Model, Land cover maps, Soil maps, position of the rain gauges and Position of hydrological stations.

3.3.1 Hydro-meteorological Data Input

This was data required for helping in simulation of the river basin hydrological characteristics as stated in the requirements. The meteorological data which was used was obtained from Uganda National Meteorology Authority (UNMA). The data was portioned into two sets, one calibration and the other for validation before using the model for simulation of other land use/cover scenarios.

3.3.2 Rainfall Data Input

The rainfall forecast data of given Landsat DEM's will be transformed into estimated runoff by a simplified lumped model in limited outputs of the catchment. The rainfall was spatially averaged in the sub-basins and hydrographs were simulated at the output of each sub-basin. The rainfall data obtained from the national meteorological station was calibrated using data from the available rain gauge stations in or near the river basin. During the incidences of missing rainfall data, interpolation on measured daily mean rainfall from weather stations within and outside the area of study was created. Using the hydrological water balance equation, the actual rainfall amount was determined from the HBV general Equation 2.1.

3.3.3 Evapotranspiration

A series of average potential évapo-transpiration (PET) data for the entire basin was calculated by Eto Calculator from The Food and Agriculture Organization (FAO) using the calculation procedures Potential Evapotranspiration (PET) and also using Thornthwaite method, the Monthly Thorthwaite Heat Index (i) calculation is required, using the following formula:

$$i = \left(\frac{t}{5}\right)^{1.514} \tag{3.3}$$

Where:

T = mean monthly temperature (^{0}C)

The Annual Heat Index (I) is calculated, as the sum of the Monthly Heat Indices (i):

$$I = \sum_{i=1}^{12} i \tag{3.4}$$

Potential Evapotranspiration (PET) estimation was also obtained for daily values, considering a month is 30 days and 12 theoretical sunshine hours per day by using the following equation:

$$PET_{noncorrected} = 16 \times \left(\frac{10 \times t}{I}\right)^{\alpha} \tag{3.5}$$

Where α is

$$\alpha = 675 \times 10^{-9} \times I^{3} - 771 \times 10^{-7} + 1792 \times 10^{-5} \times I + 0.49239 \tag{3.6}$$

The values obtained were later according to the real length of the month and the theoretical sunshine hours for the latitude of interest, using the equation:

$$PET = PET_{noncorrected} \times \frac{N}{12} \times \frac{d}{30} \tag{3.7}$$

Where:

N: are the theoretical sunshine hours for each month and d number of days for each month.

3.3.4 Temperature Data

Weather data including minimum and maximum daily temperature ranges were generated from within and closest neighboring weather stations all around the basin from Global Weather Data which was set up the UNMA.

3.4 Predicting Streamflow based on the formulated Land Use and Land Cover changes scenarios 2020 to 2040

In this study other software and tools necessary or equivalent in terms of were outsourced and used in the analysis and assessment of data of the river basin. The runoff records for different land use/cover type scenarios were analyzed and runoff predicted. The land use/cover scenarios included: Pasture Land (Natural vegetation), Cultivated lands (farm lands) and Built up areas (settlement areas). The choice of these scenarios was justified by the fact that this area is characterized by tropical climate along the equator. Therefore, it has natural vegetation and this has substantially faced degrading due to anthropogenic activities.

3.4.1 Estimating Runoff

After obtaining the values of the precipitation, evapotranspiration, temperature and soil moisture retention capacity, then the expected runoff of each land use period will be determined from the Curve Number (CN) method. This method estimates the runoff or rainfall excess (in mm/cm depth) by the relation given as;

$$Q = \left(\frac{(P - 0.2S)^2}{(P + 0.8S)} \right) \tag{3.8}$$

For $P \succ 0.2S$

Where:

Q = runoff in mm

P = precipitation in mm

S = maximum water retention parameter given as;

$$S = \left(\frac{25400}{CN} \right) - 254 \tag{3.9}$$

Where:

CN = Curve Number which determined from the combination of Soil Hydrologic Group (HSG) and land use/cover.

The values will be obtained from Soil Conservation Services (SCS) which is classified based on land use/cover types and hydrological soils groups

3.5 Selection of HBV Model

The HBV model was developed by Sten Bergström as conceptual model of runoff simulation which has simple structure. The model is semi-distributed and it allows the division of catchment into sub basins, elevations and vegetation zones.

This HBV model is easy to understand, learn and apply because it has been applied in Sweden and Nordic countries (Seibert, 1998). It has provided good results in its application. It has become a standard tool for runoff studies in Nordic countries with moderate needs of input requirement data and it can be used partly in other models (Bergström, 1992).

3.6 Model calibration

According to Bergström, (1992 and 2006); SMHI., (2015) the HBV model is sensitive to calibration of parameters and therefore the model was calibrated by a manual procedure and several sets of the model were changed during calibration process until an acceptable agreement with observations was obtained. The river was not sub-divided into basins in order to compute order of the streamflow, so downstream basins were not directly required to computed data from the upstream ones. As a result, the calibration was made as a single catchment which was more user friendly. The catchment was treated as natural stream and flow of the river remained as the natural phenomena.

Also, the three main criteria of fit were used. These were including visual inspection of the expected computed and observed hydrograph, use of the Root Mean Square Error (RMSE), Nash-Sutcliffe Efficiency (NSE), coefficient of determination criterion (R^2) and Kling-Gupta Efficiency (KGE). The above statistical parameters are described below.

3.6.1 Root Mean Square Error (RMSE)

Root Mean Square Error (RMSE) is the standard deviation of the residuals (prediction errors). Residuals are a measure of how far from the regression line data points are; RMSE is a measure of how spread out these residuals are. In other words, it tells you how concentrated the data is around the line of best fit. Root mean square error is commonly used in climatology, forecasting, and regression analysis to verify experimental results. This was used in determining the standardized observations and forecasts which were used as RMSE inputs in the HBV model; this creates a direct relationship with the correlation coefficient.

The formula is:

$$RMSE = \sqrt{\left(f - o\right)^2} \tag{3.10}$$

Where:

f = forecasts (expected values or unknown results),
o = observed values (known results)

3.6.2 Nash–Sutcliffe model efficiency (NSE) coefficient

This is used to assess the predictive power of hydrological models. It is defined as:

$$NSE = 1 - \frac{\sum_{t=1}^{T}\left(Q_m^t - Q_o^t\right)}{\sum_{t=1}^{T}\left(Q_0^t - \overline{Q_0}\right)} \tag{3.11}$$

Where:

Q_0 = mean of observed discharges,

Q_m = modeled discharge.

Q_0^t = observed discharge at time t

This statistic determines the relative magnitude of the residual variance compared to the observed data variance. NSE ranges from − ∞ to 1, where 1 denotes perfect agreement between simulated and observed variables.

3.6.3 Coefficient of Determination Criterion (R^2)

It measures the proportional variation in the simulated variable explainable by the observed variable and gives an indication of the linear relationship between the simulated and observed variables. R^2 is calculated as follows:

$$R^2 = \left[\frac{\sum_{i=1}^{n} (Q_i - S_i)(S_i - \overline{S})}{\sum_{i=1}^{n} (Q_i - \overline{Q})^2 \left(\sum_{i=1}^{n} (S_i - \overline{S})^2 \right)} \right]^2 \qquad (3.12)$$

Where:

Q_i = observed variable,

S_i = simulated variable,

Q = mean of the observed variable

S = mean of the simulated variable

n = number of observations under consideration

3.6.5 Model Calibration and Validation

The calibration of the model was made by manual try and error technique (Bergström, 1992).

Different criteria were used to assess the fit of simulated runoff to observed runoff:

- visual inspection of plots with Qsim and Qobs
- accumulated difference
- statistical criteria

The coefficient of efficiency, Reff, is normally used for assessment of simulations by the HBV model.

$$R_{eff} = 1 - \frac{\sum \left(Q_{sim}(t) - Q_{obs}(t)\right)^2}{\sum \left(Q_{obs}(t) - \overline{Q_{obs}}\right)^2} \qquad (3.13)$$

R_{eff} compares the prediction by the model with the simplest possible prediction, a constant value of the observed mean value over the entire period.

$R_{eff} = 1$ Perfect fit, QSim(t)= QObs(t)

$R_{eff} = 0$ Simulation as good (or poor) as the constant-value prediction

$R_{eff} < 0$ Very poor fit

Unfortunately, R_{eff} is often named R^2 in connection with the HBV model. This should be avoided as R^2 easily can be confused with r^2 (= coeff icient of determination).

Note:

- the calibration period should include a variety of hydrological events
- normally 5 to 10 years sufficient to calibrate the model
- validation: test of model performance with calibrated parameters for an independent period

R_{eff} compares the prediction by the model with the simplest possible prediction, a constant value of the observed mean value over the entire period.

$R_{eff} = 1$ Perfect fit, QSim(t)= QObs(t)

$R_{eff} = 0$ Simulation as good (or poor) as the constant-value prediction

$R_{eff} < 0$ Very poor fit

3.7 Parameter Overview

The following are different parameter descriptions as they were used in the HBV model. These are divided into two categories which include the;

i. Catchment parameters
ii. Vegetation zone parameters

3.7.1 Catchment Parameters

Table 3.1: Showing catchment parameters as used in hbv model

Name	Unit	Valid Range	Default Value	Description
PERC	mm/Δt	[0,inf)	1	Threshold parameter
Alpha	-	[0,inf)	0	Non-linearity coefficient
UZL	mm	[0,inf)	20	Threshold parameter
K0	1/Δt	[0,1)	0.2	storage (or recession) coefficient 0
K1	1/Δt	[0,1)	0.1	storage (or recession) coefficient 1
K2	1/Δt	[0,1)	0.05	storage (or recession) coefficient 2

Name	Unit	Valid Range	Default Value	Description
MAXBAS	Δt	[1,100]	1	length of triangular weighting function
Cet	1/°C	[0,1)	0	potential evaporation correction factor
PCALT	%/100m	(-inf,inf)	10	increase of precipitation with elevation
TCALT	°C/100m	(-inf,inf)	0.6	decrease of temperature with elevation
Pelev	m	(-inf,inf)	0	elevation of precipitation data in PTQ
Televation	m	(-inf,inf)	0	elevation of temperature data in PTQ
PART	-	[0,1)	0.5	portion of the recharge which is added to groundwater box 1
DELAY	Δt	[0,inf)	1	time period over which recharge is evenly distributed

3.7.2 Vegetation zone parameters

Table 3.2: showing vegatation zone parameters as used in HBV model

Name	Unit	Valid Range	Default Value	Description
TT	°C	(-inf,inf)	0	threshold temperature
CFMAX	mm/Δt °C	[0,inf)	3	degree-Δt factor
SP	-	[0,1]	1	seasonal variability in degree-Δt factor
SFCF	-	[0,inf)	1	snowfall correction factor
CFR	-	[0,inf)	0.05	refreezing coefficient
CWH	-	[0,inf)	0.1	water holding capacity
CFGlacier	-	[0,inf)	1	glacier correction factor

Name	Unit	Valid Range	Default Value	Description
CFSlope	-	[0,inf)	1	slope correction factor
FC	mm	[0,inf)	200	maximum soil moisture storage
LP	-	[0,1]	1	soil moisture value above which AET reaches PET
BETA	-	[0,inf)	1	parameter that determines the relative contribution to runoff from rain or snowmelt

3.8 Graphical Methodology

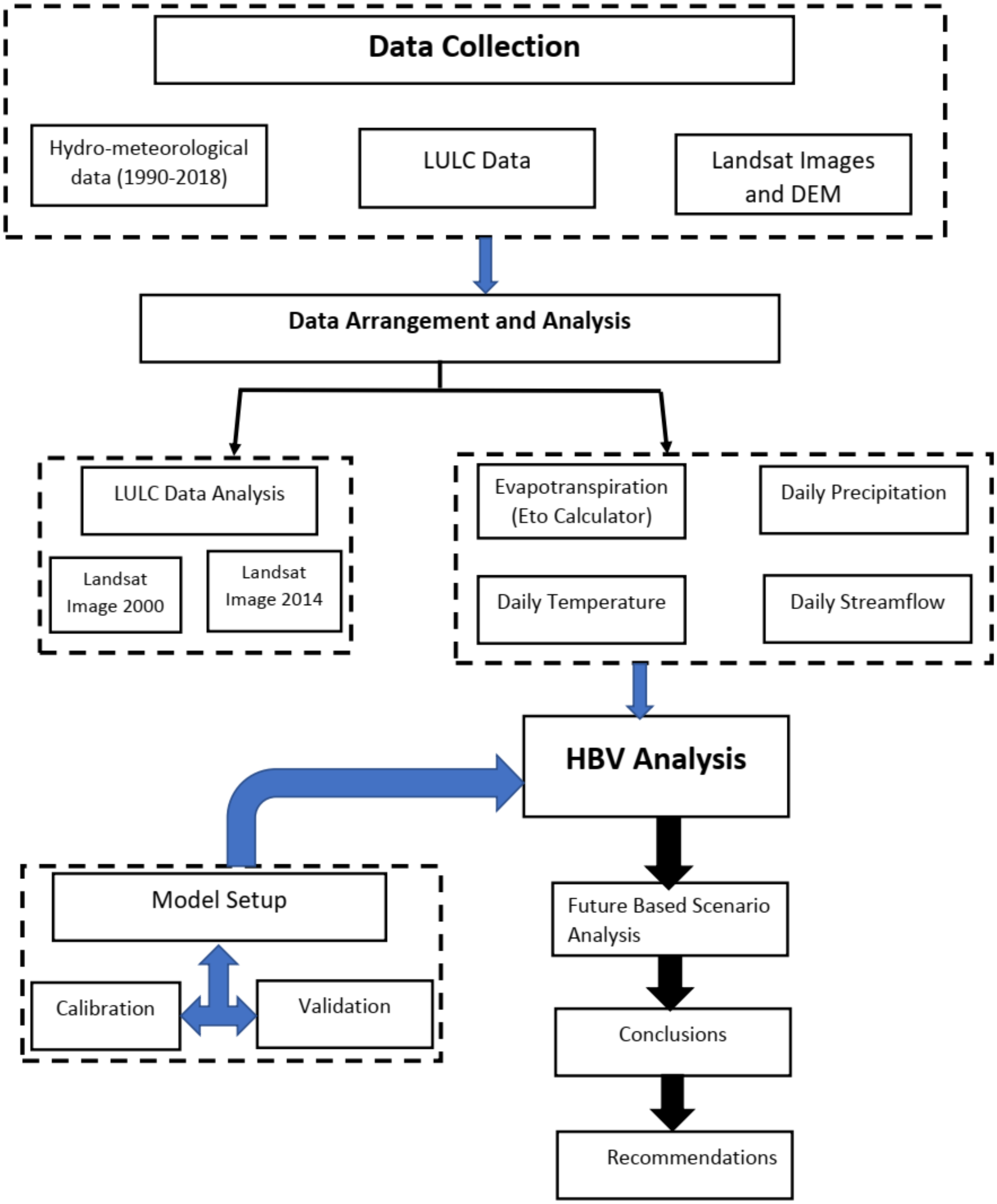

Figure 3.3: Graphical methodology description

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Land Use/Cover Changes in Katonga River Basin

The main LULC types in Katonga River basin include closed grassland, closed shrub land, dense natural forest, dense woodland, moderate natural forest, moderate woodland, open grassland, open shrub land, perennial commercial cropland, settlement, subsistence cropland, wetland and water body. These land use/cover types are illustrated in Figure 4.1

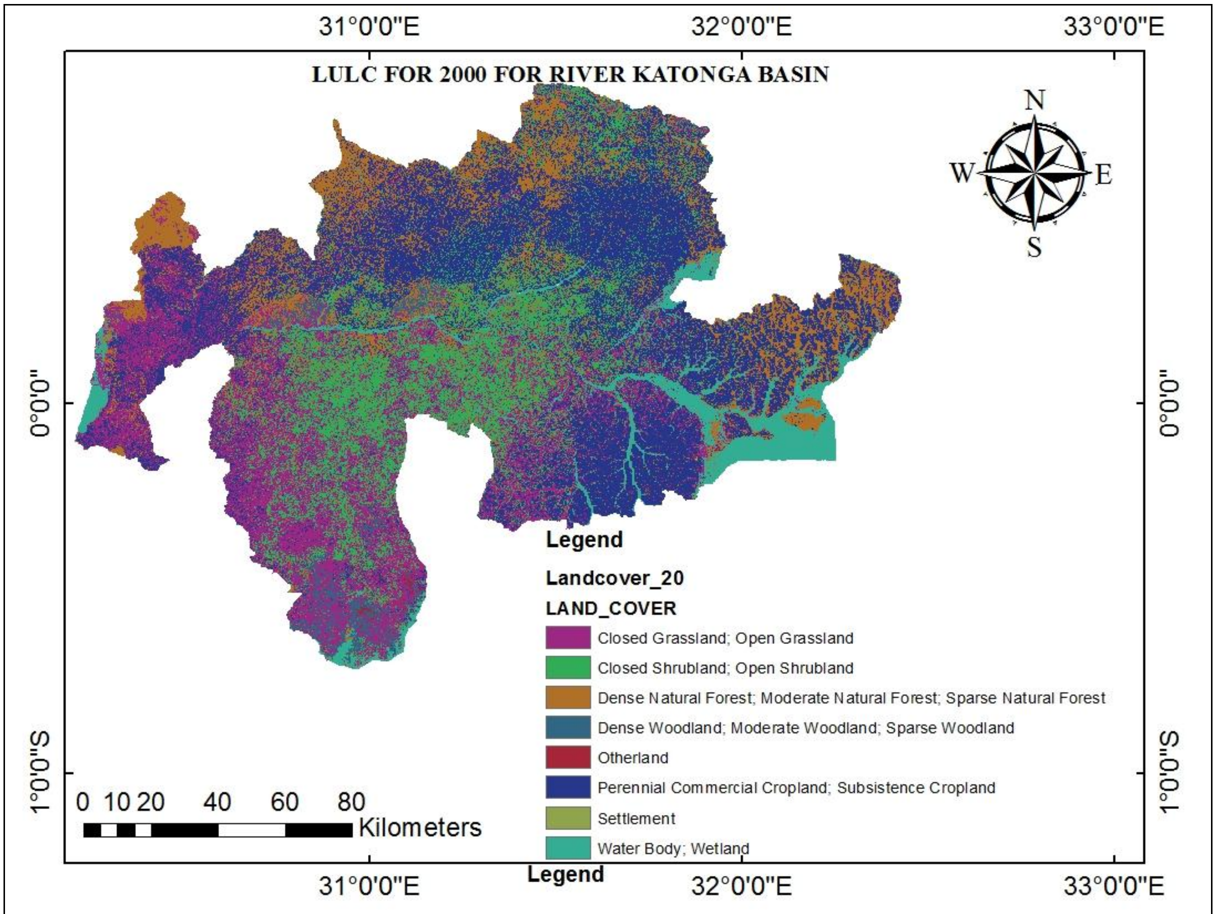

Figure 4.4: classified land use and cover map changes for river Katonga basin for 2000

According to the 2000 land use/cover condition, its dominated by wetlands and water bodies with 30% and 21%, settlement with 19%, natural forests (dense, moderate and sparse plus closed and open grasslands) with 12%, woodlands (dense, moderate and sparse plus closed and open shrubland) with 8% and subsistence cropland with 5%. These were grouped according to their closed similarity and relation in reality on ground (Table 4.1).

Table 4.1: Land use /cover classes for 2000 with corresponding areas and percentages.

Land use/Cover Class for 2000	**Area (ha)**	**Percentage**
Woodlands	1501064	8%
Natural Forests	2472365	12%
Settlement	3880308	19%
Perennial commercial Crop land	885612.8	4%
Subsistence Crop land	953128.5	5%
Water Body	4241091	21%
Wetland	6013436	30%

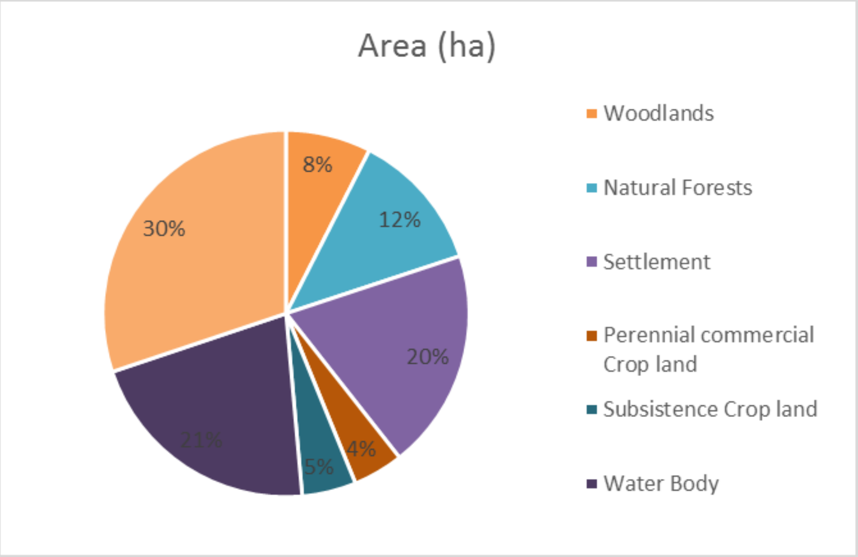

Figure 4.5: Representation of land use/ cover change 2000

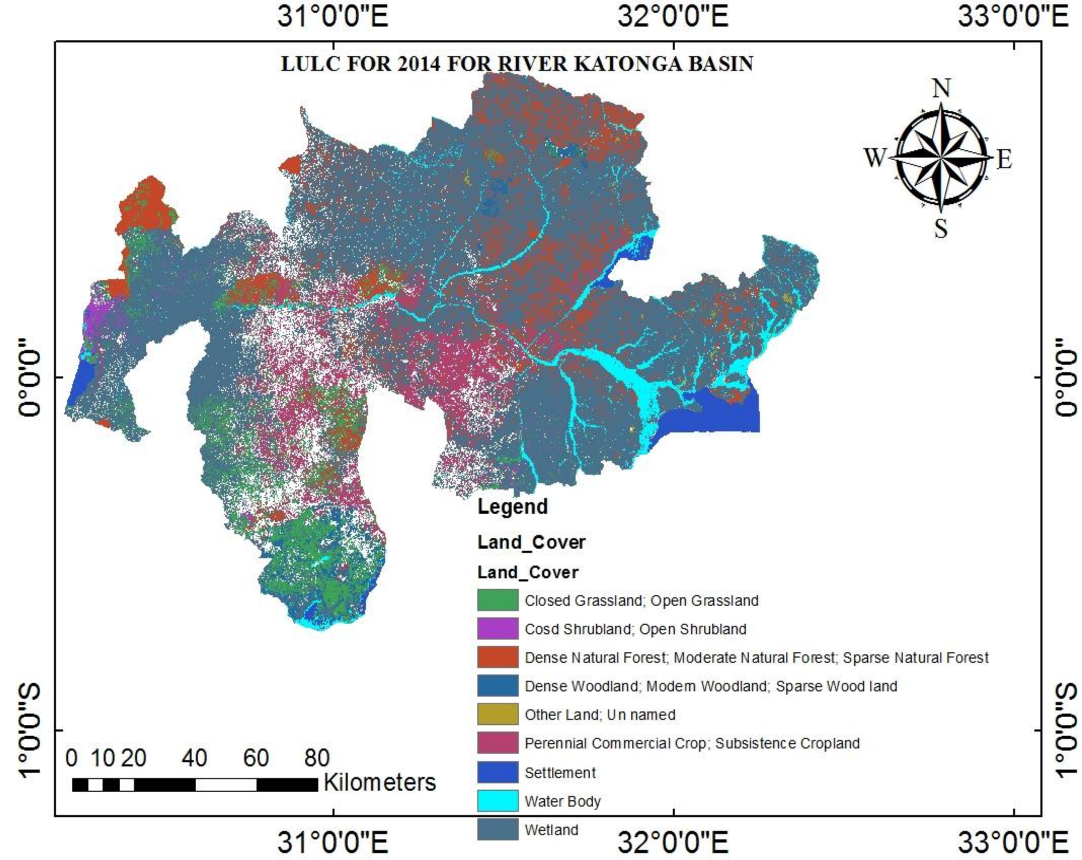

Figure 4.6: classified land use and cover map changes for river Katonga basin for 2014

The classes as shown on the legend from the map above have been regrouped accordingly depending on their close similarity as seen from reality. The woodlands in table 4.2 represent dense, modern and sparse woodlands plus the closed and open shrub lands with a percentage of 5%. The natural forests have also been grouped to consist of dense, moderate and sparse natural forests forming 18% as of 2014. The settlement of the River Katonga Basin has not been regrouped with any other Land use/cover class and it holds a percentage of 29%. Perennial commercial crop holds a 21% from the representation whereas subsistence crop holds a 1%. The area covered by water bodies and wetlands stand at 11% and 16% respectively.

Table 4.2: Land cover/ land use classes for 2014 with area in hectares and corresponding percentages

Land Use/Cover classes 2014	**Area (ha)**	**Percentage**
Woodlands	3513238.39	5%
Natural Forests	11443720.8	17%
Settlement	18672938.1	29%
Perennial commercial Corp	13291319.5	21%
Subsistence Crop	326967.651	1%
Water Body	7090841.88	11%
Wet lands	10184171.8	16%

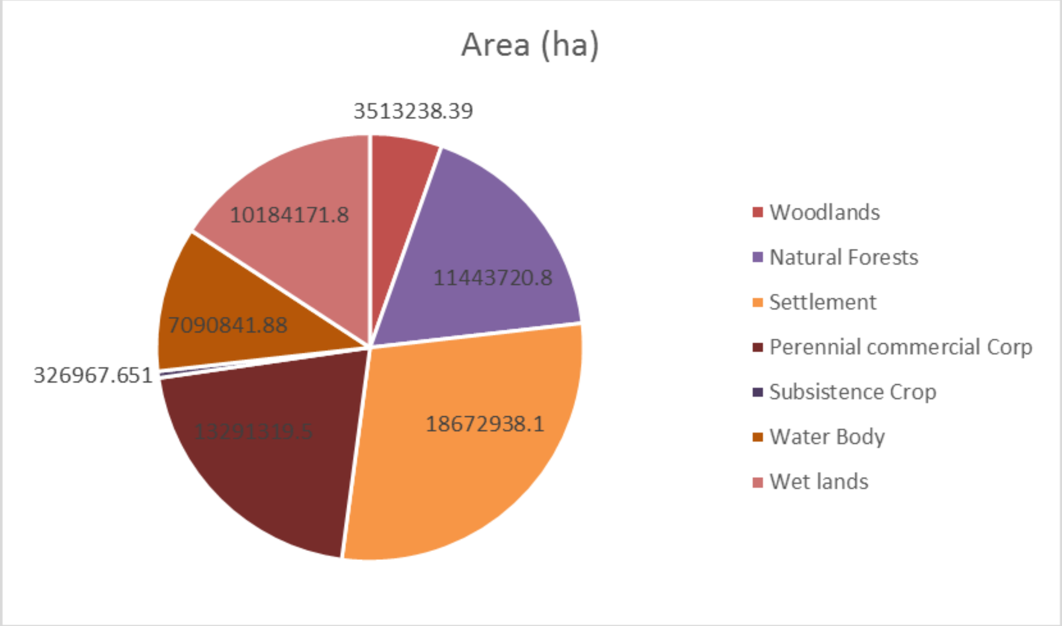

Figure 4.7: Representation of Land use/ cover change 2014

According to the results from the land use/ cover classifications of 2000 and 2014 comparisons, there significant land changes according to the percentages. Woodlands have reduced by a given percentage as observed from the percentages of 2000 and 2014. On the other hand, natural forests have increased creating and this can be attributed to the enforcement of the good land use and cover policies of re-afforestation by government to sustain the hydrological and natural ecosystems in order to balance. This explains why trees function as a media to transfer rain water to soil through the process of temporary detention of rainwater by interception, streamflow, and throughfall, indicated by the high value of base flow in Scenario.

Moreover, it can also be seen from the percentages of perennial commercial cropland has significantly risen by a higher percentage unlike subsistence cropland which has reduced. Among all these changes, the increase in perennial cropland and natural forests are more. River Katonga basin is characterized by more commercialized agriculture because of the abundant lands, water resources and sparse populations of the area.

The area covered by water and wetland classes has also witnessed a decrease from 2000 to 2014. The water and wetland class has been affected by the increased perennial commercial cropland. The luck of accessibility of water resulted in the depletion of water and ended in dried up tributaries and its replacement by either compact surfaces or the increase in bare lands due to formation of grazing grounds. Another reason for the shrinkage could be an increased rate of surface runoff due to lack of plant roots to withhold the water. As the runoff exceeded recharge capacity of ground water it resulted in the lowering of water table.

4.2 Impact of LULC on the Streamflow trend of the River Katonga

4.2.1 Precipitation, Temperature and Evapotranspiration data

The precipitation data for Katonga river basin was collected from the stations around the basin and this was recorded as daily precipitation (mm/day) values for the entire study area. The data in consideration was from 1990-2018 and this had recorded temperature values for maximum and minimum and it was computed to obtain mean daily temperature values to be used in the HBV model.

4.2.2 Data Analysis

The data was analysed and the results were obtained but according to the missing gaps of the historical years 1990 and below, it showed that data from 1990 and above was more suitable for use due to high percentages. Also, the data selected was cleaned and used to show that there were few missing data, the table 4.5 below shows the percentage of the missing data per each year. This was computed by dividing the days missing the data by the total number of days in the particular year in consideration and ten taking the value as a percentage. It was observed that as years progressed data availability increased this is due to the introduction of better weather equipment and the skilled personnel to record the data in the field. Therefore, period 1990-2018 was considered for this particular study since it had complete and reliable data set.

Table 4.3:The percentage of the present data per year.

Years	**Percentage (%) of missing data**
1990	66%
1991	76%
1992	78%
1993	100%
1994	83%
1995	100%
1996	97%
1997	68%
1998	88%
1999	95%
2000	100%
2001	100%
2002	55%
2003	78%
2004	89%
2005	100%
2006	67%
2007	87%
2008	100%
2009	98%
2010	96%
2011	75%
2012	94%

Years	**Percentage (%) of missing data**
2013	86%
2014	100%
2015	100%
2016	100%
2017	100%
2018	100%

4.3 Prediction of Streamflow Changes of the River Basin

4.3.1 Model calibration and validation

The model was setup using the warming period of 1991-1995 and 2006-2010 for the calibration and validation phases respectively. The daily streamflow observations at the Katonga river basin were available for 28 years which I requested for from the Uganda National Meteorological Authority (UNMA). The Genetic Algorithm and Powell (GAP) optimization was used to calibrate the model. The model parameter ranges (Table 4.4) were chosen for the calibration as described by the developer of the model and many other studies ((Abebe and Kebede, 2017; Al-Safi and Sarukkalige, 2017)). It is worth noting that, over-increasing the parameter range bears the risk to generate a good simulation by using unrealistic parameter sets.

The model was calibrated in 50,000 GAP runs. Parameters ranges of the model during the calibration are shown in table 4.5 and table 4.4

Table 4.4: showing warm up period, calibration and validation

	Years
Warm up period	1/Jan/1991-31/Dec/1991
Calibration	1991-1995
Validation	2006-2010

Table 4.5: Parameters ranges used for the calibration

Name	DisplayName	Unit	Description	Lower Limit	Upper Limit
PERC	PERC	mm/d	Treshold parameter	0	2500
UZL	UZL	Mm	Treshold parameter	0	2500
K0	K0	1/d	Storage coefficient 0	0.000001	0.9
K1	K1	1/d	Storage coefficient 1	0.000001	0.9
K2	K2	1/d	Storage coefficient 2	0.00000001	0.1
MAXBAS	MAXBAS	d	Length of triangular weighting function	1	30
PCALT	PCALT	%/100m	Change of precipitation with elevation	1	30
TCALT	TCALT	°C/100m	Change of temperature with elevation	0	30
Pelev	Elev. of P	m	Elevation of precipitation data in the PTQ file	0	0
Telev	Elev. of T	m	Elevation of temperature data in the PTQ file	0	0

4.3.2 Model evaluation

According to (Al-Safi and Sarukkalige, 2017) it explained that the method of evaluating the results during the calibration process is highly significant. Therefore, the modeling performance was assessed using three criteria of efficiency named Model efficiency (R_{eff} or NSE), Kling–Gupta efficiency (KGE).

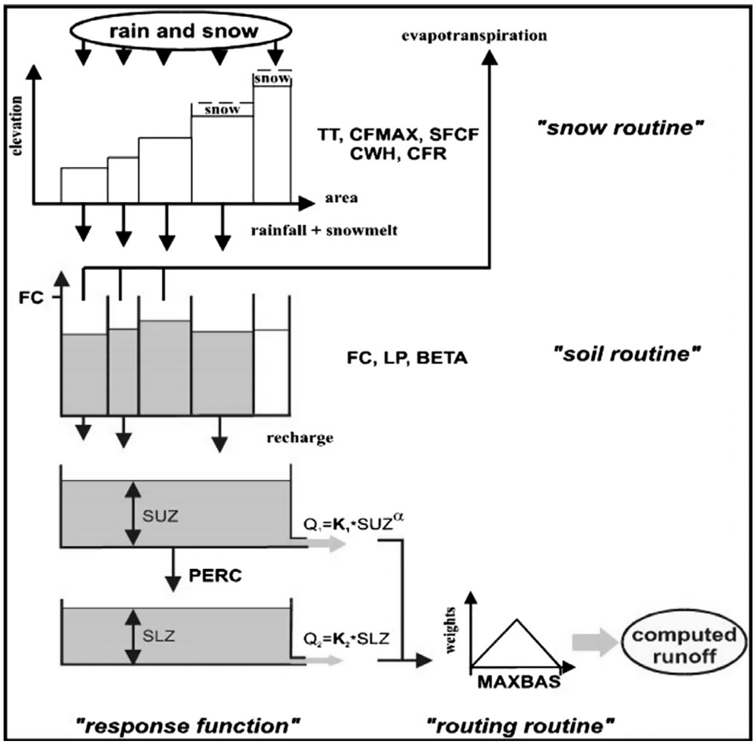

Figure 4.8: HBV-light model structure

4.3.2 Coefficient of determination (R^2)

The calibration and validation periods of the model were compared to the normal meteorology of the catchment using the SPI. The Standardized Precipitation Index of the catchment for the period indicates that 1991-2010 both calibration and validation periods are near normal with index values ranging from -0.99 to 0.99. More than 70% of the available data reflected the normal climate of the catchment and reflect the annual rainfall pattern in the catchment. Furthermore, both calibration and validation during periods have relatively similar rainfall patterns. Table 4.6 and Figure 4.4 shows the results of SPI index in and the years in which where use for calibration and validation.

Table 4.6: The normalized SPI Index years used for calibration and validation

Annual SPI:		
Year	**Annual SPI Index**	
1991 – 1992	0.19	Calibration
1992 – 1993	0.81	
1993 – 1994	0.58	
1994 – 1995	0.19	
2006 – 2007	0.70	Validation
2007 – 2008	0.41	
2008 – 2009	0.57	
2009 – 2010	1.06	

4.3.3 Model performance

Table 4.5 shows the results of the calibration and validation of the HBV-Light model. Model efficiencies of 0.48 and 0.41 were achieved for the calibration and validation respectively. One can notice that the sum of simulated discharge is higher than observed discharge for calibration and opposite for validation.

Table 4.7 Water balance and model performances for the calibration and validation periods

KATONGA RIVER BASIN CATCHMENT CAL AND VAL SUMMERY RESULTS		
Water Balance[mm/year]:	***Calibration***	***Validation***
Sum Qsim	1306.002	1844.19
Sum Qobs	1612.793	2441.12
Sum Precipitation	1652.013	1967.841
Sum AET	1349.173	76.523
Sum PET	1713.493	1662.611

Goodness of fit:	***Calibration***	***Validation***
Coefficient of determination	0.579	0.41
Model efficiency	0.4315	0.39
Kling-Gupta efficiency	0.4776	0.54

Several studies state that for the efficiency of the model coefficient of determination (R^2) describe the degree of collinearity between simulated and measured data. R2 ranges from 0 to 1, with higher values indicating less error variance, and typically values greater than 0.5 are considered acceptable (Moriasi *et al*., 2007). In this study the value of R^2 for both calibration and validation were found to be higher than 0.5. Applying the NSE scale (Table 4.6); (Moriasi *et al*., 2007), on can conclude that the simulations are for both calibration and validation periods Figure 4.5 show the value of simulated discharge, observed discharge and prescription values during the calibration year (1991-1995) and Figure 4.6 shows the value of simulated discharge, observed discharge and precipitation during the validation year (2006-2010). It can be noticed that that annual discharge pattern is indeed well reproduced by the model for both periods although some peak discharges are under or overestimated. Data quality and gaps filling can reasonably explain these discrepancies (Lo Presti *et al*., 2010). Overall, the model reproduces the hydrological regime of the catchment.

Table 4.8: NSE scale for Calibration and Validation values

Parameter/Description	**Very poor fit**		**Poor fit**		**Satisfactory fit**		**Perfect fit**	
	<0		**0-0.3**		**0.4-0.8**		**1**	
	Cal.	Val.	Cal.	Val.	Cal.	Val.	Cal.	Val.
Nash-Sutcliffe Efficiency (NSE)/ Model efficiency					0.4315	0.39		
Coefficient of determination					0.579	0.47		
Kling-Gupta efficiency					0.4776	0.54		

From the results presented in Table 4.6, it is observed that the values computed for calibration and validation period respectively fall within the ranges of the NSE scale and they are a satisfactory fit according to the comments from the scale. However, more parameters need to be altered by increasing them in order to get a perfect fit for the study.

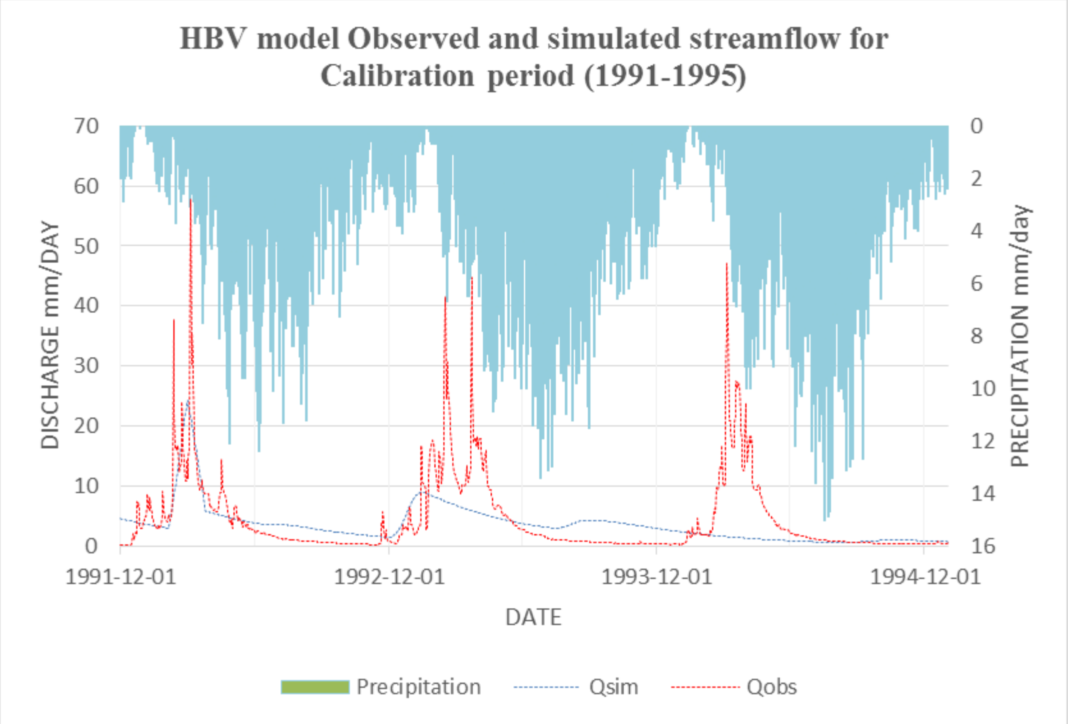

Figure 4.9:Simulated streamflow, observed streamflow and precipitation during the calibration year (1991-1995)

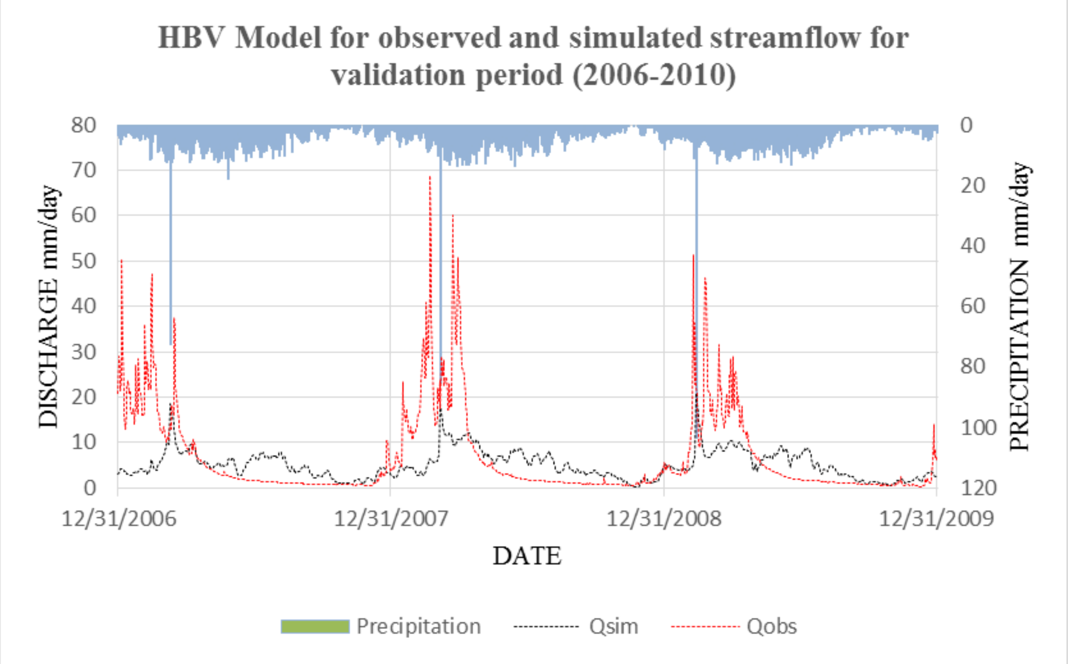

Figure 4.10:Simulated stream flow, observed stream flow and precipitation during the validation year (2006-2010)

4.4 Stream flow simulations depending on climatic

4.4.1 Temperature and precipitation influence

From the collected data which include precipitation and temperature, it can be observed that temperatures for the different period doesn't exhibit high difference and it ranges between 17 ^{0}C and 32^{0}C. The temperatures also influence directly on the evapotranspiration of the river basin. Increased temperatures lead to high evapotranspiration and hence influencing the hydrological cycle of the region in particular.

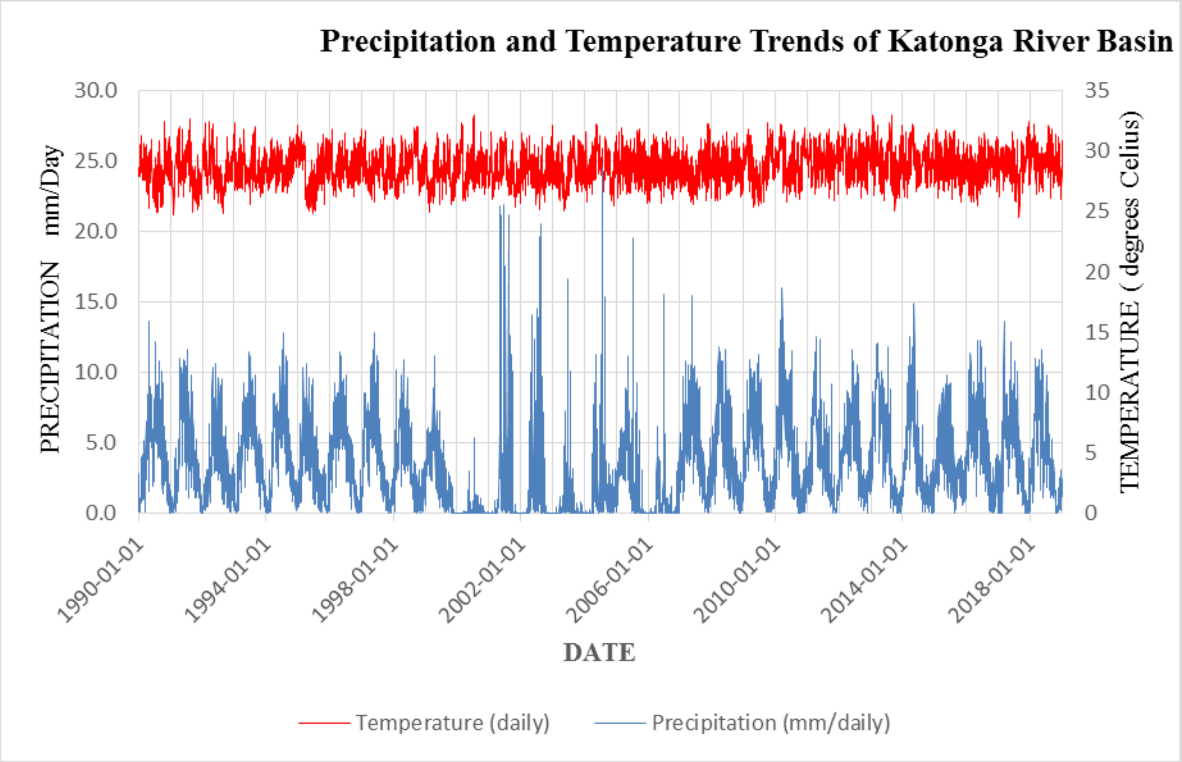

Figure 4.11: precipitation and temperature for the period (1990-2018)

For the precipitation it also follows a normal trend with a few extreme rainfall events witnessed between 2000-2006. The trend magnitude of the precipitation was assessed and at least it presented values of 0.02mm/day to 126mm/day on a daily basis. Seasonal trend magnitude was greater in wet season than in dry season for more than 50% of the years studied as clearly indicate in the Figure 4.8.

4.4.2 Modeled effects of LULC changes on evapotranspiration

Evapotranspiration (ET) is a key variable in the terrestrial water cycle that provides the link between the land surface and the atmosphere, which is potentially the largest component of the land water budget and is therefore central to quantifying and managing water resources (Sheffield *et al*., 2014). A number of studies (Milly, 1994; Cheng *et al*., 2017; Yang *et al*., 2013) have shown that, in spite of the complexity in the soil-vegetation-atmosphere system, the most important factors controlling annual mean evapotranspiration appear to be annual rainfall and land use types.

The difference in rainfall interception between forests and short grass has important implications for basin water balance because most of the intercepted rainfall is evaporated directly into the atmosphere (Zhang *et al*., 1999).

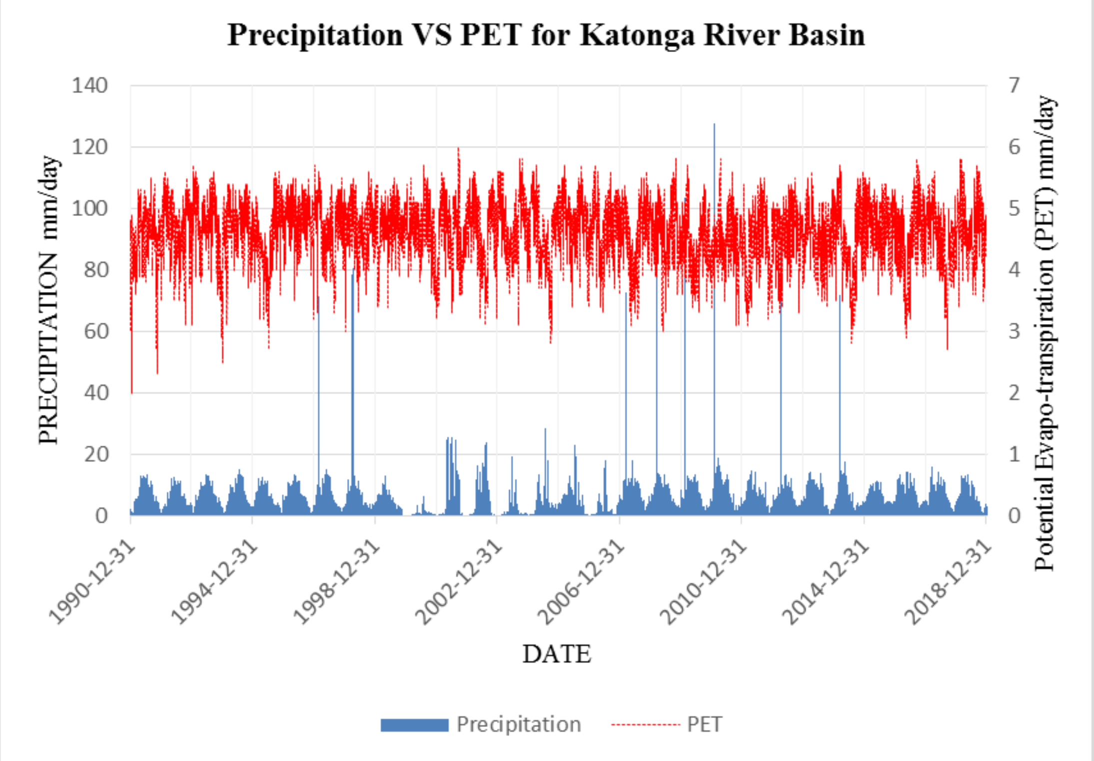

Figure 4.12: precipitation Vs PET for Katonga River basin

To assess the effect of LULC changes on the evapotranspiration, we analyzed the spatial-temporal characteristics of actual evapotranspiration (AET) in the basin. The time series variations of annual precipitation, pan evaporation (from observed recorded of all the basin station) and actual evapotranspiration (AET) remained relatively stable during the whole period (1990-2018) as simulated by the HBV model as presented in Fig. 4.9 above. From the observed values of the Eto calculator computed were ranging from 2mm/day-6mm/day of PET of the basin. It demonstrated that the change of PET was dominated by the change in precipitation and temperature, which also coincides with the conclusions of (Yang *et al*., 2014).

4.5 Forecasting Future land scenarios of Katonga River basin

Land use affect the hydrological processes including the interruptions of the natural flow equilibrium (Zhang *et al*., 2016). Several parameters influence the hydrological responses and behaviour of given watershed. This may involve inputting future natural conditions such as rainfall timing and magnitude, recharge, runoff parameters; future land scenarios of an uncertain calibrated model. All the forecasts were assessed for impact of the hydrological conditions.

4.5.1 Land Use Change Scenarios

This study aimed at understanding how different land use/cover change scenarios within the basin within since 1990. However due to the limitation of the availability of land use/cover data availability, the study considered LULC maps of 2000 and 2014 for analysis as stated in the discussions. ArcGIS 10.5 version was used for land use mapping. The study also proposed possible future land scenarios that can be incorporated in the entire management plan for the Katonga river basin.

In the study land use change was assumed in the negative direction by simulating the effects of decreased forests and increased settlements to get peak flows of the catchment. The CN values were estimated by increasing the surface of the urbanized/settlement area, and assuming low forest density vegetation cover.

In the positive direction, it was assumed that the pressure exerted on the forest patrimony with parallel actions to reforest the bare soils would eventually result in clear dense forest. Increase in forest cover percentage was assumed as a contribution from arable land with remaining percentage contributing to the range land.

We computed results based on the Land use/cover scenarios for 2014 simulations because it was latest representation of the changes compared to 2000. We looked at when we increase the percentage of settlement land, what would be the effect of the stream flow of the river basin in consideration.

Land Use/Cover classes 2014	**Area (ha)**	**Percentage**
Woodlands	3513238.39	5%
Natural Forests	11443720.8	17%
Settlement	18672938.1	29%
Perennial commercial Corp	13291319.5	21%
Subsistence Crop	326967.651	1%
Water Body	7090841.88	11%
Wet lands	10184171.8	16%

By using the formulae below and considering an average annual precipitation of 850mm in the Katonga river basin

$$Q = \left(\frac{(P - 0.2S)^2}{(P + 0.8S)} \right) \tag{4.14}$$

$$S = \left(\frac{25400}{CN} \right) - 254 \tag{4.15}$$

From the table of HSG classification or from the basic equation for CN calculation below

$$CN_{AW} = \frac{\sum_{i=1}^{n} (CN_i x A_i)}{\sum_{i=1}^{i} A_i} \tag{4.16}$$

Table 4.9: Runoff generation for different Land use scenarios for 2014

Land Use/Cover classes 2014	**Area (ha)**	**Percentage**	**CN values**	**S values**	**precipitation (mm)**	**(P-0.2S)2**	**P+0.8S**	**Q-runoff (mm)**
Woodlands	3513238.39	5%	40	381	850	598766.44	1154.8	518.5023
Natural Forests	11443720.8	17%	36	451.5556	850	577127.208	1211.244	426.4746
Settlement	18672938.1	29%	77	75.87013	850	696934.407	910.6961	715.2766
Perennial commercial Corp	13291319.5	21%	67	125.1045	850	680590.523	950.0836	716.3481
Subsistence Crop	326967.651	1%	67	125.1045	850	680590.523	950.0836	716.3481
Water Body	7090841.88	11%	100	0	850	722500	850	850
Wet lands	10184171.8	16%	98	5.183673	850	720738.626	854.1469	823.8111
Total	**64523198.12**							

From Table 4.9 the runoff for different land use scenarios is generated from the tabulations and simulations above. In the negative way we looked at changing land use scenarios by reducing wetlands and Natural forests by 5% respectively and adding it to settlement of Katonga river basin to make 39% in the Table 4.10.

After increment of settlement to 30% and reducing wetlands and natural forest by 5% respectively to see the effect on runoff of the catchment. We the runoff generated being affected and its reducing for the wetland and natural forest and having a significant increase for settlement.

Table 4.10: Runoff for Land use scenario changes and percentage increments

Land Use/Cover classes 2014	**Area (ha)**	**Percentage**	**New Area (ha)**	**Percentage**	**CN values**	**S-Values**	**Precipitation (mm)**	**(P-0.2S)^2**	**P + 0.8S**	**Q-Runoff (mm)**
Woodlands	3513238	5%	3226159.91	5%	40	381	850	598766.4	1154.8	518.5
Natural Forests	11443721	17%	7742783.77	12%	36	451.5556	850	577127.2	1211.24	476.47
Settlement	18672938	29%	25164047.3	39%	77	75.87013	850	696934.4	910.696	765.28
Perennial commercial Corp	13291320	21%	13549871.6	21%	67	125.1045	850	680590.5	950.084	716.35
Subsistence Crop	326967.7	1%	645231.981	1%	67	125.1045	850	680590.5	950.084	716.35
Water Body	7090842	11%	7097551.79	11%	100	0	850	722500	850	850
Wet lands	10184172	16%	7097551.79	11%	98	5.183673	850	720738.6	854.147	843.81
Total	**64523198**		**64523198.1**							

The changes in land use can significantly contribute to increased runoff which directly is viewed as a proportional increase in the stream flow of River Katonga. This can cause natural hazards like flooding and hence submerging of the land which is potential for agriculture in the area. Another reason for the shrinkage of natural forests was an increased rate of surface runoff due to lack of plant roots to withhold the water. As the runoff exceeded recharge capacity of ground water it resulted in the lowering of water table as it was described in (Butt *et al.*, 2015). Increased deforestation rate is believed to have also contributed to the increase in surface runoff and is responsible for down flow to the stream of Katonga river.

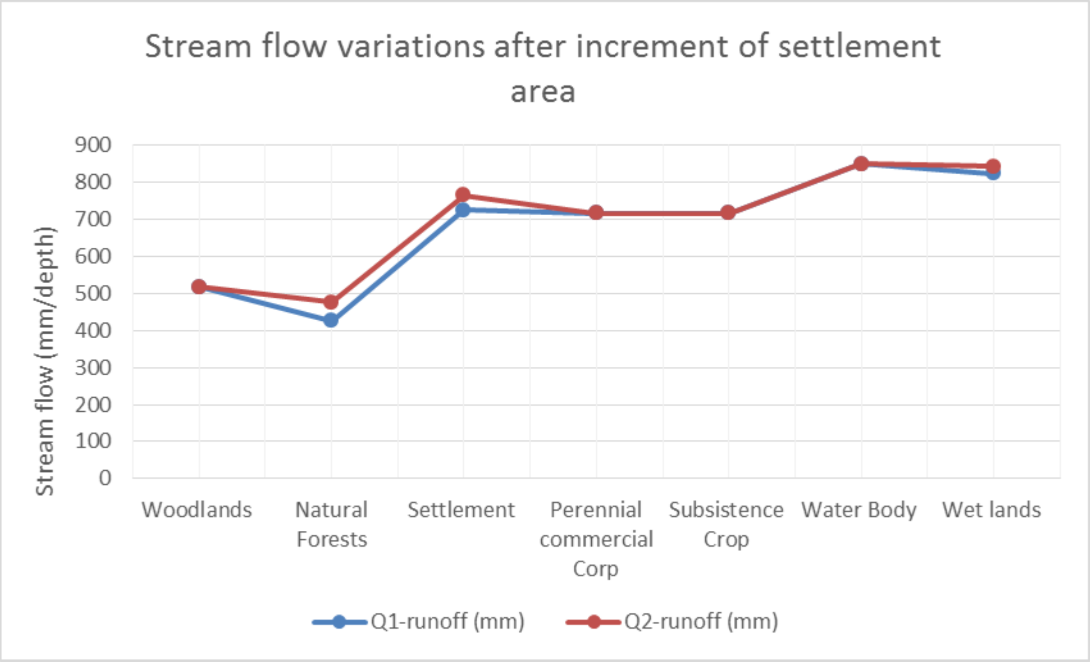

Figure 4.13: Streamflow comparison after increment of settlement Area

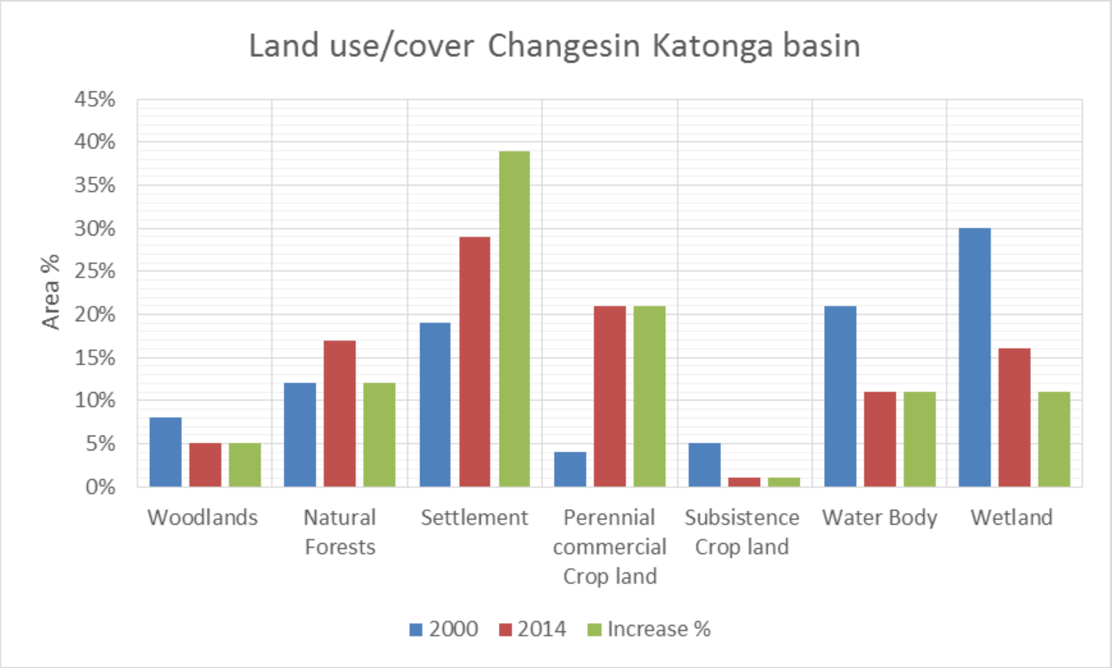

Figure 4.14: Land use/cover scenarios change in Katonga river basin

The changes from natural forests into settlement area resulted in the decrease of land capability of reducing flooding. If these land use changes continue to happen, then the peak flow in the Katonga River will also continue to increase. The increase in anthropogenic activities is predominantly caused by increasing populations which stands at 3.3% according the Ugandan population demographics. Currently almost all of woodland area has been turned into grazing grounds and agriculture lands, so the possibility of increasing forests in the future is extremely small. This will hamper greatly the hydrological responses of the catchment. Government and all concerned stake holders especially the citizens living within in the river basin, should embark more on natural resources protections and rehabilitation to maintain the status quo of the hydrological responses of Katonga River basin.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

This study was all about Katonga river basin modelling and understanding the hydrological response using HBV model and ArcGIS of the Land use and land cover changes. The study aimed at understanding how hydrological responses coupled with land use/cover changes do affect the streamflow of the river basin.

In this study, the effects of LULC changes on streamflow due to changes in hydrological responses was investigated in Katonga river basin. The Eto calculator by FAO using the Penn Monteith formula to compute Actual evapotranspiration (AET) and potential evapotranspiration (PET) for the study area and HBV model analysis was used to detect the observed and simulated according to the input data. Based on the results of statistical analysis, we applied the HBV model to simulate the streamflow and evapotranspiration in the study area.

The study satisfactorily estimated how changes in land use and cover changes affect the stream flow volumes of the Katonga river basin. The methodology presented a solution as a decision supporting tool for planners, government agencies and other research institutions on how linking the HBV model and the ArcGIS platform to analyze scenarios.

i. The HBV model analyzed the basin characteristics eliminating out the snow factor because it’s not applicable in the area of study. The study of such hydrological modelling scenarios helps in integration of future distinctive perspectives into understanding hydrological impacts of land use and cover policies before their implementation.
ii. Before application the model was calibrated for 5 years (1991- 1995) using the parameters as provided by HBV model. The model was then validated for five events (2006-2010) by using the same parameters as calibration in the model. The modelling performances was based on the NSE coefficient/Model efficiency,

Criterion coefficient R^2 and Kling-Gupta efficiency (KGE). The values obtained for the Model efficiency is 0.43, Criterion coefficient R^2 0.57 and KGE 0.477 for the calibration period and 0.39, 0.41, and 0.54 for the validation period. The HBV model simulation of the daily stream flow showed satisfactorily good and acceptable results according to the NSE scale. However, the slight challenges of the largely non gauged catchment and missing data of Katonga River Basin present drawbacks for this hydrological model.

iii. In many hydrological researches, results of hydrological models are not carefully interpreted with a given measure of un certainty. Based on the LULC maps of 2000 and 2014, there is considerable changes in settlement, natural forests, water bodies and wetlands were noted to have expanded. The results from the analysis of LULC using ArcGIS platform increased settlement and expansion of agricultural land has negatively impacted on the runoff (peak flow) and river stream flow.

iv. The increased natural forest and woodlands can be attributed to the re-afforestation and increased settlement can be attributed to the increased populations in the area. This hydrological modelling can be used to also facilitate subsequent hydrological studies within the region. The outcomes of the study would be very vital for future references of further catchment studies.

v. The streamflow trends were simulated, with a demonstrated increase in settlement of 10% deducting from natural land forest and wet lands by 5% and a significant increase in streamflow was recorded in the basin.

vi. The changing use of land from sustainable to unscientific agriculture, overgrazing, and unlimited forests exploitation is pointedly shifting the hydrologic characteristics of the Katonga River basin. Because Katonga river basin catchment is categorized as a cattle corridor according to the study.

5.2 RECOMMENDATIONS

However, proper land use strategies should be emphasized to avoid increased peak flow that wood result into flood risks in the catchment. The Katonga river basin catchment is consider as the agricultural and cattle catchment corridor and more people are still contributing to the degradation of the area.

The ministry of water and environment should have proper planning policy regarding the LULC information of all catchments in Uganda for future basin planning, development and management strategies.

The HBV model is such an in important hydrological modeling tool that should be adopted by government agencies, research institutions in anticipating hydrological response of several other basins while managing the impact of land use and cover changes within these basins.

For further research, developments and addition to this study the following are recommended;

i. Researchers willing to contributed to this related study in Uganda and elsewhere could also think of focusing on the climate variability on the stream flow of given rivers in order to ascertain the impacts presented by climate at river basin level.
ii. Since the river basin is large enough, to bring it under management practice this catchment could be broken down into sub-basins. Additionally, based on degradation stage, these sub-basins could be prioritized for conservation and management and hence proper land use policies.
iii. As the study reveals that over the last 25 years' major share of vegetation has shifted to agriculture, Government should introduce a plan to ensure a minimum percentage of vegetation cover in the Katonga catchment area.
iv. The government should consider sensitization of masses living within these particular river catchment zones on the adverse impacts of the land activities and how hydrological responses affect stream flows. Also, proper incentives could be put in place to counteract the impacts in these areas.

v. Field based approaches should be adopted when working with hydrological modelling researches. Because most of the data used is not a true representation of the particular are of study and hence call for establishment of more weather stations.

vi. Detailed land use survey of the catchment areas besides doing the streamflow measurements at River Katonga basin to verify the actual land use activities. This will help in verifying the LULC information as used from remote sensing and related data.

vii. Community participation on the adaptive and mitigation approaches should be put at the fore front in the catchment protection to maintain the hydrological cycle.

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