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ANALYSIS OF THE EFFECTS OF LAND USE / LAND COVER ON RIVER FLOW REGIME: A CASE STUDY OF MKURUMUDZI RIVER SUB - CATCHMENT

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DECLARATION

I, **Caroline Cheptoo** hereby declare that this thesis represents my personal work, realized to the best of my knowledge. I also declare that all information, material and results from other works presented here, have been fully cited and referenced in accordance with the academic rules and ethics.

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ABSTRACT

The population in Mkurumudzi catchment rely on river water for their livelihood. There are limited studies that focused on the effects of land use / land cover on river flows for sustainable water management. Land Use and Land Cover affect river flows in different ways. Physiographic characteristics of a watershed affect the hydrology. SWAT model is a reliable model used for estimating total runoff. SWAT modelling of watersheds is important in development and management of water resources. This study involved analysis of river flow discharges based on land use practices in the catchment resulting from human activities. The task included use of land use, soil properties and meteorological conditions in the area to obtain simulated flows. Landsat images for 1987, 1997 and 2017 were classified into four categories that is forest, shrubs, grassland and agricultural land and used in simulation of stream flows. Land use prediction for 2030 was made by assuming that there would be an increase in forest cover by 10 % and increase agricultural land thrice the area of 2016. SWAT calibration for the period 1982 – 1995 with three years warm up period and validated from 1996 – 2005. SWAT – CUP model was used for calibration and validation. Three indices were used for model validation and uncertainty used in this study with their respective performance factors were as follows; coefficient of determination (R^2) (0.25 – 0.31); (b) Nash–Sutcliffe efficiency (NS) (0.74 – 0.89); and Percent Bias (PBIAS) (4.51 – 8.82). The results obtained indicated that there were effect of land use change that affected the flows for the periods that were examined. Future prediction showed that there would be changes of stream flow as compared with the current flows. Therefore, it is important that the area of forest cover be increased to maintain and land degradation interventions be adopted inorder to maintain environmental flows.

RÉSUMÉ

La population du bassin versant de Mkurumudzi dépend de l'eau de la rivière pour sa subsistance. Il y a un manque d'études sur les effets de l'utilisation des terres / de la couverture terrestre sur les débits des rivières pour une gestion durable de l'eau. L'utilisation des terres et la couverture des terres affectent les flux des rivières de différentes manières. Les caractéristiques physiographiques d'un bassin versant affectent l'hydrologie. Le modèle SWAT est un modèle fiable utilisé pour estimer le ruissellement total. La modélisation SWAT des bassins versants est importante pour le développement et la gestion des ressources en eau. Cette étude consiste à analyser les débits des cours d'eau en fonction des pratiques d'utilisation des terres dans le bassin versant résultant des activités humaines. La tâche comprenait l'utilisation de l'utilisation du sol, les propriétés du sol et les conditions météorologiques dans la région pour obtenir des débits simulés. Les images Landsat pour 1987, 1997 et 2017 ont été classées en quatre catégories: forêts, arbustes, prairies et terres agricoles et utilisées pour la simulation des débits. La prévision d'utilisation des terres pour 2030 a été faite en supposant qu'il y aurait une augmentation de 10% du couvert forestier et une augmentation des terres agricoles trois fois plus qu'en 2016. Étalonnage SWAT pour la période 1982-1995 avec période d'échauffement de trois ans et validé à partir de 1996 - 2005. Le modèle SWAT-CUP a été utilisé pour l'étalonnage et la validation. Trois indices ont été utilisés pour la validation du modèle et l'incertitude utilisée dans cette étude avec leurs facteurs de performance respectifs étaient les suivants: coef fi cient de détermination (R2) (0,25 - 0,31); (b) ef fi cacité de Nash-Sutcliffe (NS) (0,74 - 0,89); et le pourcentage de biais (PBIAS) (4,51 - 8,82). Les résultats obtenus indiquent que les changements d'affectation des terres ont eu un effet sur les débits pour les périodes étudiées. Les prévisions futures montrent qu'il y aurait de légères modifications du débit des cours d'eau par rapport aux flux actuels. Par conséquent, il est important que la superficie du couvert forestier soit augmentée pour maintenir les flux environnementaux.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

1.0 Organizations

KISCOL	Kwale International Sugar Company Limited
KMD	Kenya Meteorological Department
RCMRD	Regional Center for Mapping of Resources for Development
WRA	Water Resource Authority
WMO	World Meteorological Organization
USDA-ARS	United States Department of Agricultural-Agricultural Research Service

2.0 Specific terms

DEM	Digital Elevation Model
CLUE	Conversion of Land Use and its Effects
CLUE-s	Conversion of Land Use and its Effects at Small regional extent
GIS	Geographical Information System
LULC	Land Use and Land Cover
IWRM	Integrated Water Resources Management
NOAA	National Oceanic and Atmospheric Administration
NSI	Nash-Sutcliffe index
PBIAS	Percent Bias
PES	Payment for Ecological Services (PES)
SDGs	Sustainable Development Goals
SWAT	Soil and Water Assessment Tools

Chapter 1: Introduction

1.1 Background

Two-thirds of the whole earth's surface is covered by water; one of the major resource in Kenya. Kenya is classified as 'chronically water scarce' in which demand for water largely exceeds the available supply. Kenya's available renewable freshwater resources is estimated to be 20.2 km^3 per year, which corresponds to 647 m^3 per capita per year. Land and water are two important resources to social life and they are elements that affect the perseverance and degeneration of watershed (Thi, et al., 2014). This water is limited for human consumption, agriculture (environmental) and industrial purposes. One of the major factors that contributes to the loss of water is lack of proper asset management. This status is even complicated by poor water governance, increasing urbanization, shifting populations, poor project design, scarcity of water resource, uncertainty of climatic conditions, and increasing public concern for the environmental impacts of everyday living.

Land use changes in the past have affected the amount of water discharged into the rivers. Anthropogenic activities including clearing of vegetation to pave way for agricultural and livestock farming is one of the major activity contributing to land use changes. These activities lead to alteration of biophysical and biochemical properties of the soil. Streams become the direct casualty because of the human induced changes on land. When protected from development, these stream corridors filter out and substantially reduce pollutants entering streams (Atlanta, M. 2002). Urbanization is also a contributor to changes in the flow regime. Establishment of urban centres occasionally involves clearing, construction of houses and pavement of surfaces. This reduces the infiltration rates resulting in increased surface and overland flow.

Kenya Water Resource Authority (WRA), a public institution in Kenya, has been mandated to regulate, manage and equitably allocate the national water resources to all users. WRA operates in the five-catchment regions in Kenya. One of the sub catchment being the Mkurumudzi. Mkurumudzi River situated in South - Coastal part of Kenya. It is the main river serving community, sugar factory and a mining firm. The community depend on the river for agricultural purposes since the area is prone to erratic rainfall. Over the years river discharge has gradually decreased in the area forcing the community and other people to seek for alternative sources of water for example by using ground water. Companies too have been forced to construct dams so that they can store water for use during low river flow seasons.

This research involved the use of GIS and SWAT models in analyzing the impact of land use changes on river flow regime. Understanding the effects of Land Use/ Land Cover change in this catchment will help in management of river flows.

1.2 Problem Statement

Mkurumudzi River is a major source of irrigation water to one of the sugar producing industries in South Coast that employs thousands of Kenyans apart from earning the country foreign exchange. The livelihoods of the community is largely dependent on uninterruptible and regular flow of the river which is sensitive to the effects of uncertainties of hydrological changes due to human triggered land use activities.

The tributaries of the Mkurumudzi River faces critical challenges from the surrounding environment. The past studies done by Katuva, (2012) focused on assessing the amount of water abstracted from the river. This study seeks to determine the impact of land use changes in the Mkurumudzi River sub catchment on the flow of the Mkurumudzi River.

The use of computing and advanced modelling software profits today's researchers in that such investigation can be done and possible/likely outcomes determined without the risk of learning from actual 'doing'. This is so especially when trial and error approach yields ineffective, costly and undesirable results.

1.3 General Objective

The overall objective of this study was to assess human induced land use practices and their effects on Mkurumudzi river flows and formulation of alternative measures to maintain water supply for domestic, agricultural, industrial and environmental flows.

1.4 Specific objectives

1. To assess the current land use practices in relation to Mkurumudzi river flows,
2. To analyze the effect of land use on river flow regime,
3. To predict future effects of land use change on river flow,
4. To evaluate alternative solutions for maintaining adequate raw water.

1.5 Research Questions

1. What are the current land use practices?
2. What are the ideal land use practices?
3. What are the requirements to maintain environmental flows?

1.6 Justification

Most of the studies conducted in the sub – catchment mainly focused on the water availability, water abstraction and sediment loads. Katuva, (2012) conducted water allocation assessment in the sub catchment. Impacts of land use on the river flow have not yet been examined. Negative human activities impacts on the land poses a great effect to the water resources. This study focused on the sub catchment to determine the impacts of various land uses. Rainfall, topography, land use/land cover and soil shall be used as key variables for various constraints in the analysis.

This study involved the use of SWAT model subjecting the past scenarios of land use and land cover to predict the future scenarios. In order to minimize the reduction in river flows, there is need to understand the daily land use practices. Strategic planning techniques in water management are required for sustainable water reduction.

Use of models are widely used since they are accurate, reliable and less costly compared to other methods used for determining changes in river flows. This will in turn inform the up-scaled efforts in land conservation in developing countries to achieve water and sanitation Sustainable Development Goals (SDGs).

Chapter 2: Literature review

2.1 Land Use / Land Cover

Land in Kenya is regarded as the most important resource from which the country's economy is based on. Land is a resource used for generating goods and services. Ninety percent of the population living in rural areas derives its livelihood directly from land (Mwagore, 2003). The main land cover types in Kenya are forests, grasslands, wetlands, savannahs, fresh and saline water bodies and deserts. 2.4% of the total land cover is under indigenous and exotic forest. Land in Kenya are used for agriculture, water catchments, nature reserves, industry, urban and rural settlements, mining, pastoralism, transport and communication , tourism and recreation.

Table 2.1 shows the land cover area from 1990 Based on Kenya Vision 2030, Forest cover is expected to increase by 10%.

Table 2. 1 Kenya Land cover coverage (FAO, 2015)

Name of variable	**Area ('000Ha)**				
	1990	**2000**	**2005**	**2010**	**2015**
Forestland	4724	3557	4047	4230	4413
Cropland	9258	9661	9868	10072	10276
Grassland	41522	41654	41496	41080	40664
Settlements	57	87	109	126	143
Otherlands	1004	1574	1035	1044	1053
Wetlands	1472	1504	1482	1485	1488
Total Area for country	58037	58037	58037	58037	58037

2.2 Land Use/ Land Cover Change

Land Use and Land Cover (LULC) are used together for geographical and environmental analysis/studies. Land Cover refers to the physical appearance of a land while land use refers to purpose of which the land is being used. Land cover data provides information about the amount covered by forest, area under agriculture and other land and water types (which refer to wetlands or open waters) while Land use shows how people use the landscape for development, conservation, or mixed uses (NOAA). Management and use of land cover differs from one place to another. LULC is a dynamic variable because it reflects the interaction between socio-economic activities and regional environmental changes, and for this reason, it is necessary to be updated frequently (Butt *et al.*, 2015).

LULC represents the relationship between the socio- economic activities and environmental effects affecting a particular area. Evaluation of watersheds and development of a management strategy require accurate measurement of the past and present land cover/land use parameters as changes observed in these parameters determine the hydrological and ecological processes taking place in a watershed (Butt *et al.*, 2015). Prediction of the effects of land use/land cover on stream flows are important for maintenance of environmental flows and associated services. Basins run off model are used for planning of water resources.

Water resources are greatly affected by land use/land cover (LULC) which is further complicated by the impacts of climate changes more so to the vulnerable ecosystems in arid and semi-arid regions. Reliable prediction of watershed scale availability of water under the inevitable changes of the climate change is crucial for water resources planning and management (Mango et al., no date). These models are able to simulate flows based on various scenarios that affects the catchment. Accurately modelling future runoff regimes is challenging in African catchments with limited current and historical runoff data, but an increasing number of model applications suggest that useful simulations are possible (Mango *et al.*, no date).

Land use activities, development and management of water resource are interdependent (Use and Cover, 2017). According to Yin et al. (2017), human induced catchment activities causes many impacts. Therefore, LULC should be assessed in areas that have critical effects to a country's economic base. These human activities changes the hydrological cycle of a place on processes such as interception, evaporation, infiltration and runoff. Water and environmental management in the region requires improved knowledge of the hydrological impacts of LULC and climate changes. Vegetation cover within the catchment has changed considerably due to human activities, mainly through the conversion of natural vegetation to agriculture, livestock and sugarcane(Yure *et al.*, 2014). These effects can change the water availability in the watershed and the river flow regime.

Studies on the effects of LULC on river flows have been researched by many writers (Yure *et al.*, 2014 , Petchprayoon *et al.*, 2010). Butt et al. (2015) studies on Simly watershed showed that there was a major decline of area under vegetation and increase in area of settlements, which had impact on the river flows. Mutie *et al.* (2006) used the USGS Geo Streamflow model for the analysis of the effects of land use and land cover change on the stream flow on Mara River, which is a transboundary water resource in Kenya and Tanzania.

According to Koch *et al.* (2012), changes in land use in the area is highly expected in an area with increasing population,. Clearing of forest and vegetation for agricultural use is likely to be rampant. Urban development contributes to changes in land surface structure. Building of roads, walkways, rooftops results to decrease in infiltration and increase in the amount of surface runoff especially when there is less water storage. These effects result to high river flows in the entire watershed

Better land management practices lead to reduction of soil erosion and surface runoff. Changes of Biophysical and morphological characteristics of the land cover vegetation affects the circulation of water on the land and atmosphere. According to Yure *et al.* (2014) changes in streamflow matched the land use dynamics. Changes in land cover/land use in watershed area including urbanization and de(/re)forestation continuously affect the water availability as well as the nature and extent of surface and subsurface water interactions thus influencing watershed ecosystems and the services provided by them (Butt *et al.*, 2015) .

Effects of land use change studies manly factor in annual surface runoff received in a catchment. This involve subdividing the catchment, pairing them and conducting hydrological modelling. Paired catchment studies can provide direct evidence of land-use change impacts on runoff; however, they generally require long durations and cover small study areas (Wang *et al.*, 2008). Distributed hydrological models are the most effective tools for predicting land use changes.

2.2.1 Frame work for integrated Land Use Classification

Classification of land use changes depend on structural and behaviour affecting the environmental demand associated to biodiversity and aquatic ecosystems. Change analysis of features of Earth's surface is essential for better understanding of interactions and relationships between human activities and natural phenomena (Yure *et al.*, 2014). The following are frameworks used in classification of land use:

1. Classification should be done for the entire study area.
2. Classified categories should not overlap
3. Classification should cover all the activities in the entire study area.
4. Classification should merge with the legend
5. In areas with more than one activity, each activity should be clearly defined.
6. Policies attached to study area and respective activities should be clearly defined.

Assessing land use changes and patterns is important for planning and management. Land-use change influences land-cover type, alters surface runoff generation and then affects the catchment hydrological process (Wang *et al.*, 2008) . The absence of trees and shrubs in the first vegetation type implies a minimum in surface evapotranspiration and, consequently, a maximum in runoff, with the opposite occurring in the later vegetation type scenario (Saurral, Barros and Lettenmaier, 2008). Table 2.2 shows land use classification developed for use under remote sensing.

Table 2. 2 U.S.G.S Land Use Classifications (Shekhar and Xiong, 2008)

LEVEL 1	LEVEL II
1 Urban or Built-up Land	11 Residential 12 Commercial and Services 13 Industrial 14 Transportation, Communications and Utilities 15 Industrial and Commercial Complexes 16 Mixed Urban or Built-up Land 17 Other Urban or Built-up Land
2 Agricultural Land	21 Cropland and Pasture 22 Orchards, Groves, Vineyards, Nurseries and Ornamental Horticultural Areas 23 Confined Feeding Operations 24 Other Agricultural Land
3 Rangeland	31 Herbaceous Rangeland 32 Shrubs and Brush Rangeland 33 Mixed Rangeland
4 Forest Land	41 Deciduous Forest Land 42 Evergreen Forest Land 43 Mixed Forest Land
5 Water	51 Streams and Canals 52 Lakes 53 Reservoirs 54 Bays and Estuaries
6 Wetland	61 Forested Wetland 62 Nonforested Wetland
7 Barren Land	71 Dry Salt Flats 72 Beaches 73 Sandy Areas other than Beaches 74 Bare Exposed Rocks 75 Strip Mines Quarries and Gravel Pits 76 Transitional Areas 77 Mixed Barren Land
8 Tundra	81 Shrubs and Brush Tundra 82 Herbaceous Tundra 83 Bare Ground Tundra 84 Wet Tundra 85 Mixed Tundra
9 Perennial Snow or Ice	91 Perennial Snowfields 92 Glaciers

Land Use / land cover classification System (LULCCS) used in classification of remote sensor data is a resource – oriented type of land cover classification system This classification system is purely designed for use in US and therefore require to be modified so as to fit classification of Mkurumudzi catchment. A classification scheme has to be taxonomically correct, which means it is exhaustive, mutually exclusive, and hierarchical in order to guarantee high classification accuracies (Mango *et al.*, no date)

In the study of Mkurumudzi River, Anderson Land Use land Cover classification system was adopted. Table 2.3 shows the classified scheme based on the type of land cover and land use available in the basin:

Table 2. 3 Mkurumudzi river catchment land use/land cover system

No.	Land Cover / Land Use Type
1.	Forest
2.	Shrubs
3.	Grassland
4.	Agriculture

The above land classification was implemented and used in the study of the land use / land cover effects on river flow in the sub-catchment.

2.2.2 Mapping Land Cover

Geographical Information System (GIS) is a tool used to create geo-database and integrate the satellite data through use of overlaying, analysis and assessment techniques. According to Butt *et al.* (2015) there are many satellite images available and free from downloading as shown in the Table 2.4.

Land cover features are obtained through supervised area classification. An area of study is divided into sections of polygons that act as a set of training areas. Polygons with the same features are grouped together as one land use. In this study, the land use for Mkurumudzi river catchment was classified into four main categories for identifying the changes in land use. These land use categories include forested area, shrubs, grasslands and agricultural land. Land conversion of forested area to agricultural area is assumed to contribute to increased streamflow in a catchment due to high overland flows although in some areas the rainfall trend affect the flows.

Remote Sensing is one of the tools used for mapping of land cover. This is through the studying and analysing satellite and aerial images. An area of study is characterised by depressions, hills, forest and shrubs with agricultural farming done. Remote sensing involves use of multi-temporal spectra to analyse quantitatively historical human activities on the land.

Table 2. 4 Available Satellite Images (Butt et al., 2015)

Datasets	Year of acquisition	Spatial resolution / scale	Source	Format
Landsat 8 OLI satellite image	June 2015	30 m	U.S Geological Survey	Raster
CORINE Land Cover (CLC)	2012	25 m	European Environment Agency	Vector
GlobeLand30	2012	30 m	Geomatics Center of China	Raster
Elevation EU-DEM	2010	30 m	GMES / Copernicus	Raster
Orthophotos	2013	0.5 m	National Agency for Cadaster and Land Registration (A.N.C.P.I. Bucharest, Romania)	Raster
NDVI, NDBI, NDWI Indices	2009	30 m	Landsat 8 OLI	Raster

Use of different techniques for classification of LULC have been used for the extraction of thematic information that are found in an image. Classification can be carried out by a number of methods and they include; Algorithms based on parametric and nonparametric statistics that use ratio and interval – scaled data, use of hard or soft (fuzzy) set of classification logic to create their respective thematic outputs, use of per-pixel or object oriented classification logic, and hybrid approaches (Mango, 2010).
Supervised classification, which involve processing of satellite images with the help of computer techniques, and manual calibration that involves visual interpretation were employed in classification of land use categories in the catchment. In this type of classification, it is important to know the location of the land cover and the types of land use that exists in the study area before classification is done. This method uses combination of ancillary data that are obtained from photographs interpretation, fieldwork study, personal experiences and map analysis. Homogeneous land cover types and their spectral characteristics which are located from these auxiliary data are used to train classification algorithm which helps in the classification of the entire image. Maximum likelihood classifiers are commonly used in most studies for supervised classification. This process adopts the assumption of training data statistics, whereby each class found in each band has a multivariate normal

distribution (Gaussian) used for calculation of covariance matrices and class variance. The maximum likelihood method requires more computations per pixel than other techniques like parallelepiped or minimum distance classification algorithm (Petchprayoon *et al.*, 2010)

Supervised classification based on decision rules have proven to be successful and they are able to perform a classification based on conditions and rules stored as a knowledge base within the computer and these can be called upon when it comes to the solution of classification problems (Mango, 2010). Satellite images are used to validate the classified images. Satellite image data sets are re-processed before determining and assigning the land use to a particular pixel. A pixel contains signatures that helps in classification that denotes a particular land use. All the polygons with same spectral signatures are grouped together. Landsat Thematic Mapper has 7 spectral bands. These infrared bands are the Blue, Green, Red, Near infrared, Thermal infrared and 2 Middle infrared bands. Short wave infrared band has high reflectance values of 0.65 – 0.80. This indicates a vegetated area with high moisture from the soil. It is important to ensure that there is minimal confusion in assignment of these spectral signatures. Different bands of the electromagnetic spectrum are used to detect or differentiate biophysical variables and the selection of these bands is carried out in a way to increase the contrast between them and their background, improving the probability that the desired features will be separated from the remote sensor data (Mango, 2010).

2.2.3 Land Cover Accuracy Assessment

The remote sensing derived thematic maps obtained from the satellite imaginary data sets sometimes may contain errors. It is important for the user to ensure that this data are error free before used in policy decisions and scientific research. The sources of these errors should be identified and the errors minimised this is by subjecting the data through accuracy assessment.

To understand the land cover map accuracy and its limitations, the magnitude and relative importance of these causes must be determined (Mango, 2010). There are two factors, which influences the accuracy assessment of the remote sensed data. These factors are the correctness of the labelling procedures and information contained in the data. Correctness of the labelling procedures depends on how the analyst is performing the analysis. Analysis done by an expertise has few errors compared to one done by a non-expertise. The second method involve comparing the signals recorded by a sensor and uniqueness of the relationship between the different land cover types to be identified in the studies.

2.3 Hydrological modelling

Hydrological processes in a water shed have impacts on the climate, topography, geology and land use. A watershed includes a land area with different water channels (rivers and streams) draining to a larger water body. Research has demonstrated that a disturbed hydrological cycle results in a disturbed human society & natural environment with respect to health, industrial and municipal water. Extreme rainfall events results in flooding, soil erosion, deposition of sediments at riverbanks and destruction of infrastructure in which key economies of the country rely on. Adverse drought conditions has often led to reduced irrigation and domestic water. These conditions greatly affect human life cascading to retarded socio-economic development. Decreased surface flow, increased infiltration capacity of water and enriched base flow resulted in the growth of land cover (Thi, et al., 2014).

Hydrological process involves mathematically defining the amount of runoff leaving the watershed and the amount of rainfall received. Hydrological models provide a means of quantitative prediction of catchment runoff that may be required for efficient management of water resources systems (Mango *et al.*, no date). Physical models are used for the assessment of the hydrological processes in a water shed. Use of current effects being experienced can be used to predict future hydrological processes in the watershed. Analysis of hydrological responses to climate and land-use change in a basin can be performed by combining a calibrated basin-scale model with historical data or future scenarios (Yure *et al.*, 2014).

Disturbed hydrological cycle threatens human health, industrial, and availability of municipal water. Climatic changes disturbs human society & natural environment. Poor farming methods, clearing of forests, and draining of wetlands causes modifications to the surface of the Earth. The mode of land cultivation and deforestation alters the infiltration and runoff rates. The type of irrigation system changes the use and distribution of water. Water abstraction for agricultural use also changes the natural distribution of surface and ground water. Reduction in rainfall leads to higher demand for crop water requirement for irrigated crops. This leads to reduction of water in the streams and underground water.

The relative amounts of conversion or absorption, the losses by evaporation and transpiration, and the quality of the water produced as streamflow depend to a considerable extent on the condition of the land that receives the precipitation (Bullard, E. W. 2015.). Bare or impervious areas and a more developed storm water drainage produce greater volumes of high-energy stormflow and reduce base flow in a stream (Atlanta, M. 2002).

The hydrological cycle (also known as the water cycle can be described as the continuous circulation of water in the earth and atmosphere. The main influencers of the hydrological cycle of a watershed include rivers, land cover and land use changes. The relative amounts of conversion or absorption, losses by evaporation and transpiration, and quality of water produced as streamflow depend to a considerable extent on the condition of the land that receives the precipitation. This water content in a hydrological cycle processes occur simultaneously and remains the same thou distribution changes. Land use and land cover change can alter the basin hydrology by affecting evaporation, soil infiltration capacity, and surface and subsurface regimes and ultimately affecting water quantity and water quality(Shrestha *et al.*, 2018).

The hydrological processes describing a watershed include:

1. Precipitation
2. Runoff
3. Evaporation
4. Transpiration
5. Infiltration
6. Interflow
7. Ground water flow

Figure 2.1 represent an example of a hydrological process of a watershed.

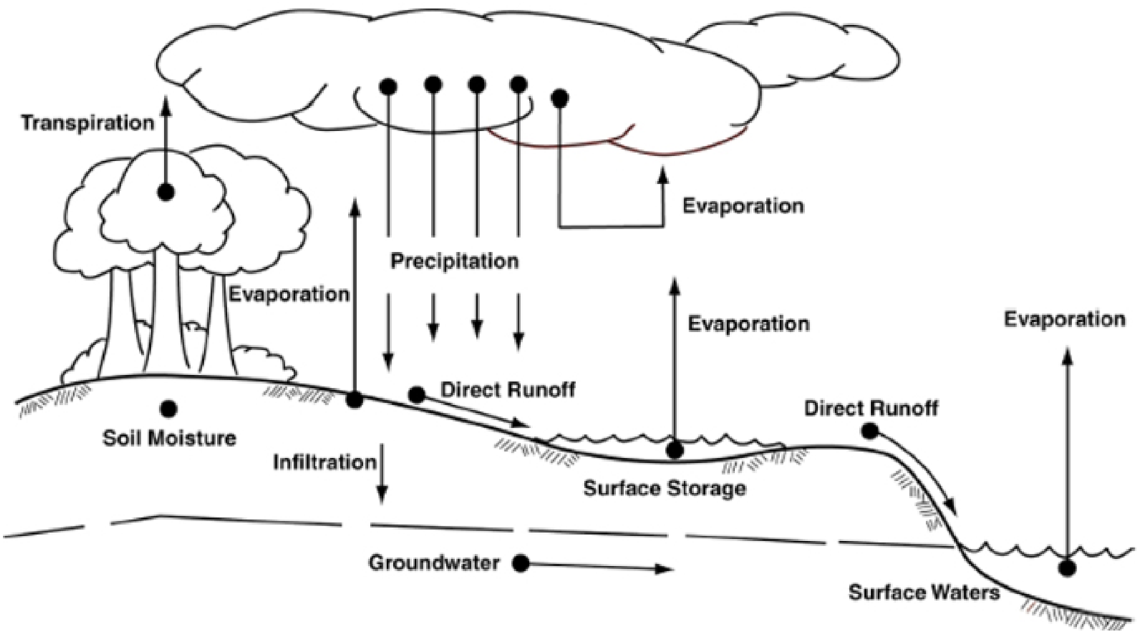


Figure 2. 1 Representation of a hydrological cycle (Shaver et al., 2007)

2.3.1 Precipitation

This is defined as a process that occur when water falls to the land surface because of rainfall, snow and other processes such as hail and sleet. The three main mechanisms through which precipitation is formed are frontal lifting, orographic lifting and convective lifting. Precipitation is formed when air rises and cools making water vapour to condense to liquid state. Precipitation varies in space and time. These factors are affected by the atmospheric circulation pattern and local factors.

There are different methods of computing the amount of rainfall received in a catchment. Arithmetic mean method is the simplest method of determining the average rainfall received. This involves averaging the rainfall recorded at a number of gage stations that have been uniformly distributed.

Thiessen polygon method is applied when some gages are considered more representative of the area than others. It is based on the assumption that at any point in the watershed, rainfall is the same as that of the nearest gage. Thiessen polygon formula is expressed as:

$$\bar{P} = \frac{1}{A}\sum_{j=1}^{J} A_j P_j$$

Where:

$\bar{P}$ = Mean rainfall (mm)

J =gages number

A_j = area within watershed (km^2)

P_j = rainfall recorded at the j^{th} gage (mm)

The watershed area (A) is calculated as follows:

$$\mathrm{A} = \sum\nolimits_{j=1}^{J} A_j$$

2.3.2 Evaporation

This is the loss of water from the surface to the atmosphere. The main factors influencing evaporation are the supply of energy and ability to transport the water vapor. Transportation of water vapour depend on wind velocity. Water is lost from–leaves of plants through transpiration. The two evaporation processes constituting loss of water from the land surface and through the plant leave is known as evapotranspiration.

The most common method for measuring evaporation is energy balance method determined as according to the expression.

$E_r = 0.0353R_n$ (mm/day)

Where:

R_n = net radiation (W/m^2)

Actual evapotranspiration is represented by the equation:

$$E_t = k_s\, k_c\, E_{tr}$$

Where:

E_{tr} = Referenced crop evapotranspiration

K_c = Crop coefficient ($0.2 < kc < 1.3$)

E_t = Actual evapotranspiration

K_s = Soil coefficient.

2.3.3 Infiltration

This is a process whereby water from the ground surface penetrates into the soil. The rate at which water infiltrates depends on the surface condition, soil properties such as porosity, hydraulic conductivity and moisture content.

In this study, Green –Ampt formular was used to calculate the amount of water that infiltrated. Different soil types/classes has various parameter as shown in table 2.5.

Green – Ampt formular is expressed as follows:

$$F(t) = L(\eta - \theta_i)$$

$$= L\Delta\theta$$

Where:

Θ = Moisture content

η = Porosity

L = Depth of soil (cm)

2.3.4 Runoff

It is also known as overland flow. This include the water that travel over the land surface, discharged to streams and rivers, and further into larger bodies such as oceans and seas. Surface runoff occurs when rainwater hits saturated and impervious ground and overflows. This water begins to flow through the land surface downhill through gravity. Human activities influences the amount of surface run off. Urbanization and development of the natural land has led to increase in impervious surfaces which includes homes, parking and buildings. This leads to increase in volume of runoff and decreased runoff time. These effects may result to high frequency of floods.

There are different methods of estimating the amount of runoff from rainfall. These methods are:

1. Runoff volume method

   This method involve obtaining the total rainfall, the drainage area, soil and characteristics of land cover. Soil characteristics is used in obtaining the initial abstraction rate and infiltration rates. To obtain the runoff volume, the total amount of water infiltrated is subtracted from the total amount of rainfall received

2. Peak Runoff Rate methods

This method estimate the peak runoff rate from a given storm event. The drainage area Time of concentration is also estimated.

Table 2. 5 Green –Ampt Infiltration Parameters for various soil classes (David et al., Applied Hydrology)

Soil Class	**Porosity η**	**Effective Porosity θ_i**	**Wetting front soil suction head φ (cm)**	**Hydraulic conductivity κ (cm/h/**
Sand	0.437 (0.374-0.500)	0.417 (0.354-0.480)	4.95 (0.97-25.36)	11.78
Loamy sand	0.437 (0.363-0.506)	0.401 (0.329-0.473)	6.13 (1.35-27.94)	2.99
Sandy loam	0.453 (0.351-0.555)	0.412 (0.283-0.541)	11.01 (2.67-45.47)	1.09
Loam	0.463 (0.375-0.551)	0.434 (0.334-0.534)	8.89 (1.33-59.38)	0.34
Silt loam	0.501 (0.420-0.582)	0.486 (0.394-0.578)	16.68 (2.92-95.39)	0.65
Sandy clay loam	0.398 (0.332-0.464)	0.330 (0.235-0.425)	21.85 (4.42-108.0)	0.15
Clay loam	0.464 (0.409-0.519)	0.309 (0.279-0.501)	20.88 (4.79-91.10)	0.10
Silty clay loam	0.471 (0.418-0.524)	0.432 (0.347-0.517)	27.30 (5.67-131.50)	0.10
Sandy clay	0.430 (0.370-0.490)	0.321 (0.207-0.435)	23.90 (4.08-140.2)	0.06
Silt clay	0.479 (0.425-0.533)	0.423 (0.334-0.512)	29.22 (6.13-139.4)	0.05
Clay	0.475 (0.427-0.523)	0.385 (0.269-0.501)	31.63 (6.39-156.5)	0.03

2.3.5 Transpiration

Transpiration is a process whereby a plant extracts water by the roots, transported through the stem and lost to the atmosphere through stomata (tiny pores/openings in the plant leaves). Transpiration is a factor that is mostly used to determine local microclimate and rainfall.

2.3.6 Interflow

Interflow is the downward movement flow water because of restriction by an impenetrable layer of material. This causes movement of water in a lateral direction and discharge at a point formed naturally or by human being.

The rate of lateral flow depends on the soil properties such as the interconnection of pore spaces. Primary requirement for interflow is the presence of a shallow soil horizon of high hydraulic conductivity underlain by at least one horizon of significantly lower hydraulic conductivity(Chanasyk and Verschuren, 1983).

2.3.7 Ground water flow

Ground water flow creates base flow for ground water recharge and surface flow. Ground water is mostly used for drinking and irrigation. Groundwater can be found under unconfined to semiconfined conditions, in weathered and fractured formations, respectively with specific hydrodynamic properties from the top to the bottom. Seepage from the surface water bodies and streams are additional input to the watershed recharging system.

2.4 SWAT Modelling

Computer modelling is one of the effective method of quantifying the nature of surface runoff and determining effective land management practices. Snyder and Stall (1965) defined "model" as a symbolic form in which a physical principle is expressed. A hydrologic model can be defined as a mathematical model used to represent the hydrological processes in a water shed which results from precipitation that generates surface runoff. A model approximates the actual system whereby its inputs and outputs are measurable input and output variables that are equation inputs. These variables may be function of space and time and or probabilistic or random in nature. SWAT Model provides variables for assessing changes in the hydrological processes in a catchment. The hydrological responses to LULC and climate changes are often investigated through scenario simulations using the SWAT model(Yin *et al.*, 2017).

SWAT model simulates hydrological processes such as surface runoff at the daily timescale based on information regarding weather, topography, soil properties, vegetation, and land management practices(Yin *et al.*, 2017). The hydrological process is driven by climatic variables and requires moisture and energy inputs. These inputs include precipitation, maximum and minimum temperatures, solar radiation, wind speed and relative humidity. Hydrologic processes simulated by SWAT include canopy storage, surface runoff, infiltration, evapotranspiration, lateral flow, tile drainage, redistribution of water within the soil profile, consumptive use through pumping (if any), return flow, and recharge by seepage from surface water bodies, ponds, and tributary channels(Arnold *et al.*, 2012).

SWAT has been used to model the sediment and nutrient loss increase and reduction as a result of land use change in agricultural lands and it has also successfully been used to quantify the impacts of the implementation of best management practices (BMPs) through implementation of water quality management plans on the long term. The catchment is divided into HRU with homogenous characteristics such as areas with same land use, slope and topography(Mango *et al.*, no date). It has several advantages, such as multiple functions, a modular design and only a few parameters need to be optimized compared with many other hydrological models (Wang *et al.*, 2008).

SWAT is a temporally continuous, physically based hydrological and qualitative model. United States Department of Agricultural-Agricultural Research Service (USDA-ARS) developed this model. SWAT operates on a daily time step and is designed to predict the impact of land use and management on water, sediment, and agricultural chemical yields in ungauged watersheds (Arnold *et al.*, 2012).The model is a process based and is able to continuously compute simulations for a long period of time. SWAT model considers both upland and stream processes and it can be used to assess and quantify several land management practices in catchment. The size of the land area does not affect the output results of the catchment These land management practices include water discharge, sediment and chemicals yields in a catchment with different soil, land use and management conditions. SWAT has the following main modules: weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond & reservoir storage, crop growth & irrigation, groundwater flow, reach routing, nutrient & pesticide loading, and water transfer (Gupta, S.K. 2011).

This model requires spatial and temporal data. Spatial data include a digital elevation model (DEM), land-use map and soil map. The temporal data include hydrological data (stream flow & sediment yield) and climatic data (precipitation, solar radiation, relative humidity, wind speed and temperature) (Welde *et al.*, 2017). Landsat thematic Mapper data for 2008 with 30m resolution were used for analysis. Land use classification was done based on the USGS land use/land cover classification system (LULCCS).

SWAT model contains land cover/plant growth parameters under ideal conditions. The model is able to quantify the impact of stresses on plant growth. SWAT groups plants into seven categories: warm season annual legume, cold season annual legume, perennial legume, warm season annual, cold season annual, perennial and trees, (Biannual plants are classified as perennials). The model uses same base temperature (T_BASE) for calculating the heat unit accrued daily throughout the growing season. This factor affects the results obtained.

Water balance is the driving force behind all the processes in SWAT because it impacts plant growth and the movement of sediments, nutrients, pesticides, and pathogens (Arnold *et al.*, 2012). The process involves separation of the water shed hydrological processes into land phase and routing phase. Land phase include controlling the amount of water, sediments, nutrients and pesticides load while routing phase also known as in-stream phase include the movement of water and nutrients. SWAT simulates the hydrological cycle based on the following water balance equation:

$$SW_t = SW_0 + \sum_{i=1}^{t} \left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right)$$

where,

SW_t = final soil water content (mm)

SW_o = initial soil water content on day i (mm)

t = time (days)

R_{day} = amount of precipitation on day i (mm)

Q_{surf} = amount of surface runoff on day i (mm)

E_a = amount of evapotranspiration on day i (mm)

W_{seep} = amount of water entering the vadose zone from the soil profile on day i (mm)

Q_{gw} = amount of return flow on day i (mm)

Chemical and physical soil parameters are part of SWAT model input parameters. Soil types vary from region to region. The volume and the rate of surface runoff and infiltration is affected by the type of soil in surface and subsurface. These soil characteristics include soil texture, permeability, moisture content, structure and thickness.

Permeability affect the rate at which rainfall can enter and move through the soil. Soil texture, thickness and structure is used to determine the amount of water that can be absorbed and detained by the soil. Sandy soils has high water storage capacity than silts and clays. The distribution of the underlying soil within a basin affect the amount of water availability in the river. Thin layers of soil found at the top of soil structure has less water storage capacity than soils in deeper soil that has similar texture. Soil moisture content is the measure of the available storage capacity and affects the permeability rates

SWAT model uses two methods for calculation infiltration. They include Green & Ampt infiltration and SCS curve method.

SC equation is expressed as follows:

$$Q_{surf} = \frac{\left(R_{day-} - I_a\right)^2}{R_{day} - I_a + S}$$

Where:

Q_{surf} = accumulated rainfall run off (mm)

R_{day} =Rainfall depth in a day (mm)

S = Retention Parameter (mm)

Retention parameter S is affected by changes in land use, slope, managements and slope. It varies from one area to another. Retention parameter is estimated from the formula include:

$$S = 25.4(\frac{1000}{CN} - 10)$$

Where:

CN = curve number for the day

The model uses two modules for calculation of surface runoff. The first method involves use of runoff curve number. The runoff curve number method used for calculation of infiltration. This runoff curve number method was developed by the Soil Conservation Service (SCS) , an institute in United States Department of Agriculture. The second method is the use of the Green-Ampt infiltration method. Runoff curve number has been proved more efficient than Green-Ampt infiltration method.

Penman –Monteith equation is used for calculation of potential evapotranspiration. Soil evaporation is affected by soil depth, soil moisture and potential evaporation. Factors that affect vegetation transpiration are soil root depth, leaf area index and potential evapotranspiration. The model depends on kinematical storage model for calculation of soil interflows. This model depends on hydrological conductance, slope and soil moisture change. Base flow equation is expressed as follows:

$$Q_{gw,i} = Q_{gw,i-1}\ exp(-\alpha_{gw}\Delta t) + w_{rchrg}[1 - exp(-\alpha_{gw}\Delta t)]$$

Where:

$Q_{gw,i}$= Ground water flow into the channel on day i (mm)

$Q_{gw,i-1}$= Ground water flow into the channel on day i-1 (mm

α_{gw}= Base flow recession constant

Δt = Time step (1day)

w_{rchrg}= Amount of recharge entering the aquifer on day i

Mango *et al.* (no date) made use of the SWAT model in assessing the effects of land use and climate change scenarios of on the hydrology of the upper Mara River, Kenya. SWAT model was applied to the arid region of northwest China to examine the effect of snow, rainfall and temperature changes and land-use change on the hydrological cycle in the area (Wang et al., 2008). Studies done by Katuva (2014) on accessing the availability of water for allocation to various users indicated that there are 18 water abstractors who depend on river Mkurumudzi. Due to high water demand, there is possibility of increased water abstractors in the catchments. Shimba Hills forest, which is lies in catchment, also faces encroachment by human beings and destruction by wildlife. According to the studies done in the coastal rea by Ruri Consultants (2013) the key drivers for afforestation are: Subsistence agriculture, Commercial agriculture – sugar / bio-fuels, Infra-structure - Tourism establishments, Wood extraction, Poles ,Charcoal production, Firewood, Timber , Agricultural expansion , Grazing and browsing Wildlife damage – elephants in (Shimba Hills), Kwale Mining – still minor but growing at the coast. This has resulted to massive destruction of vegetation. These activities has resulted to reduction of increased surface water flows during rainy seasons.

2.5 Model Sensitivity Analysis, Calibration and Validation

Once the model has been run, the output results obtained (in this case, the simulated flows) are subjected to calibration and validation. The first step is to find out the sensitive parameters that affects the flow in the watershed. Sensitivity analysis is a process of varying various parameters to in order to determine the rate at which it affects the model output. SWAT model has various parameters of land management, soil properties and climate that influences the output results of the stream flows in a catchment. The following are parameters that were used for sensitivity analysis within Mkururmudzi catchment:

I. The curve number (CN)
II. Ground water delay
III. Base flow alpha factor
IV. Depth of water in the aquifer
V. Soil hydraulic conductivity
VI. Available water capacity of the soil.

There are two methods used in SWAT for analyzing sensitive parameters in a water shed. The first method is known as local method. This method uses one parameter at a time in the simulation. Its disadvantage is that it is difficult to analysis more than one parameter at the same time. The second method used in sensitivity analysis is known as global method. This method involves the use of many parameters at the same time to determine the effects on the output results. This method requires a high number of simulations hence requires a lot of time in order to obtain the results. The results obtained from these two methods are different.

SWAT – cup model was used to analyse the sensitivity of the parameters which affect the simulated flows. The SWAT –cup model has two methods which can be used to determine the sensitive parameters. These methods include:

i. One-at-a-time sensitivity analysis

This sensitivity analysis is used to show the sensitivity of one variable when all the other variables with certain values have been kept constant. The disadvantage of this method is that it is difficult to know the right values of the other constant variables. Therefore, the sensitivity of one parameter depends on the other parameters. Figure 2.2 Shows the variability of the parameters.

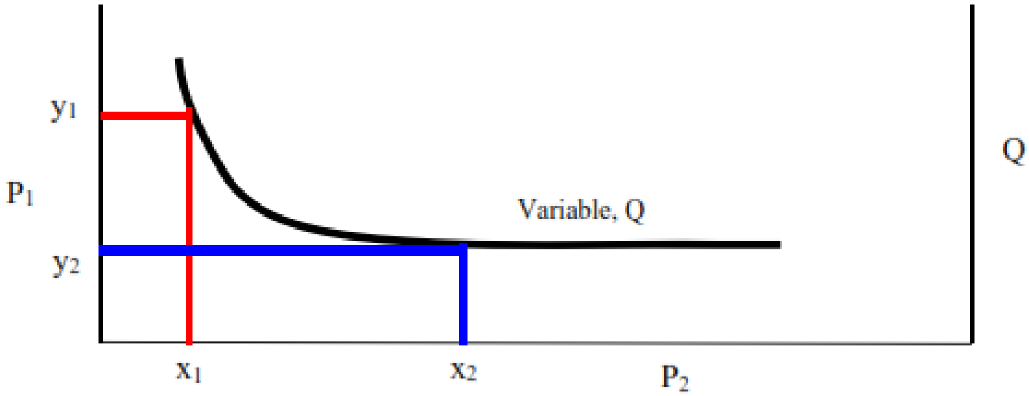


Figure 2. 2 An illustration of parameter variability (Shekhar and Xiong, 2008)

The graph in figure 2.2 illustrates as follows, If value of parameter P_1 is kept constant at y_1, then small changes is parameter P_2 make significant changes in variable Q. This indicates that P_2 is quite a sensitive parameter. While if the values of parameter P_1 is kept constant at y_2 value, then changes in parameter P_2 around x_2 will give the impression that P_2 is not a sensitive parameter as the variable does not change by much. Therefore, the values of the fixed parameters make a difference to the sensitivity of a changing parameter.

ii. Global Sensitivity analysis

In this method, sensitive parameters are determined by use of multiple regression system, which regresses the Latin hypercube generated parameters against the objective values. The results of the sensitivities are the estimates of the average change in the objective functions resulting from changes in each parameter, while all other parameters are changing. In this method, t-stat and p-value are used to measure the sensitivity of a parameter. The larger, in absolute value, he value of t-stat, and the smaller the p-value, the more sensitive the parameter. The t-stat is the coefficient of a parameter dived by its standard error. It is a measure the precision with which the regression coefficient is measures. If a coefficient is large compared to its standard error, then it is probably different from 0 and the parameter is sensitive. The p-value is used to describe the effectiveness of a parameter. The p-value for each term tests the null hypothesis that the coefficient is equal to zero. A p-value of < 0.05 is generally the accepted point at which to reject the null hypothesis. A large p-value means that the changes in the predictor are not associated with the changes in response.

Calibration of the simulated flows is then done after sensitivity analysis. Calibration is a process whereby the difference between the simulated values obtained from the model and the observed values are reduced. This difference is reduced by varying the parameters that have been identified to be influencing the output results. Calibration involves optimization of the objective function and comparison of the predicted output and observed data under the same conditions. It is important to select carefully the input parameters that are within the certainty range. Parameter estimation through calibration is concerned with the problem of making inferences about physical systems from measured output variables of the model (e.g., river discharge, sediments concentration, nitrate load, etc.) (Abbaspour, Vaghefi and Srinivasan, 2017). Mathematical equations for calibration are represented as follows:

$$Min: \; g(\theta) = \sum_{j}^{v}\left[w_j\left(\sum_{i=1}^{n_j}(x_0 - x_s)_i^2\right)\right]$$

$$Max: g(\theta) = \sum_{j}^{v}\left[w_j\left(1 - \frac{\sum_{i=1}^{n_j}(x_0 - x_s)_i^2}{\sum_{i=1}^{n_j}(x_0 - \bar{x}_0)_i^2}\right)\right]$$

Where:

g = The objective function

θ = A vector of model parameters

x_0 = An observed variable

x_s = The corresponding simulated variable

v = The number of measured variable to be used to calibrate the model

w_j = The weight of the jth variable

n_j = The number of the measured observations in the jth variable

The variable v is also known as the multi – objective function and is always greater than 1. In SWAT model, it represents the variable of the discharge, sediments and pollutants. In this study, it represents catchment discharge. Input uncertainty in SWAT – CUP is express as 95% prediction uncertainty (also expressed as 95PPU)

Calibration is also linked to model uncertainty. Model uncertainty analysis refer to multiplication or increasing all the model uncertainty inputs required by a model output. These model uncertainty inputs are zoned for the particular area of interest/study. Input uncertainties can stem from the lack of knowledge of physical model inputs such as climate, soil, and land-use, to model parameters and model structure (Abbaspour, Vaghefi and Srinivasan, 2017). Conceptual and technical issues are some of the problems faced during calibration. These include:

i. Difficulties in parameterization
ii. Definition of objective function
iii. Inadequate definition of the base model
iv. Insufficient model parameters
v. Time constraints
vi. Different optimization algorithms
vii. Non-uniqueness
viii. Model conditionality

Once calibration has been done, the next step that follows is validation. Validation refers to selection of model input parameters for comparison of the output values with observed data. Validation is a process used to build model confidence by use of calibrated parameters. During this process, the input parameters obtained during calibration are used without changes. The simulated results are then compared with the observed values and used for further analysis.

SWAT model has more than 40 parameters used for calibration. Filtering out the most influential parameters before calibration is important. There are two methods of calibration applied in ARCSWAT; Manual calibration and automatic calibration. Manual calibration involve assigning and varying a parameter one at a time, while automatic calibration involve use of SWAT-CUP tool for calibration. Figure 2.3 shows an example of a flowchart that shows the steps followed when using manual calibration in SWAT model.

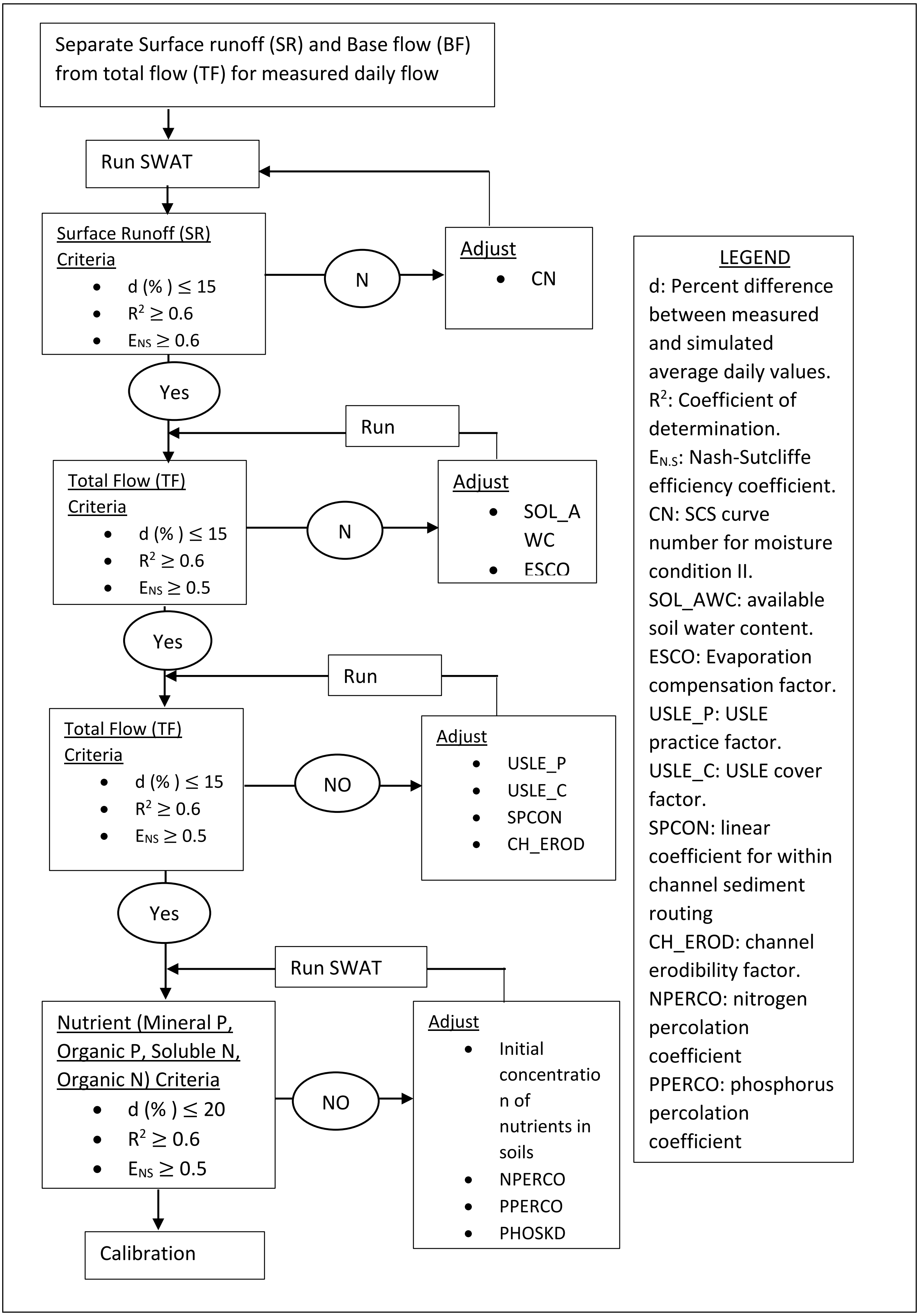


Figure 2. 3 An example of SWAT manual calibration flowchart (D. N. Moriasi *et al.*, 2007)

Use of manual calibration enables the user to understand best the hydrological processes in the catchment and parameter analysis. Sensitivity analysis in SWAT modelling is useful in during calibration and uncertainty analysis in order to achieve the best goodness – of – fit.

SWAT-CUP is a calibration uncertainty program recently developed as a decision making tool, which uses a semi-automated approach mechanism for calibration, sensitivity, and uncertainty analysis. SWAT-CUP contains the following calibration methods: Sufi-2, GLUE, ParaSol, McMc and PSO.

Sufi-2 method was used in this study to investigate sensitivity and uncertainty of various parameters that affect stream flows. This method has been widely used for sensitivity and uncertainty analysis of hydrological models. SUFI – 2 operates by running more than 5 simulations. Each iteration has parameters which ranges get smaller zooming per study area. The results produced after each iteration are better than the previous. As the parameters gets smaller, the value of 95PPU also gets smaller thus producing small values of R and P factors.

Input uncertainty in SWAT – CUP is express as 95% prediction uncertainty (also expressed as 95PPU). Figure 2.4 illustrates the representation of 95PPU with best-simulated and observed values. T-test and p-values are used in measurement of sensitivity and its significance to the model. 95PPU factor is used to quantify the fitness between the simulated results. P factor refers to the percentage of the observed data enveloped by the modelling results while R factor is the thickness of the 95PPU envelop. P- factor of > 70% and R- factor of around 1 is ideal for discharge. R - factor is calculated using the following equation:

$$\mathrm{R-factor} = \frac{(1/2)\sum_{t_t}^{M}\left(y_{t\,t97.5\%}^{M} - y_{t\,t2.5\%}^{M}\right)}{\sigma_{obs}}$$

Where:

$y_{t\,t97.5\%}^{M}$= Upper boundary of the 95PPU

$y_{t\,t2.5\%}^{M}$ = Lower boundary of the 95PPU

σ_{obs} = Standard deviation of the observed data

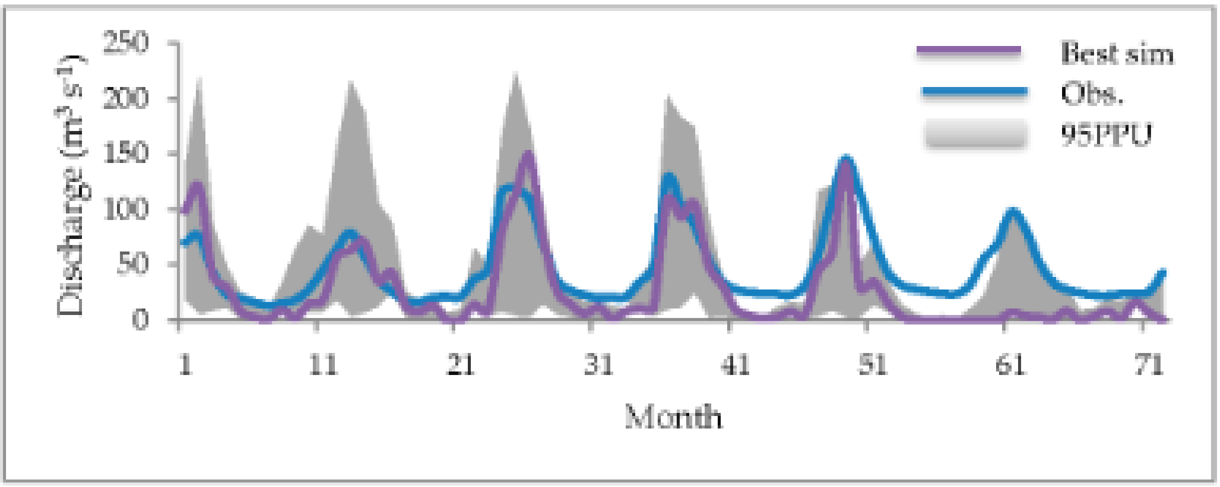


Figure 2. 4 An illustration of 95% model prediction (95PPU) (Abbaspour, Vaghefi and Srinivasan, 2017)

It is important to test model efficiency and accuracy. There are many methods for accessing the efficiency and accuracy of the results obtained from a model. In this study, three methods were used. These are:

1. Coefficient of determination (R^2)
2. Nash-Sutcliffe Efficiency (NSE)
3. Percent Bias (PBIAS)

Nash-Sutcliffe index (NSI), the coefficient of determination (R^2) and Percent Bias (PBIAS) are statistical indexes that were used to represent the correlation between the observed value and simulated value in the SWAT model.

i. Nash-Sutcliffe index (NSI)

NS is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance (da Silva *et al.*, 2018). The NSI formula is as follows:

$$\text{NSI} = 1 - \frac{\sum_{i=1}^{n}(O_i - P_i)^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2}$$

Where:

O_i = Observed flow discharge at time i,

$\bar{O}$ = Average observed flow discharge,

P_i = Simulated flow discharge at time i,

n = Number of registered flow discharge data.

According to Moriasi et al., (2007), the simulating quality of a model is assessed in four levels (

- 0.75<NSI=1: very good.
- 0.65<NSI=0.75: good.
- 0.50<NSI=0.65: satisfaction.
- NSI<0.50: dissatisfaction,

A model prediction with NSI value of greater than 0.5 is considered satisfactory.

ii. Coefficient of determination (R^2)

The R^2 describes the degree of collinearity between simulated and measured data, and defines the proportion of the variance in measured data explained by the model(da Silva *et al.*, 2018). The R^2 formula is as follows:

$$R^2 = \left[\frac{\sum_{i=1}^{n}(O_i - \bar{O})(P_i - \dot{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \bar{O})^2}\sqrt{\sum_{i=1}^{n}(P_i - \dot{P})^2}}\right]^2$$

Where:

O_i = Observed flow discharge at time I (m^3/s),

$\bar{O}$ = Average observed flow discharge (m^3/s),

P_i = Simulated flow discharge at time I (m^3/s),

$\dot{P}$= Average simulated flow discharge (m^3/s),

n = Number of registered flow discharge data.

Model prediction is considered "unaccepted or poor" if R^2 value is less than or very close to zero. If R^2 value is one, then the model prediction is "perfect". However, there are no explicit standards specified for assessing the model prediction using these statistics (Santhi et al., 2001).

iii. Percent Bias (PBIAS)

PBIAS measures the tendency of the observed values to be higher or lower than the simulated. PBIAS value ranges between -10 to 10 with optimal value of 0.0. Low values indicate that the model is more accurate. PBIAS is calculated using the following formular:

$$\text{PBIAS} = \frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)\times 100}{\sum_{i=1}^{n}\left(Y_i^{obs}\right)}$$

Where:

PBIAS = Deviation of data being evaluated (%)

2.6 River Flow Analysis

Different statistical methods can be used to analysis of the changes of the stream flow during the periods being analyzed. In this study, use of box blot technique was adopted. Box plot is a statistical toll used to visualize grouped data under study. Use of 25^{th} , 50^{th} and 75^{th} percentile which represents the lower quartile (Q1), median (m or Q2) and upper quartile (Q3) respectively and interquartile range (IQR = Q3 – Q1), which represents 50% of the data display the level, spread and symmetry of the data. Maximum and minimum values are set are the end of the data sets. Figure 2.5 illustrates an example of a box plot.

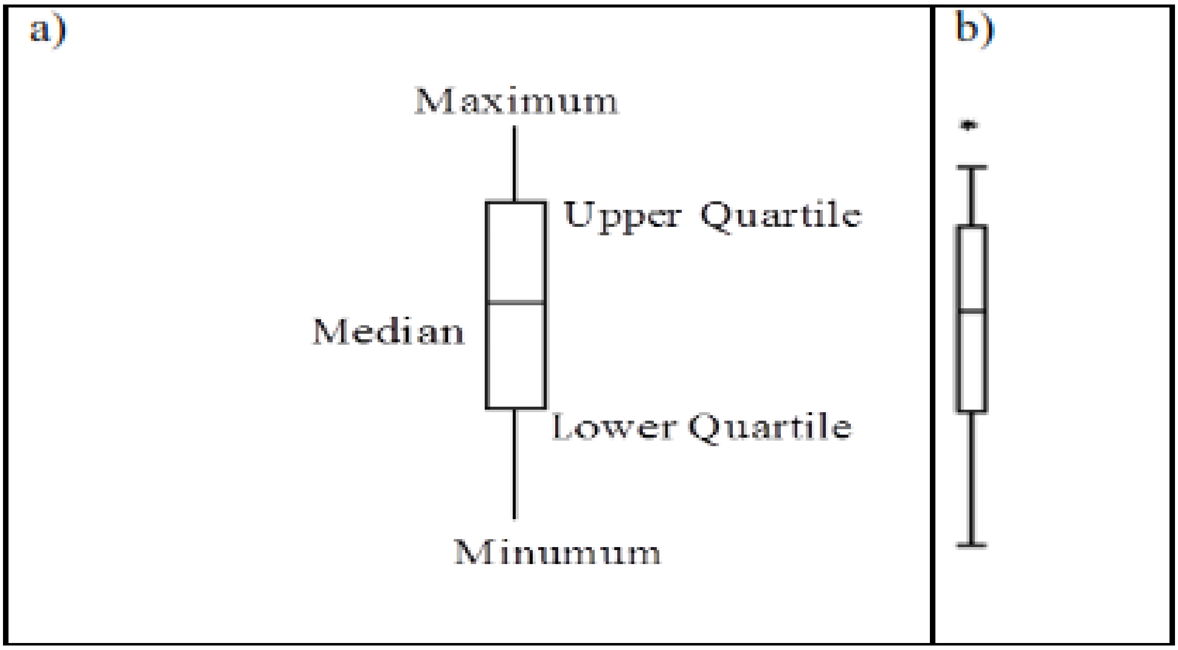


Figure 2. 5 An example of an anatomy of a box plot (a) and the box plot (b) (Mueni, 2016)

2.7 CLUE-s Modelling

Conversion of Land Use and its Effects modelling framework (CLUE) model was developed to simulate the effects of changes in land use as a result of the driving forces. This model was first used in Central America, Ecuador, China and Java, Indonesia. CLUE model uses land use map and remote sensing images to denote the land use types. CLUE model cannot be used on regional scale hence use of CLUE-s (the Conversion of Land Use and its Effects at Small regional extent) is applied. CLUE-S is specifically developed for the spatially explicit simulation of land use change based on an empirical analysis of location suitability combined with the dynamic simulation of competition and interactions between the spatial and temporal dynamics of land use systems(Verburg, 2010).

CLUE-s model is divided into two parts namely the demand analysis and demand distribution. Demand distribution calculates the demand for different land use types while demand analysis calculates the area of different land use changes. CLUE-s model require provision of all conditions so that it can compute the most likely changes to occur. According to Zhang et al., (2013), the CLUE-S model to simulate the spatial layout change of the land use based on the land use policies like „construction land up the hill", „towns providing land for plough", „construction land developing along the river and road", „important industrial land expansion", „centralized layout" and „the intensive use of land" can be at the same time. Figure 2.6 shows overview of information flow in a CLUE-s model.

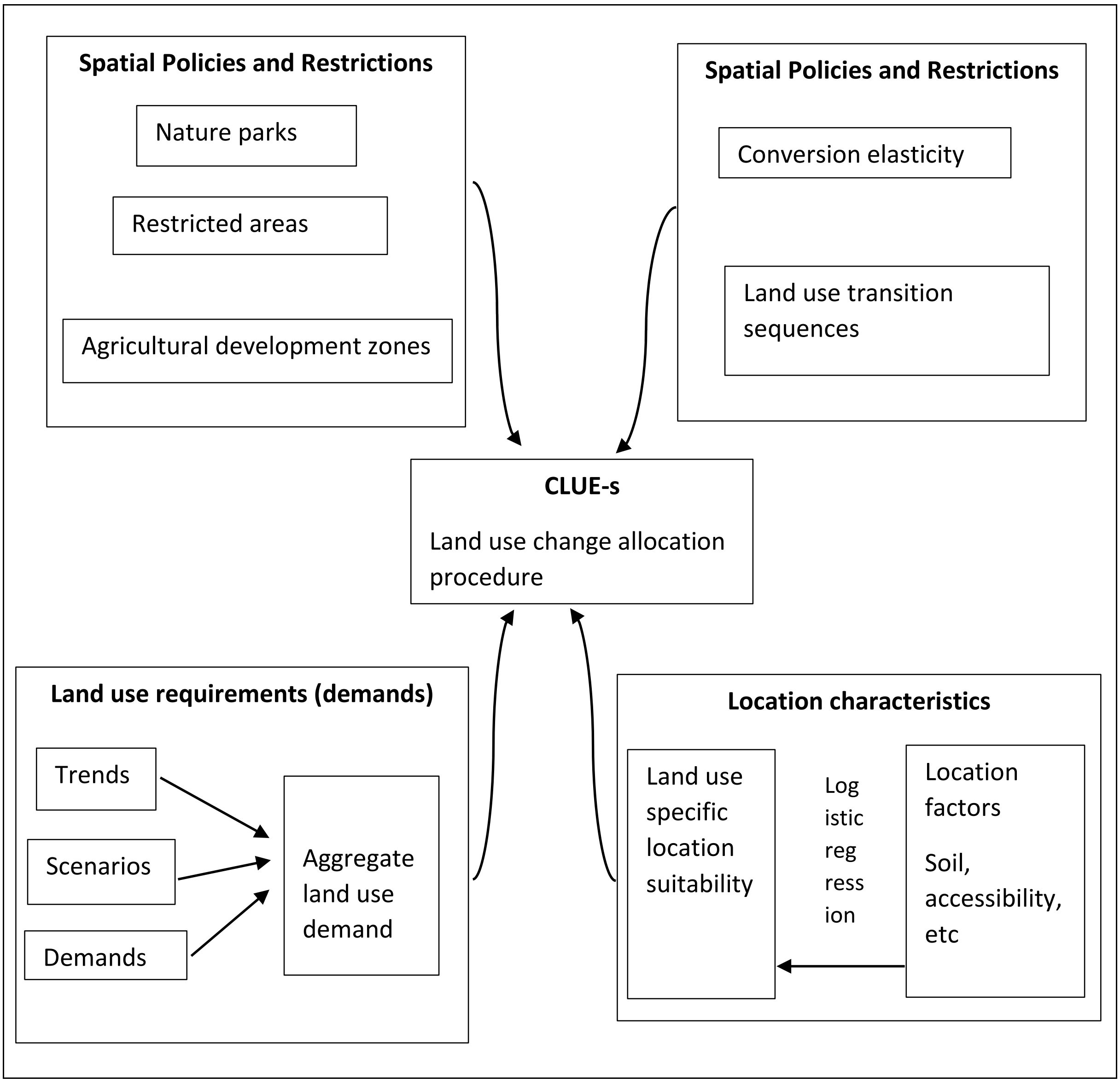


Figure 2. 6 Overview of information flow in a CLUE-s model.

Chapter 3: Methodology

3.1 Study Area

The Mkurumudzi River catchment is located in Kwale County, southern part of Mombasa in Kenya about the coordinates 4^0 18'. Kenya is located in the east coast of Africa bordering Somalia, Ethiopia and South Sudan in the north, Uganda in the west, Tanzania in the south and Indian Ocean in the east. Kenya has an area of 582,646 km^2 of which 571,416km^2 is covered by land while 11,230 km^2 is covered by water. The basin covers command area of approximately 230km^2 with 40 km river stretch. The area of study lies in Athi Catchment Area. This catchment is one of the six catchments areas in Kenya and covers an area of 58,639 km^2. The sub basin's area of interest is approximately 70km^2. The catchment's river network flows from Shimba hills draining its waters into the Indian Ocean. Figure 3.1 shows the location of the study area in Kenya.

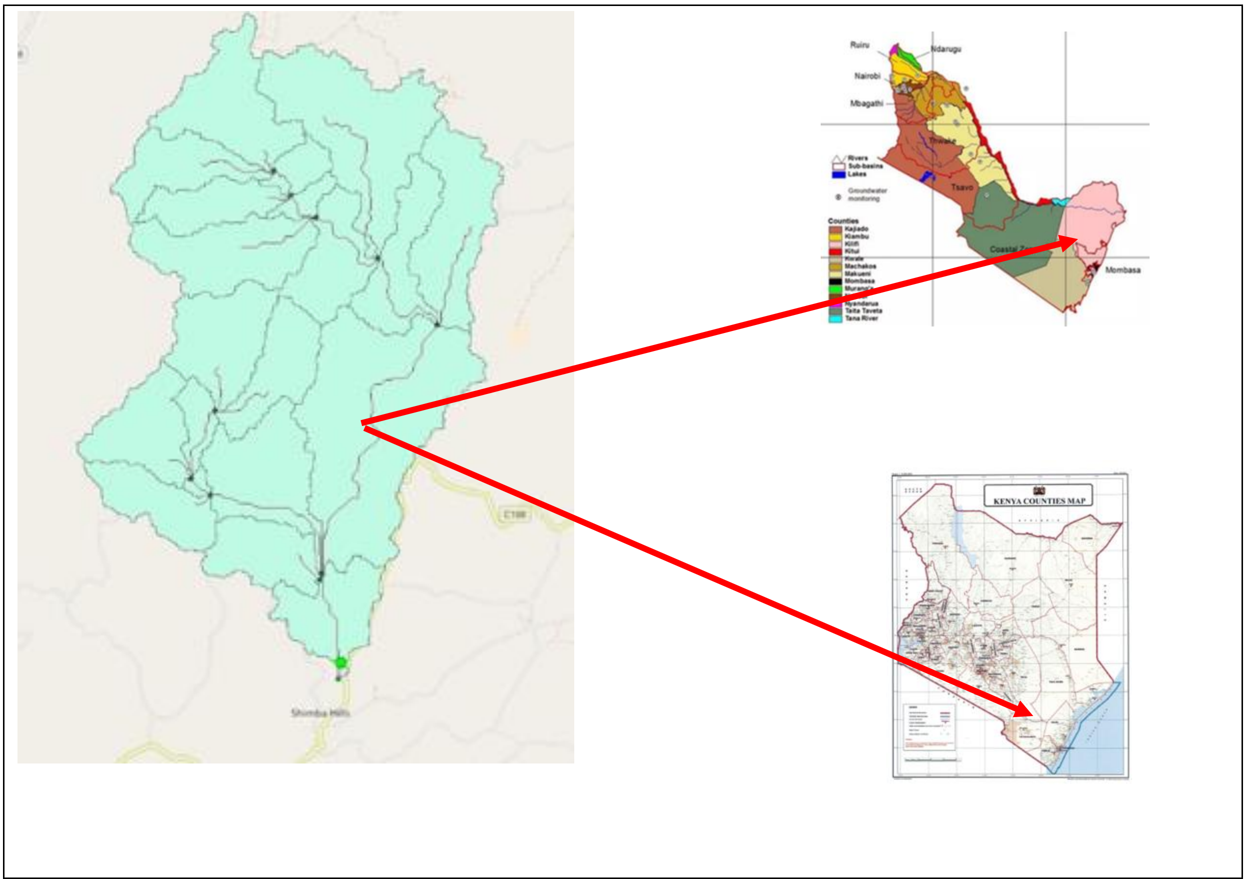


Figure 3. 1 General Location of Mkurumudzi River catchment in Kenya Source: www.google.co.ke

The river basin is characterized with typical coastal type of climate receiving longest rains between the months of March – June while short rains occur between October – December. Annual rainfall in the catchment falls within the range 1100 - 1300mm. On the other hand, mean annual evaporation has been estimated to be 2170 mm/yr in which November – April is usually the warmest period with mean temperatures of 26.0 - 28.0 ^{0}C. Further, the coolest months are July – August with mean temperatures of 24.0 - 26.0 ^{0}C. During these periods, the catchment experiences average constant temperature of 26^{0}C with monthly maximum average temperature of 30^{0}C and minimum of 22^{0}C. Daily mean evapotranspiration rate is about 4.4 mm/day and aridity index of about 0.55. The effects of the two (2) monsoon winds and impacts of the Inter - tropical Convergence Zone (ITCZ), affect the study area. The North Eastern and South Eastern Monsoon winds occurs between December - March and June – August respectively.

Apart from the runoff, the river is recharged by the ground water originating from the Shimba Hills. The main economic activities in the catchment include; subsistence farming; livestock keeping; commercial fishing; sand harvesting; commercial farming of sugarcane and commercial mining.

Mkurumudzi River lies along the coastal plain. The chief underlying basement rock are the gemstone area, which are the oldest rocks in the region. They occur as gneisses schists, quartzites, granitoids, and crystalline limestone. Rock type in the study area is Duruma sandstone series representing the Karoo sediments that consists of sandstones and arkoses, which form the Shimba Hills and are the source of ground water in the catchment. Shimba Hills are underlain by faulted and moderately folded sandstones of Triassic age, the Mazeras sandstones and the principal groundwater unit in the area is the Gongoni aquifer, which is a south-east to north-west aligned depression filled with Pliocene and Pleistocene sediments (Katuva, 2014).

3.2 Data Collection

The secondary data used in the study were obtained from local and global sources. The input data used are land use map, soil map, topography and climatic conditions. The climatic conditions include temperature, rainfall, humidity, evaporation rate. The main tools used in carrying out the study are ArcGIS and SWAT model.

Meteorological and hydrological data were obtained from Kenya Meteorological Department. Daily river discharge data were obtained from the gauging stations within the study area, Water Resources Authority. Daily climatic variables required for use in the SWAT model include precipitation, minimum and maximum air temperatures and wind speed. Solar radiation and dew-point temperature were produced from a weather generator using values from the nearest standardized weather station. Table 3.1 shows the summary of data collected and the source obtained.

Table 3. 1 Type of data collected and source

S/No.	Type of data	Source	Period	Frequency
1.	Land Sat Images	United States Geological Survey (USGS) -Earth Explorer & Glovis)	1987, 1997 & 2016	
2.	Climate Data	Kenya Meteorological Department	1979 - 2014	Daily
3.	Soil Map	Kenya Soil Survey Food and Agriculture Organization (FAO) soils	-	-
4.	Stream Flow	Water Resource Authority	1950 - 2012	Daily
5.	DEM	USGS (Earth Explorer)	-	-

3.2.1 Land Use

There are different land sat image sources for local, regional, and continental. Land imagery images were obtained from Glovis USGS and Earth explorer USGS that contain LandSat8, 7, 4-5 images. The years with clearer images were 1987, 1997 and 2016. It was impossible to obtain clearer images of the study area for the year 2007. However, Most of the satellite images had more than 10% cloud cover. Figure 3.2 shows classified land use images 1987, 1997 & 2016 that were used to analyse the land use changes and further used in obtaining the stream flows.

3.2.2 Soil Map

National Soil Map vector dataset was obtained from Kenya Soil Survey. The vector dataset contains the following parameters used in SWAT model namely; depth of soil layer, soil texture, hydraulic conductivity, bulk density and organic carbon content and soil depth.

3.2.3 Stream Flow

The data on stream flow was obtained from Water Resource Authority, an institution under the Ministry of Water and Irrigation. According to survey done by Water Resources Authority (2013), Kenya has available water resources that consists of ground water surface runoff and sustainable yield of ground water. Table 3.2 shows the annual available water in 2010 and predicted amount in 2030. It is expected that available water resources will increase by 8.7% by 2030.

Table 3. 2 Available water resources in Kenya (NWMP, 2030: Wrma, 2013)

	Available Water Resources (MCM/year)		
Year	**Surface Water**	**Ground Water**	**Total**
2010	1,198	305	1,503
2030	1,334	300	1,634
Percentage of 2010 values	111	98	109

Mkurumudzi River has only one gauge station named 3KD06. The available data obtained from this gage station is for the period 1950 – 2014. The data collected had many gaps for up to 4-5 years. Rating curve was created and used to generate discharge flows for the missing days. The average monthly flows of Mkurumudzi River is 0.15m^3/s. Figure 3.2 shows observed monthly stream flows for the years 1987, 1997 and 2007. Highest flows were experienced in April – June and October - December in all the three years under consideration. This was attributed to high rainfall received in the catchment. Figure 3.3 summarise the average monthly rainfall received in the study area in 1987, 1997 & 2006.

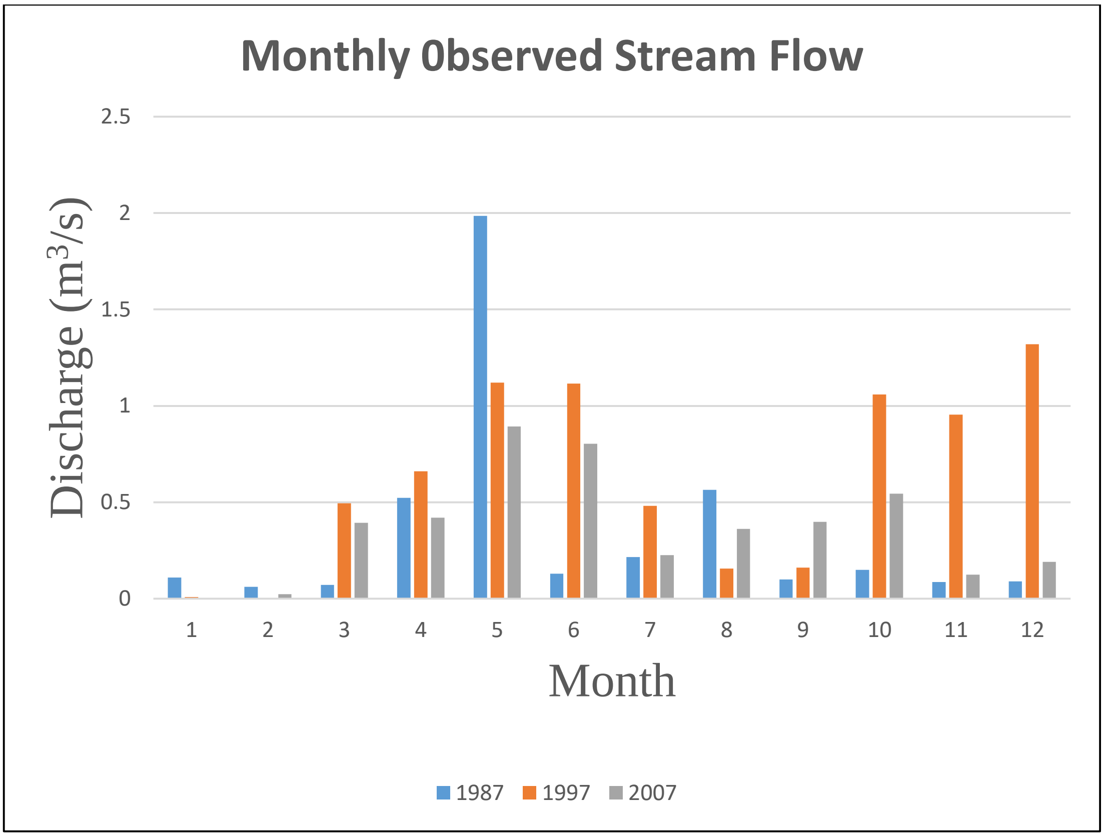


Figure 3. 2 Monthly stream flow for the years 1987, 1997 & 2007

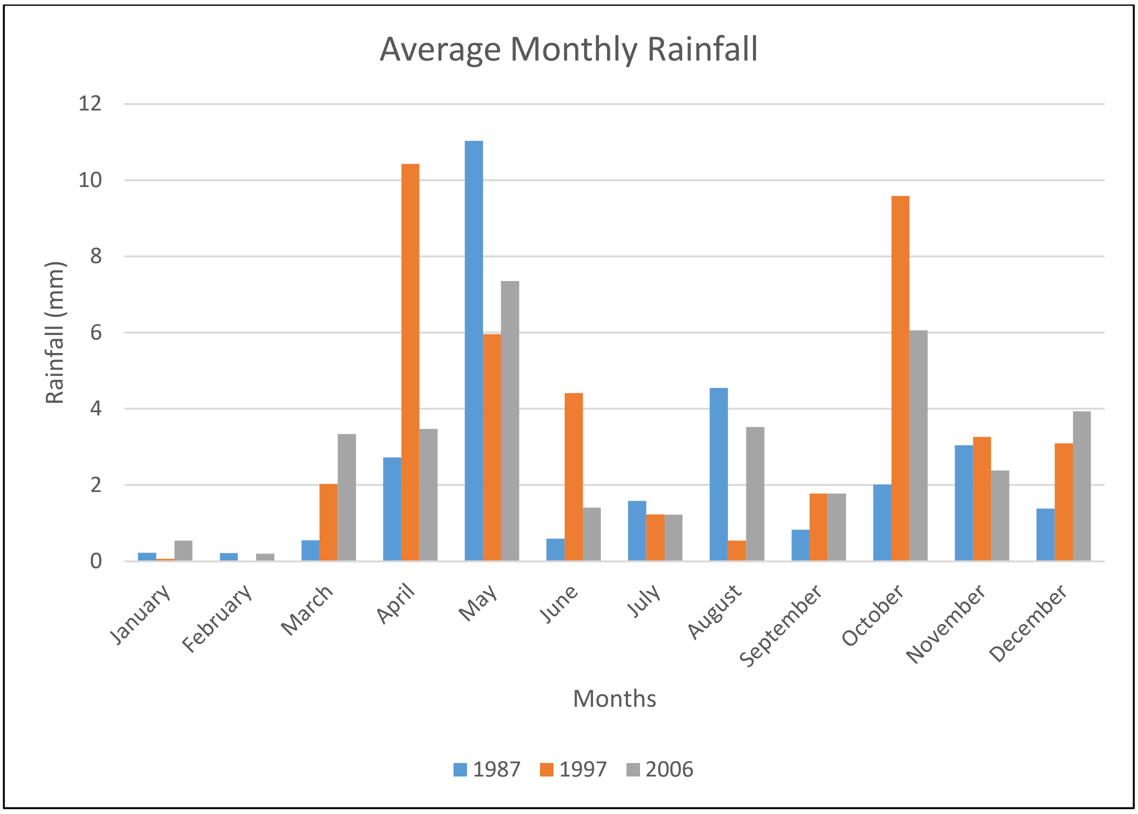


Figure 3. 3 Monthly stream flow for the years 1987, 1997 & 2006

3.2.4 Climate Data

The long-term climate data was obtained from Kenya Meteorological department. SWAT require daily climate data. The nearest station to study area is Msambweni Station that record daily rainfall. Daily Maximum and minimum temperature, Solar Radiation, Wind speed were obtained from Mombasa Station. Since the study area falls in the same altitude, hence the data obtained from Mombasa Station were used in this study. Instat+V3.37 was used to generate evapotranspiration for the entire area. This software uses Pentmant Monte formular for calculation of evapotranspiration.

3.2.5 Digital Elevation Model (DEM)

Digital Elevation Model (DEM) is one of the most important input file with data for delineating the watershed. It defines the topography by defining the elevation at different points. The use of DEM assists in analysis of drainage pattern, channel width, slope and length of the stream. DEM files for the water shed with 30m resolution were downloaded from the USGS earth explorer website: https://earthexplorer.usgs.gov. Mkurumudzi River watershed covers an area of 7,000 ha with an average elevation of 17m above sea level. Figure 3.4 illustrates the Digital Elevation Model of Mkurumudzi river catchment which was generated from DEM file downloaded. The DEM shows its highest and lowest points in the catchment.

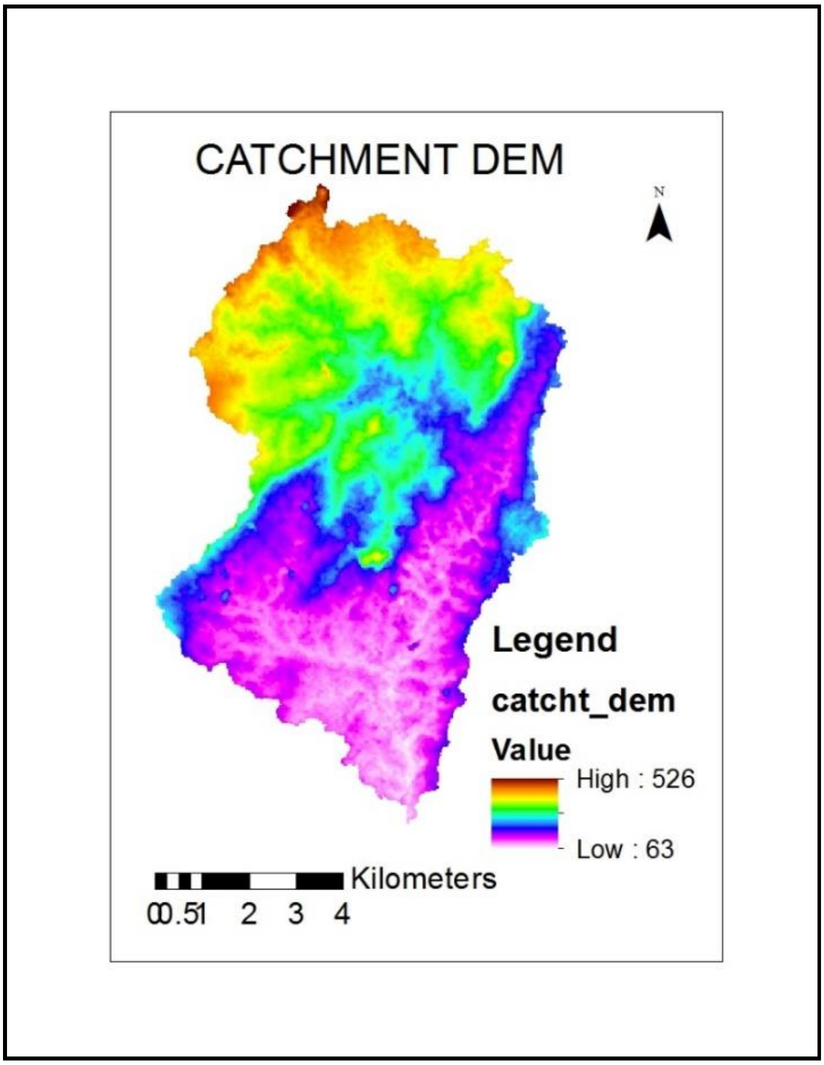


Figure 3. 4 Catchment DEM of Mkurumudzi River sub - catchment

3.3 The Methodology of Research

3.3.1 Data Preparation

The stream flow data and climate data obtained for the study area had data gaps. Preparation of this data before used in modelling is necessary. According to the standards for estimation of missing data set by World Meteorological Organization (WMO) (1966), all the missing data required for scientific use should be 10% of the total records. There are many techniques and methods which are available for use in estimatiom of missing data. These methods are:

i. The arithmetic mean method
ii. The Isohyetal method
iii. The isopleths method
iv. The finite differencing method
v. The correlation method

vi. The thiessen polygon method

The arithmetic and correlation methods are discussed below in detailed. The two methods were used in stream flow data processing because of their simplicity. Other advantages of using these two methods are that the data sets obtained were independent values taken at one point of time and were not extreme.

i. Arithmetic mean method

This method assume equal weights of all nearby stations. Records for a long period of time are required for use in calculation. The data should also be homogeneously distributed to ensure that stable averages for each station are generated. Best-correlated neighbouring stations which require estimation of missing recorded data are identified. If the normal annual precipitations at surrounding gauges are within the range of 10% of the normal annual precipitation at station X, then the Arithmetic procedure could be adopted to estimate the missing observation of station X (De Silva, Dayawansa and Ratnasiri, 2007).

The arithmetic mean method formula is expressed as follows:

$$X_{Aj} = \frac{X_{Bj}}{\bar{X}_B} \cdot \bar{X}_A$$

Where

X_{Aj} = the missing record of station A in the jt^h year,

X_{Bj} = the record for station with reliable records (B) in year j,

$\bar{X}_A$ = the long-term averages for stations A based on the period of records available at station A.

$\bar{X}_B$= the long-term averages for stations B based on the period of records available at station A.

ii. The correlation method

It is a simple method to use for calculation and interpretation of variables. Correlation method is used to assess a possible linear association between two continuous variables. This method involve use of correlation coefficient to quantify the relationship between two pairs of variables under study. A correlation coefficient It is a dimensionless quantity that takes a value in the range -1 to +13 A correlation coefficient of zero indicates that no linear relationship exists between two continuous variables, and a correlation coefficient of -1 or +1 indicates a perfect linear relationship (Mukaka, 2012). If the correlation is stronger, the coefficient comes to ±1

The correlation method formula is expressed as follows:

$$r_{xy} = \frac{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})\,(y_i - \bar{y})}{\left[\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2 \cdot \frac{1}{N}\sum_{i=1}^{N}(y_i - \bar{y})^2\right]^{1/2}}$$

Where,

r_{xy}= the correlation coefficient between the values of the two stations,

N = the total number of years with complete records,

x_i = the available datasets for station with missing data,

$\bar{x}$ = the mean of the available data for the same station,

y_i = the dataset for the neighboring station with complete records

$\bar{y}$ = the long-term mean of the station with complete records.

Student T-test was used to test the correlation coefficient significance. This was done by comparing the t-statistic. A correlation coefficient is concluded to be significant if the t computed is more than the t value tabulated for a given value of confidence.

The student t-test formula is expressed as follows:

$$t_{n-2} = r\sqrt{\frac{n-2}{1-r^2}}$$

Where:

n = the length of the data that were used,

$n - 2$ = the degrees of freedom,

t_{n-2} = the value of the confidence level computed from the correlation coefficient

r = the correlation coefficient.

In most cases, the climatological recorded data are characterized by inconsistencies as a result of faulty measuring instruments, changes in the location of recording stations, influences by the surrounding conditions and changes in procedures of recording the observations. Methods used in data collection, estimation of missing records, transmission and processing could have associated errors and this may cause the heterogeneity of the records (Mueni, 2016). It is therefore important to check these inconsistencies and errors to ensure that the data sets are of required quality. There are two most commonly used methods which are used to test the quality of these data. These two methods are the single and double – mass curves methods. The two methods used in this study to assess the quality of climatological datasets are the pettitt's test and the mass curves analysis.

I. The mass curves analysis

This involves plotting on an arithmetic cross - section paper the cumulative values of one variable against the cumulative values of another variable, or against the cumulative computed values of the same variable for a concurrent period of time. In this method, it is assumed that the inconsistencies shown by the curves indicates the inconsistencies due to changes in the methods used for collecting the data. Homogeneous recorded data is assumed to follow a straight line.

When the double – mass curve of precipitation data from a particular station indicates a break in slope and the reason for the break is determined, the record for one set of conditions may be adjusted to what it would have been if it had been collected under the other set of conditions.

II. The pettitt's test

This is a nonparametric test used to detect a single change – point of continuous data. Unlike mass curve analysis, this method does not involve assumption of the distribution of data. Mann-Whitney test is used in this method to allow identification of the time when a shift in the records occurred. To discover a single change-point in hydrological or climate series with continuous data set the method is commonly applied (Mueni, 2016). It tests the H0: The T variables follow one or more distributions that have the same location parameter (no change), against the alternative: a change point exists (Pohlert, 2016).

The Pettitt's test method is established on the rank, r_i of the Y_i and does not consider the normality of the series. The Pettitt's test method is expressed as follows:

$$X_y = 2\sum_{r=1}^{y} r_i - y(n+1), y = 1,2,\dots,n$$

Where the break occurs at year k is given by the formula:

$$X_k = \ max_{1 \le y \le n} \ / \ X_y \ /$$

3.3.2 Land Use Classification

Satellite images were classified to different land use categories with the use of QQIS software. QQIS is an open source and free Geographical Information System Software. It is used for viewing, editing and classifying geospatial data. The software supports both raster and vector layers. Figure 3.5 shows the flow chart on how to process satellite images to produce classified land use map. Use of QQIS software enable the processing of Landsat images of a large area over long time spans to represent land cover and land use. The classified LULC are unique and indispensable for monitoring, mapping, and management. The classified LULC are unique and indispensable for monitoring, mapping, and management. To detect changes and monitor LULC by use of remote sensing, several multi – date images are required for evaluation. As a result, differences of LULC that occurred during the period because of environmental conditions and human actions can be noted.

Supervised classification and manual interpretation were used in the classification of land use. The land use were then categorized into four categories including forest, grassland, shrubs and agriculture. This classification was done according to the features present and according to spectral signatures. Maximum likelihood method was used in supervised classification. Advantages of this method is its availability and the good quality results produced after classification. The images were validated using a classified image obtained from the Regional Center for Mapping of Resources for Developments (RCMRD) and CCI Land Cover (LC) 21016. The CCI Land Cover (LC) 21016 obtained has 20m resolution of 2A sentinel. The Coordinate Reference System used for the global land cover database is a geographic coordinate system (GCS) based on the World Geodetic System 84 (WGS84) reference ellipsoid. The legend of the S2 prototype LC 20m map of Africa 2016 was built after reviewing various existing typologies (e.g. LCCS, LCML…), global (e.g. GLC-share, GlobeLand30) and national experiences (Africover, SERVIR - RMCD). The legend includes 10 generic classes that appropriately describe the land surface at 20m: "trees cover areas", "shrubs cover areas", "grassland", "cropland", "vegetation aquatic or regularly flooded", "lichen and mosses / sparse vegetation", "bare areas", "built up areas", "snow and/or ice" and "open water". Raster calculation was then applied to determine the LULC changes between the period 1987 – 2016.

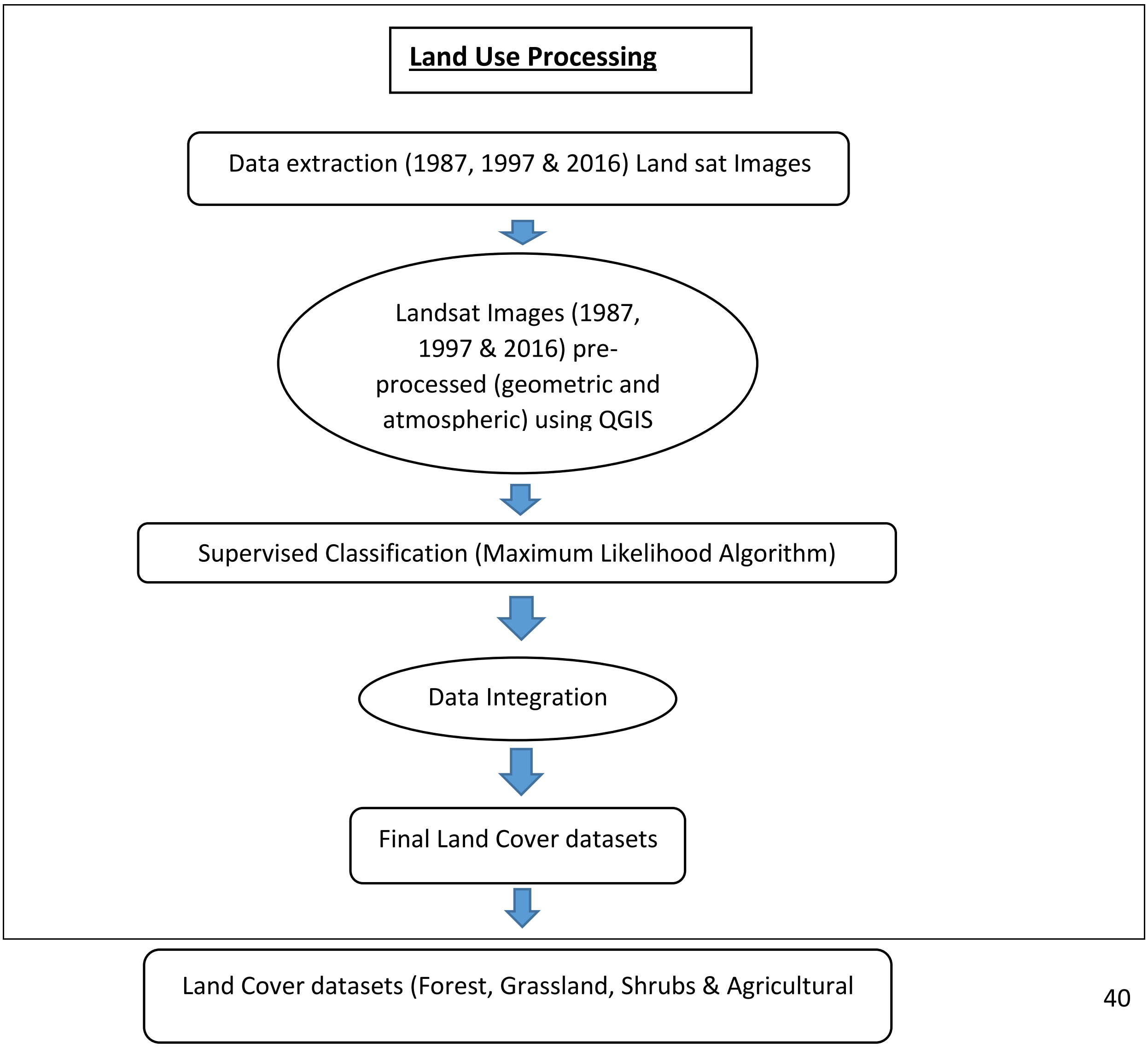


Figure 3. 5 Flow chart of the integration of data layers for land cover classification

3.3.3 SWAT Modelling

SWAT model uses daily time step data for the analysis and prediction of the effects of land use management, sediment yields and chemical effects on an agricultural land in a water shed. This model is able to compute the simulated values for a long period in an effective way. The model input data are used in this study are climate data that is precipitation, maximum and minimum temperatures, relative humidity, wind speed and solar radiation. Other data also required are DEM, soil properties and land use.

In SWAT modelling, the catchment under study is first divided into homogenous Hydraulic Response Units (HRU) for easier analysis. These HRUS has the same slope, soil properties and land use.

During SWAT modelling, it was assumed that runoff had effect on the streamflow. This effect was then assessed through use of SWAT model. Figure 3.6 shows the SWAT model step-by-step procedures followed in simulation of stream flows SWAT model involve use of water balance equation that considers the unsaturated zone layer and shallow aquifers above the impermeable layer in simulation of stream flows.

Before doing calibration, sensitive parameters for the study area were first determine. Model sensitivity analysis is the process of determining the rate of change of a parameter based on the model output. This process is necessary and important in model calibration. Local and global are the two methods used in sensitivity analysis. Local method involve changing the values one at a time while global involves allowing all the parameters to change. These two yield methods gives different results output. Disadvantage of using local method is that the sensitivity of one parameter depends on the other parameter and working on more than two parameters at once is difficult. The disadvantage of using global method is that high number of simulation is done to achieve the best-fit parameters for the simulated flows. The varied parameters used in this study are curve number (CN), Ground water delay, Base flow alpha, factor, depth of water in the aquifer, soil hydraulic conductivity and available water capacity of the soil.
SWAT – cup model has two methods of analyzing the sensitivity analysis. These two methods are:

i. Global Sensitivity analysis
ii. One-at-a-time sensitivity analysis

In this study, global sensitivity analysis was used. This method involve use of multiple regression system. The Latin hypercube generated parameters against the objective values through the regression method. The average change in the parameters under study gives the output results. Global Sensitivity analysis involves use of t-stat and p-values. The t-stat values are obtained by dividing the coefficient of a parameter by its standard error. If the value obtained is high, the parameter is regarded as sensitive.

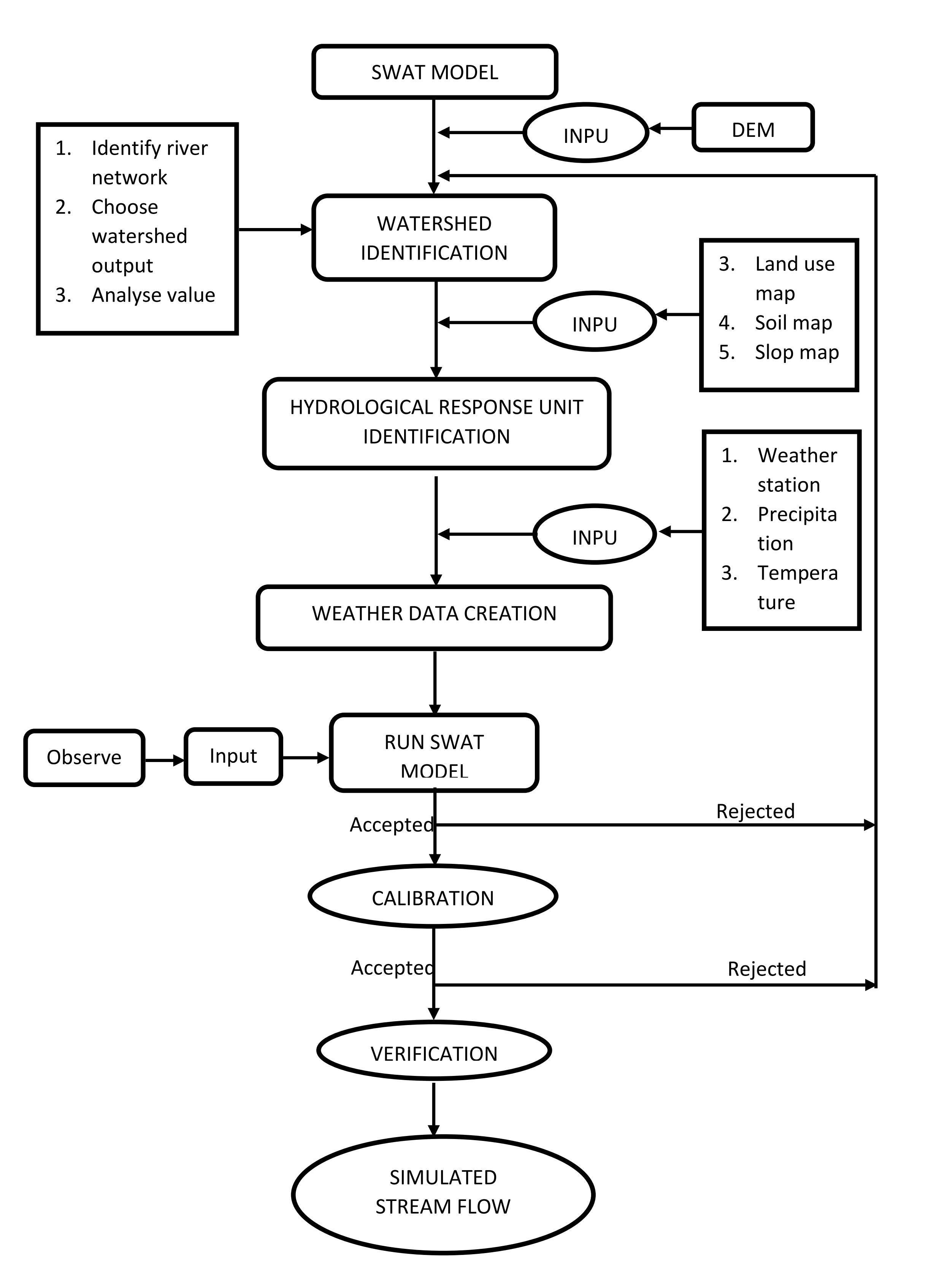


Figure 3. 6 SWAT Model steps

The p-value describe the effectiveness of a parameter. The p-value measures the null hypothesis of a coefficient if it is equal to zero. A p-value of < 0.05 is acceptable. If a p-value obtained is low, it shows that the parameter is sensitive. Very sensitive parameters have a p-value of zero.

Once the model has been run, the simulated flows were calibrated and validated by using the observed data obtained from the gauge station. Calibration can be defined as process of reducing the prediction uncertainty in a model by setting up parameters in a model to that best fit the local conditions of the area of study. Calibration is the second step done after sensitivity analysis. Model calibration is performed by carefully selecting values for model input parameters (within their respective certainty ranges) by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions (Arnold *et al.*, 2012).

The final step during SWAT modelling is validation. This is a process of proofing that the set parameters (conditions) for a particular site is capable of providing accurate simulated results. This process involves SWAT model uses two techniques for calibration and validation. These methods include manual calibration and automated procedures. SWAT _ CUP is an example of an automatic procedure that involve adjusting parameters and ranges in an iterative way until the best values are archived. The parameters obtained during calibration are used in validation by and comparing the results obtained from the simulated data and observed data. The data used during validation should be the one not used during calibration. SWAT-CUP was recently developed and provides a decision-making framework that incorporates a semi-automated approach (SUFI2) using both manual and automated calibration and incorporating sensitivity and uncertainty analysis (Arnold *et al.*, 2012).

3.3.4 Analysis of Impacts of Land Use

Four scenarios were used in the assessment of the impact of land use on river flow. Figure 3.7 shows the flow chart on how analysis of impacts of land use was done Changes in land use and vegetation affect the water cycle and its influence is a function of the density of plant cover and morphology of plant species (‘Simly_Dam_Watershed.pdf’, no date).

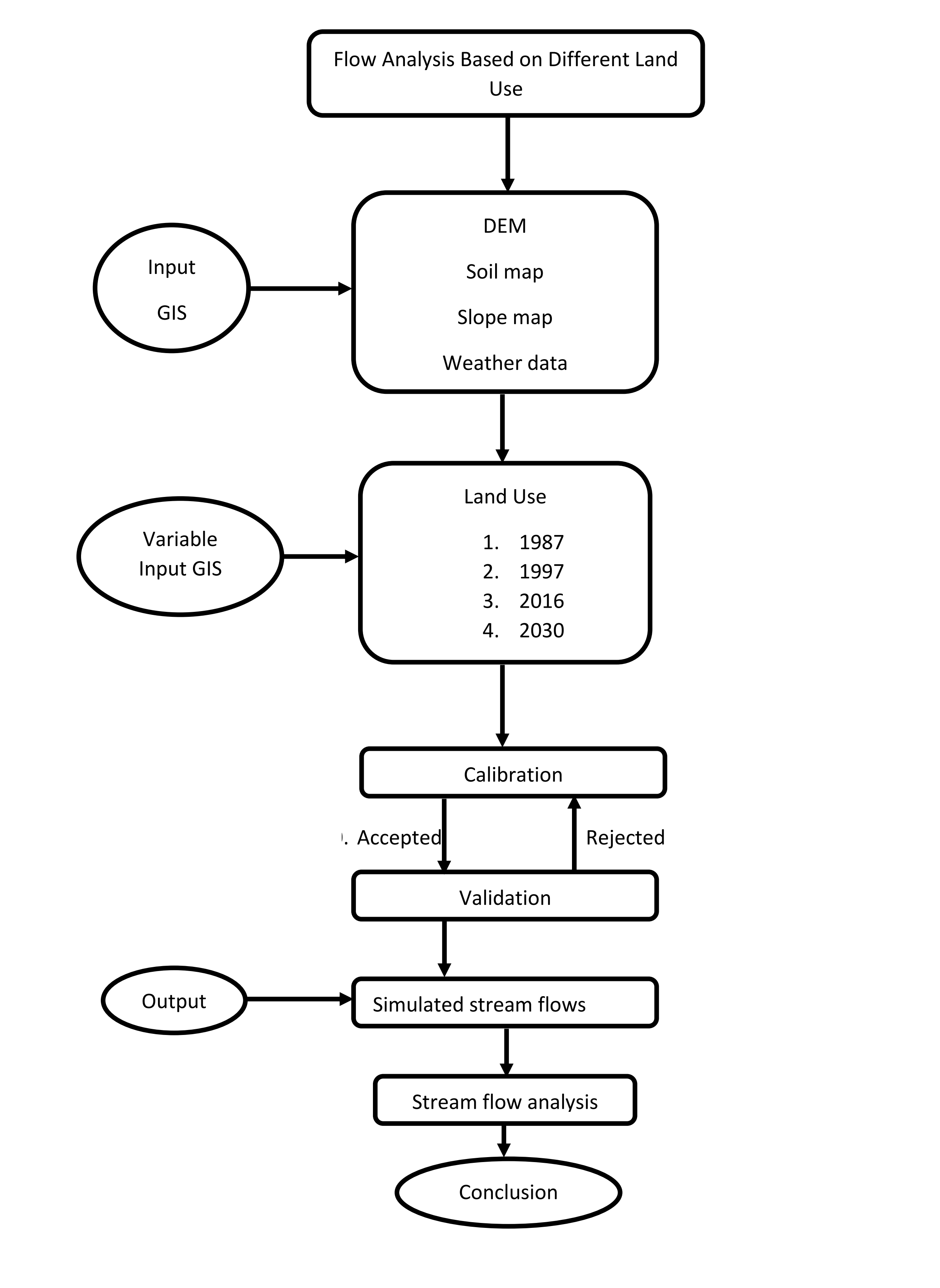


Figure 3. 7 Land Use Analysis Flow Chart

Scenario I, II, III & IV involved use of 1987, 1997, 2016 & 2030 land use classified image respectively as an input data. 2030 land use data were obtained by attempting realistic scenarios based on the ongoing land use trend and also by Kenya Vision 2030 goals of increasing the forest cover. The land use 2030 scenarios are as follows:

1. Increase of 10 % in forest cover. The Kenya government has put measures to ensure to ensure that the current forested area is increased by 10% by the year 2030 (The Ministry of Planning and Devolution, 2007). This is a policy established to ensure that there is conservation of all the forests within all the water towers.
2. Reduction of 5% in grassland area and converting to agricultural land and some parts to conversion to deciduous forest especially in Shimba Hills forest.
3. Increase of 5 % in agricultural land. It assumed that the area under agriculture will increase three times the current are. This is due the increasing population.
4. Reduction of 10% in shrubs. This involves conversion of area under shrubs to forest, agricultural land and some parts to grassland area.

Each land use scenario for the years under study were calibrated and validated by using SWAT - cup tool. Analysis was then made by comparing simulated flows obtained from different land use scenario to draw conclusion on how these land use changes have affected the flows.

3.3.5 Stream Flow Analysis

The simulated stream flow obtained after calibration and validation were evaluated to obtain the effects brought by land use/ land cover change. Box plot (also known as box - and – whiskers plot) is one of the statistical technique that was used to visualize results. This method involve use of exploratory data analysis to detect hidden patterns in a group of numbers. It is used to compare and summarize data that has been group. Approximated quantiles, median, lowest, and highest data points are used to display the level, symmetry and the spread of the data distribution.

Box plots characterize a sample using the 25th, 50th and 75th percentiles—also known as the lower quartile (Q1), median (m or Q2) and upper quartile (Q3)—and the interquartile range (IQR = Q3 – Q1), which covers the central 50% of the data (Krzywinski and Altman, 2014). The whiskers are lines extending from Q1 and Q3 to end points that are typically defined as the most extreme data points within Q1 – 1.5 × IQR and Q3 + 1.5 × IQR, respectively (Streit and Gehlenborg, 2014). Individual mark represents each outlier found outside each whisker. At the end of the whiskers are maximum and minimum value of the data sets that are used as ends. Figure 3.8 shows an example of Box plots for an n = 20 sample. The box bounds the IQR divided by the median, and Tukey-style whiskers extend to a maximum of 1.5 × IQR beyond the box. The box width may be scaled by √n, and a notch may be added approximating a 95% confidence interval (CI) for the median. Open circles are sample data points. Dotted lines indicate the lengths or widths of annotated features.

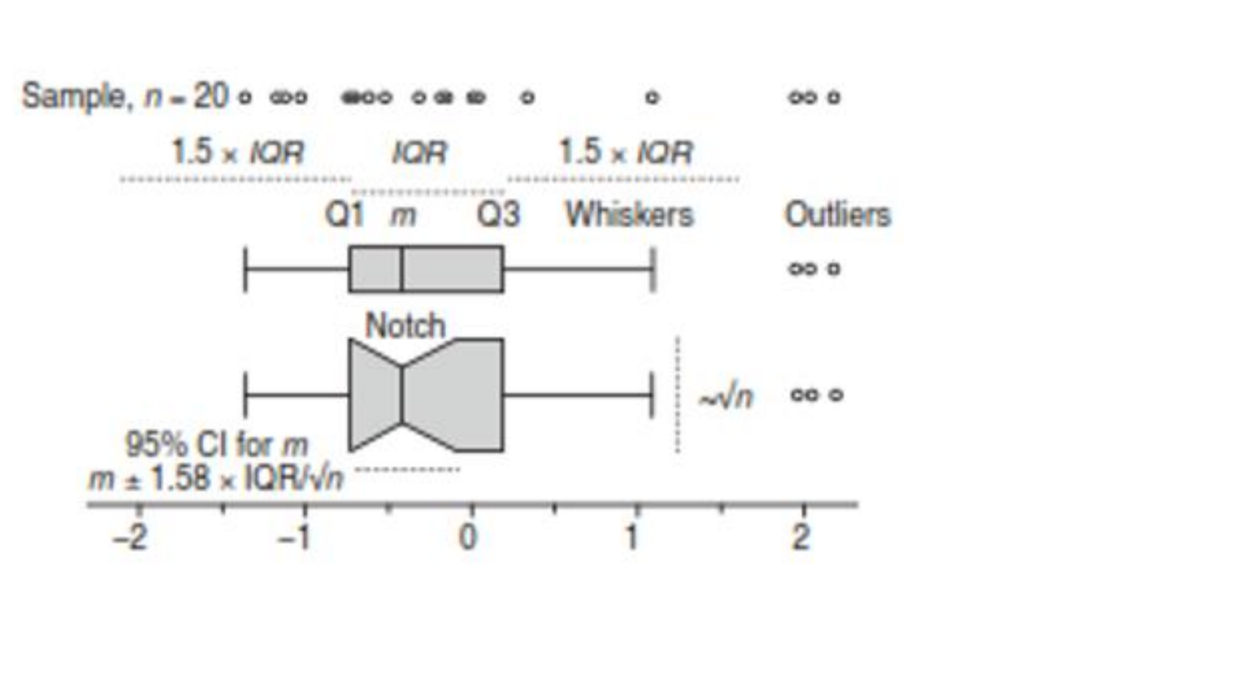


Figure 3. 8 An example of box plot (Krzywinski and Altman, 2014)

3.3.6 Developing Alternative Measures for Adaptation using CLUE-s

Land use and Land Cover changes situations and purposes thus demand different adaptive approaches for increased river flows to environmental standards. Characteristics of the existing land use is first be assessed before planning and measures are adopted.

Conversion of Land Use Change and its Effects at Small Regional Extent (CLUE-s) is used for dynamic modeling of land use change (Veldkamp and Fresco, 1996). CLUE-s model simulates land use conversion and change in space and time as a result of interacting biophysical and human drivers (Nguyen, Castella and Verburg, 2002). Biophysical drivers include land use history, distribution of land use, distribution of infrastructure and pests and diseases. Figure 3.9 is a flowchart showing the CLUE-s modelling procedure used to develop alternative measures in this study.

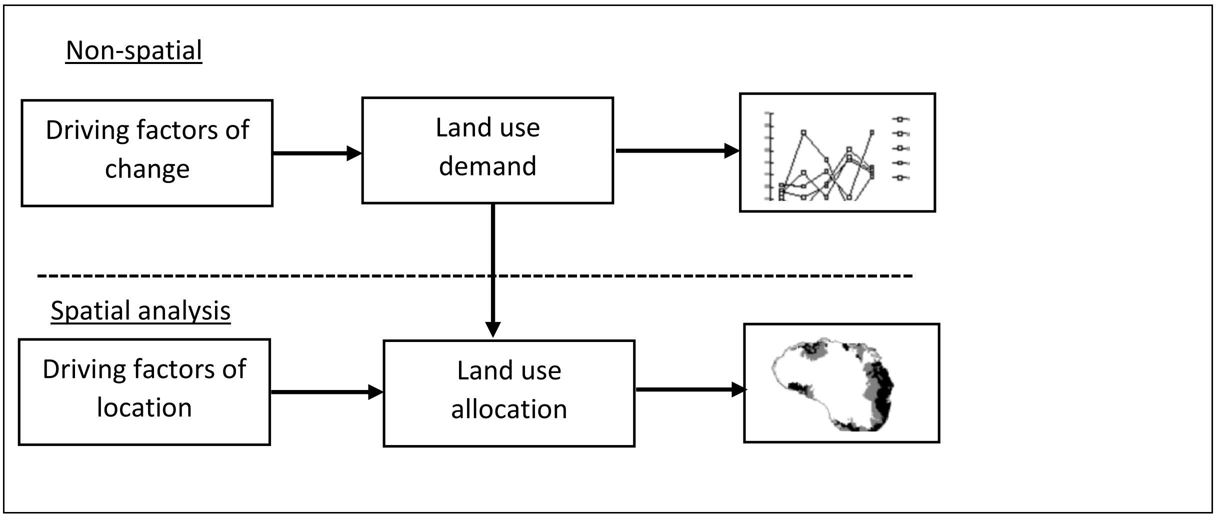
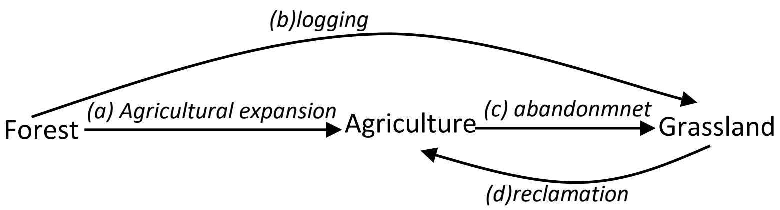


Figure 3. 9 CLUE-s modelling flowchart (Veldkamp and Fresco, 1996)

Land use types connversion settings are then used to determine the temporal dynamics of the simulations of land use change in the catchment. Conversion elasticities and land use transition sequences are two parameters used to characterise an individual land use type. For each classified land use type, a specified value that represent a relative elasticity change is alocated. These value ranges from 0 to 1. A value near zero means that conversion is easy while a value near 1 means irreversible change is possible. overview of information flow in a CLUE-s model. The simulation of these interactions combined with the constraints set in the conversion matrix will determine the length of the period before a conversion occurs (Verburg, 2010). Figure 3.10 provides an example of the use of a conversion matrix for a simplified situation with only three land use types.

Land Use Change Sequence



Present Land Use	**Future Land Use**		
	Forest	Agriculture	Grassland
Forest	+	-	-
Agriculture	-	+	+
Grassland	+	+	-

+ ve means Conversion possible

–ve means conversion not possible

Figure 3. 10 Illustration of the translation of a hypothetical land use change sequence into a land use conversion matrix ((Verburg, 2010)

Chapter 4: Results & Discussion

4.1 Current land use

SWAT CUP simulation results indicates that Mkurumudzi catchment has been experiencing deforestation in the last two decades. To a large extent forest cover has been reducing as increasing population convert them for agricultural, and other land uses. Conversion of forests for agricultural and residential urban areas has shown that it has an impact on flow regime and thus increasing nutrient concentrations, although the magnitude of the impacts are influenced by the type of agricultural practices and the alteration of the riparian zone (Castillo *et al.*, 2012). The current land use in Mkrumudzi river catchment was studied using 2017 land sat image. The catchment land uses were classified into four classes namely: forests, shrubs, grassland and agriculture. Table 4.1 shows the area covered by each land use:

Table 4. 1 The current area of land use

No.	Classification	Percentage (%)	Area (ha)
1	Forest	34.83	2419.38
2	Grassland	8.02	557.1
3	Shrubs	54.60	3792.96
4	Agriculture	2.55	177.21

According to Table 4.1, it is absolutely clear that shrubs cover the largest area (55%) while agriculture covers the least area standing at a paltry 3% of the total area under consideration. A large part of the sections in the forest is covered by grassland. The Main agricultural activities including sugarcane and horticultural faming are carried out in the lower part of the catchment. It was also noted that there are some farming activities in the forest.

The upper part of the catchment is covered by deciduous forest. Figure 4.1 is a pictorial view showing that some parts inside the forest have been cleared. This was shown by the presence of other classified land use. It was also noted that there were agricultural practices inside the forest. In addition, a section of the forest is covered by grassland. These activities shows that forest has been encroached.

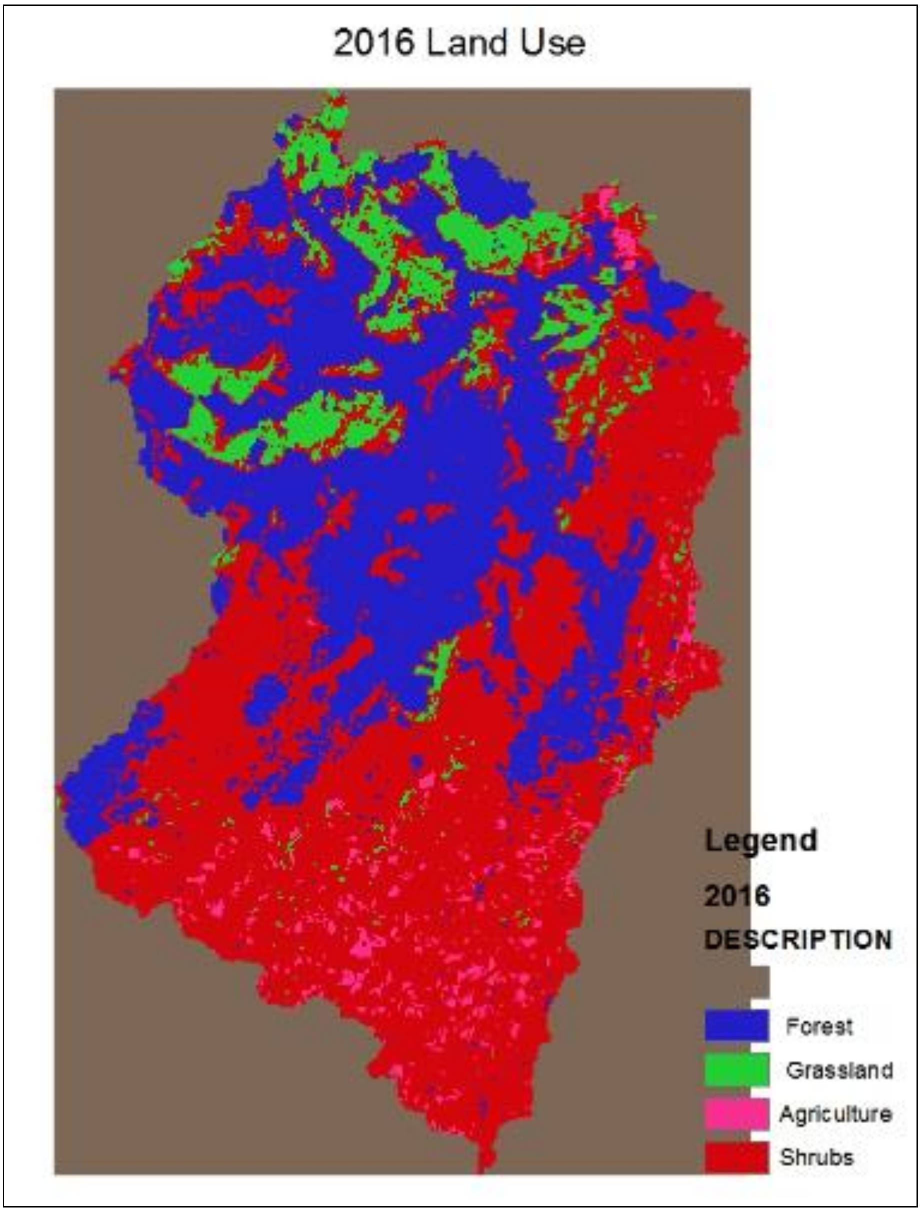


Figure 4. 1 Classified 2017 land use image

4.2 Land Use and Land Cover Change

Continual, historical, and precise information about the land use and land cover (LULC) changes of the Earth's surface is extremely important for any kind of sustainable development program, in which LULC serves as one of the major input criteria (Abd El-Kawy *et al.*, 2011). The results obtained from the land use provides insights about the changes of land use in a decade. This will provide a basis for making informed decision on better land use management within the catchment. Table 4.2 shows the area of each land use area of the respective year while

Table 4. 2 Area of each land use in 1987, 1997 and 2016

Description	**Land Use Area**		
	1987	**1997**	**2016**
Forest	3472.2	2086.2	2419.38
Grassland	2161.26	2892.96	557.1
Agriculture	598.5	741.6	177.21
Shrubs	714.69	1225.89	3792.96

Land use map for 1987, 1997, and 2016 were overlaid in ArcGIS to obtain the changes in land use as shown in figure 4.2 . A process known as quantitative analysis of remote sensing data of identifying the differences over the years was employed. This was done through observing the changes at different times. Table 4.3 shows land use change expressed as percentage based on coverage in the preceding year for 1987, 1997 and 2017 under study. Further, Table 4.3 positive value denoted an increase while negative means there is a decrease in land are coverage.

Table 4. 3 Land use percentage change

Description	**Percentage (%) change In Land Use Based on Preceding Year**	
	1997	**2016**
Forest	-13.86	3.3318
Grassland	7.317	-23.3586
Agriculture	1.431	-5.6439
Shrubs	5.112	25.6707

The percentage land use changes indicates that the area under forest cover had the highest decrease in land use of 14% while the area under grassland increase by 7 % in 1997. Agricultural area increased by 1.4% while shrubs also increased by 5% in the same year. It was also observed that there was an increase in deforestation consistent with increase in grassland area that provided potential footprint for agricultural activities. This could imply that farming was carried out in the areas where there was deforestation. Results have also demonstrated that Shrubs mushroomed in some of the areas that were initially forested. The remaining areas were left for grassland. During this period, there was likelihood that the forest was encroached.

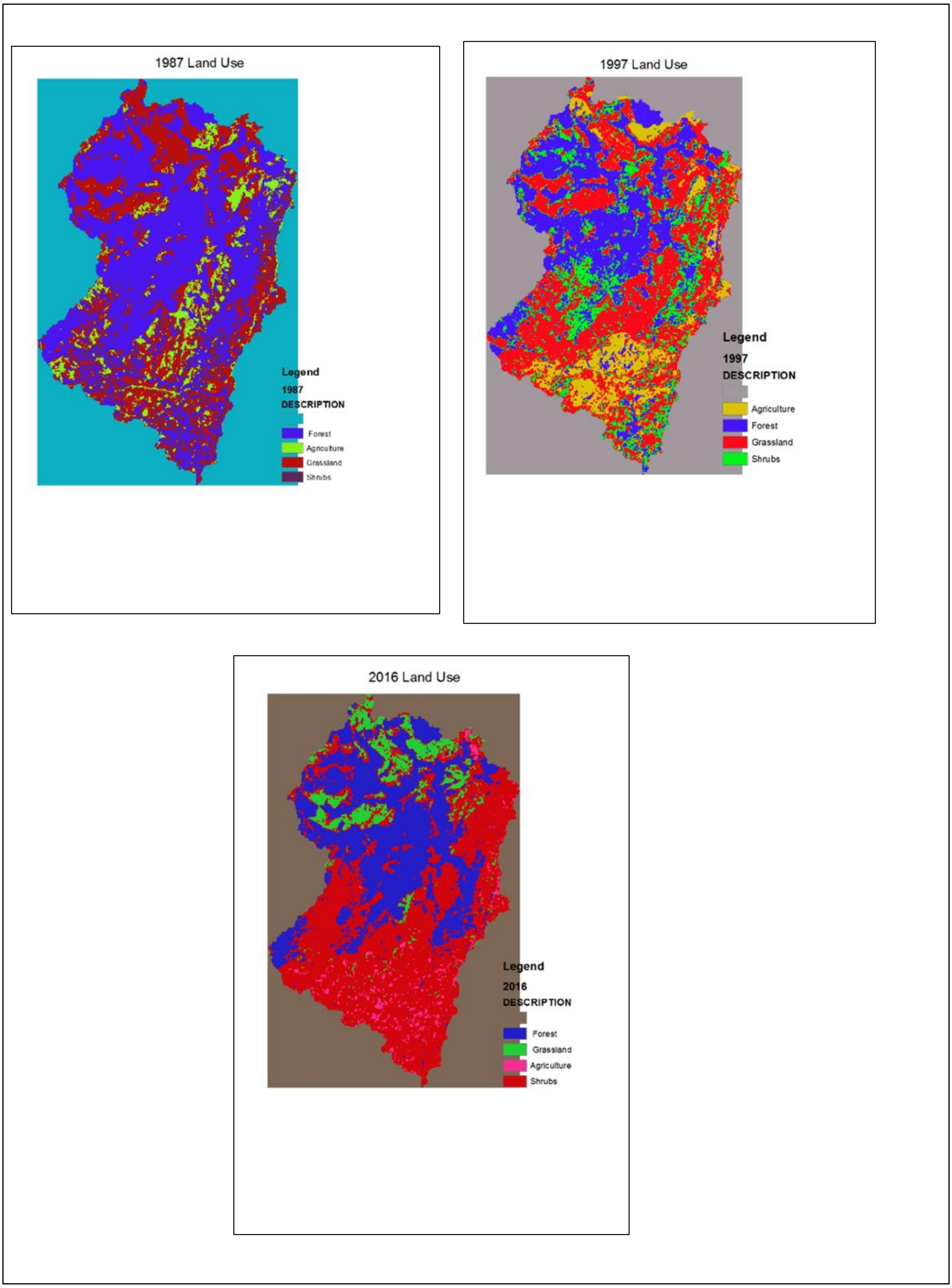


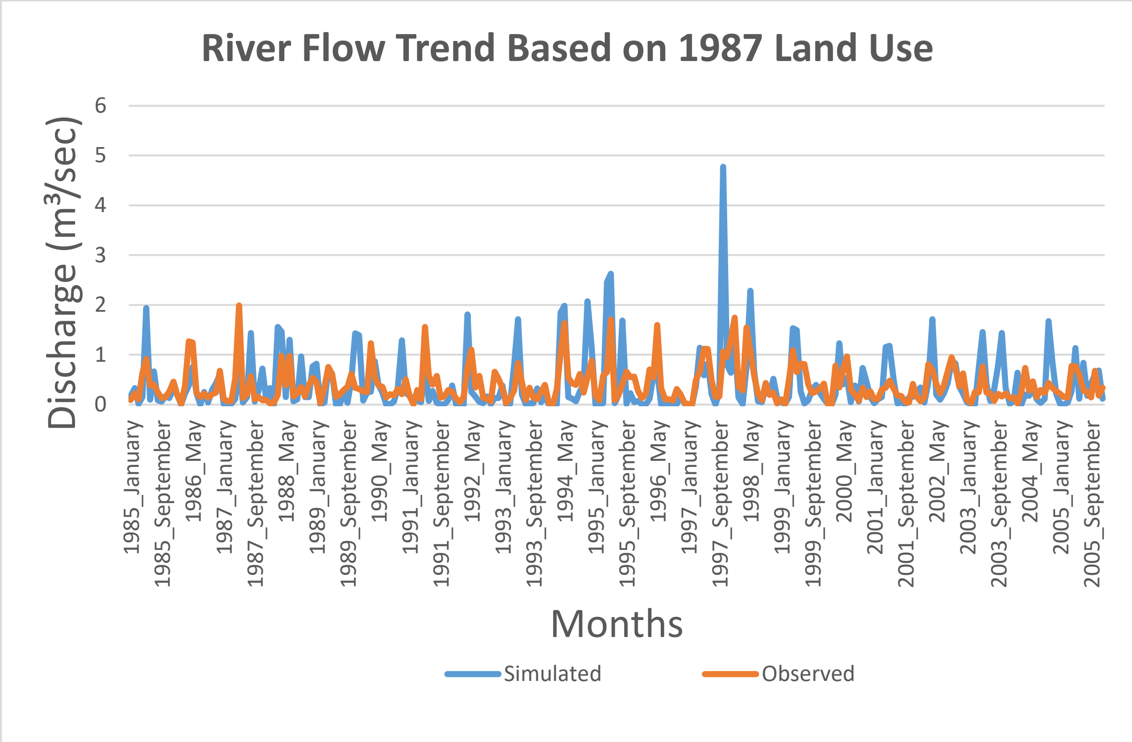
Figure 4. 2 Land Use Classification of 1987, 1997 & 2016

In 2016, there were high decrease in area under grassland, and increase in area under shrubs. This could be attributed to increased vegetation in the area that was under grassland that paved way for flourishing of shrubs. The decline in the agricultural area is because of developments that led to increases in the price of land, providing a new source of income for the local communities that formerly practiced traditional farming methods such as free-range grazing, rain-fed agriculture. The community also depends on fishing and hospitality in tourism sector as income generating activities for a living.

4.3 River Discharge Observations

SWAT model tool was applied in simulation of Mkurumudzi river flows. . This involved simulation of river flows for a period of 24 years. The specific window period considered is from 1982 to 2005.However, the only years with reasonably sufficient land use data were 1987, 1997, 2016 and 2030 and were therefore adopted in simulation assuming they are representative. SWAT model estimates water balance components daily, and monthly discharge in the water shed. Average annual basin values for water balance components during a base year simulation period shows average annual watershed gains and losses with change in soil water storage (Shawul, et al., 2013). This research has shown that land use changes in a water catchment results in slightly erratic discharges due to rainfall and air temperature changes that has an impact on the discharge and water balance components.

Figure 4.3, 4.4 & 4.5 shows the monthly stream flow from 1985 to 2011 based on 1987, 1997 and 2016 land use. From the results of the simulations, it was noted that the SWAT model is capable of tracking the seasonal trend of stream flows for the entire period under consideration. Graphical displays of observed monthly stream flow obtained shows satisfactory level of match with the simulated monthly stream flow. However, the model overestimated the stream flow output for the watershed and simulated output required to be calibrated.



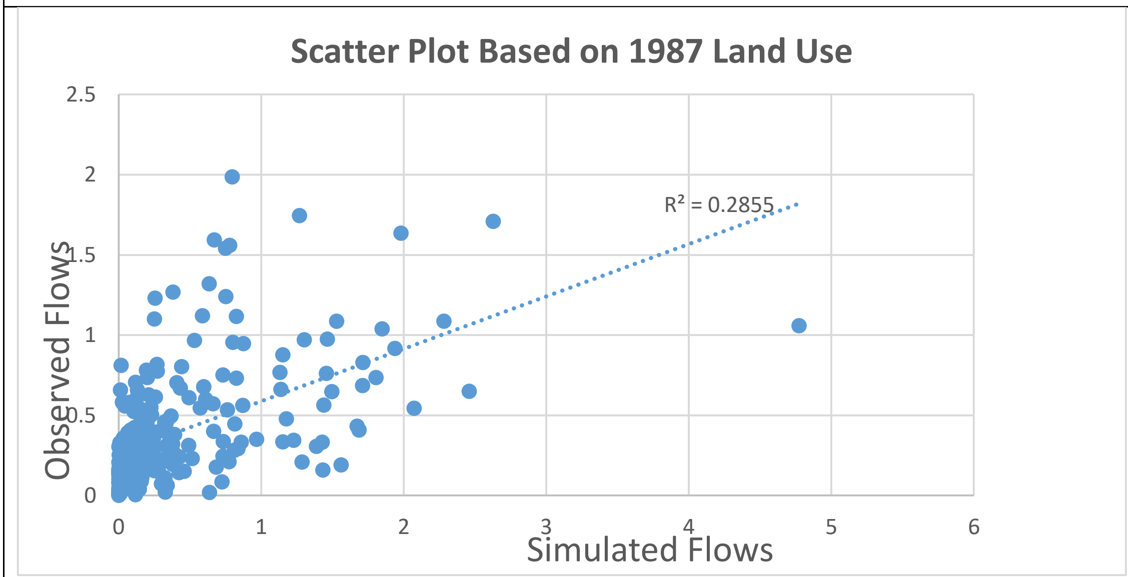
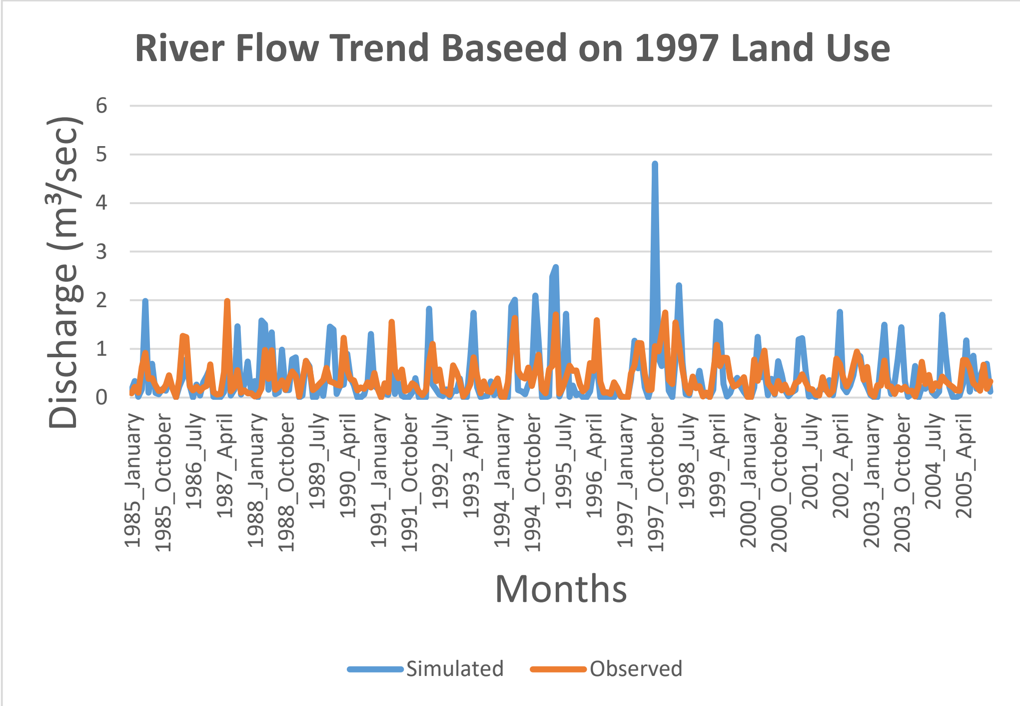


Figure 4. 3 River flow trend generated from 1987 land use



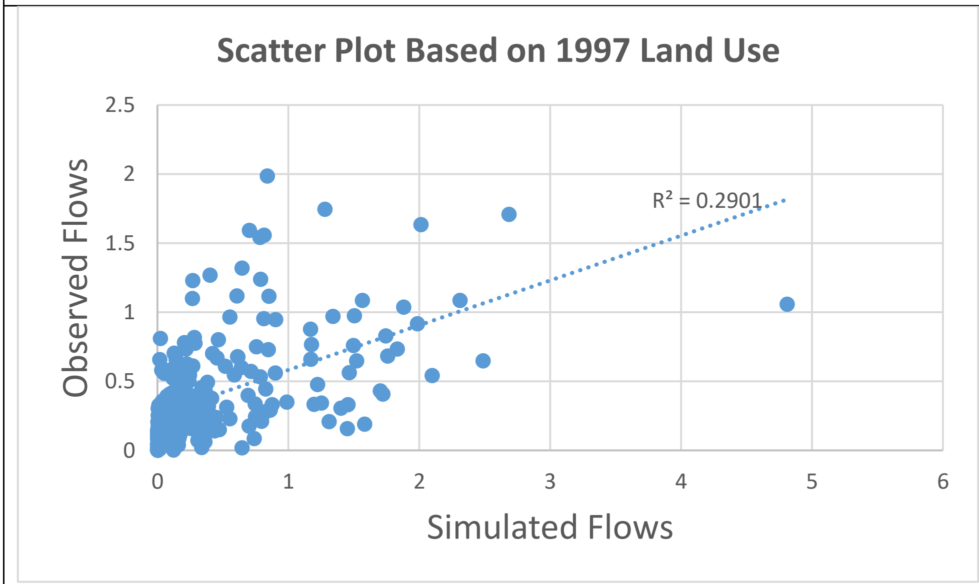


Figure 4. 4 River flow trend generated from 1997 land use

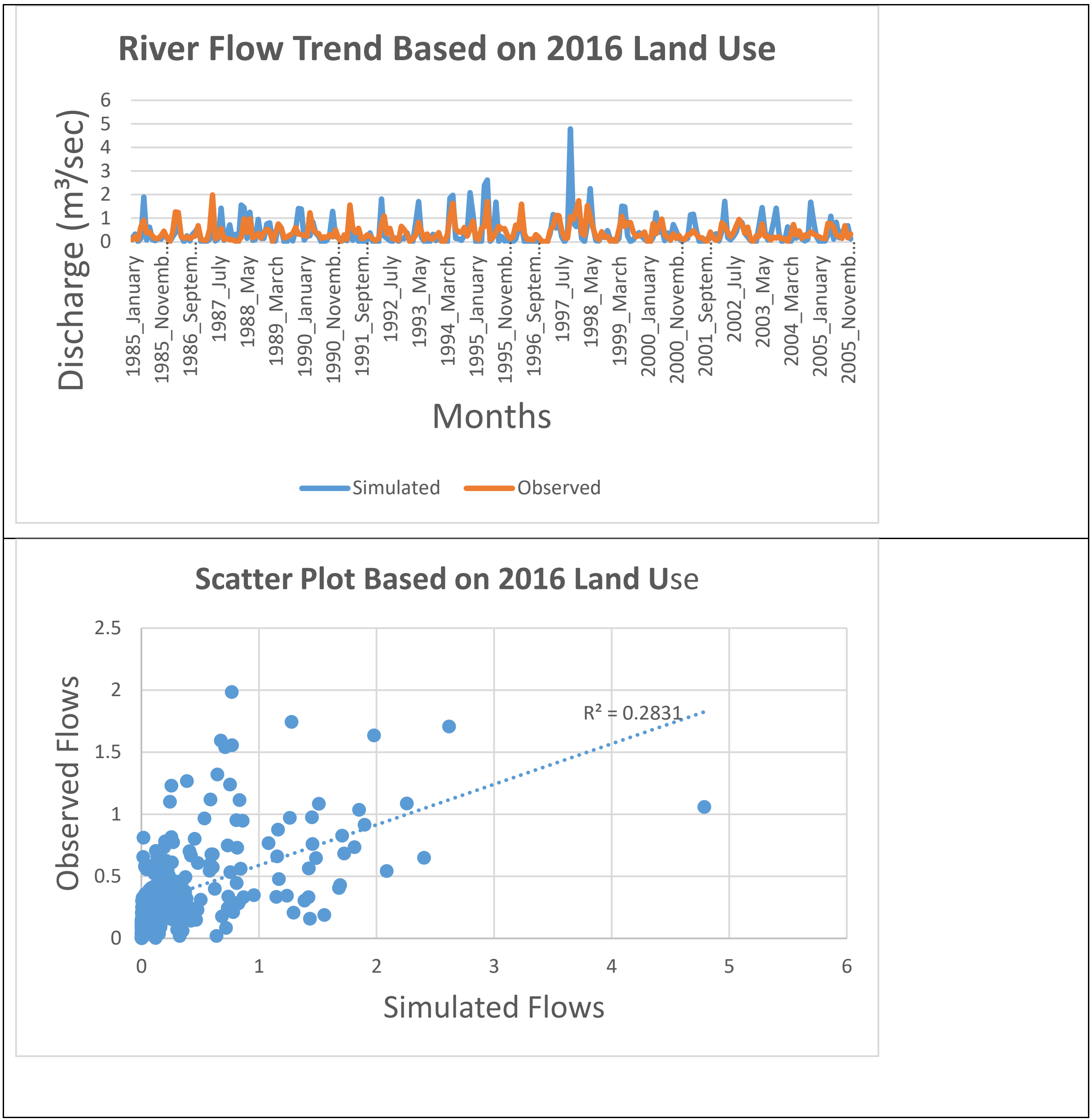


Figure 4. 5 River flow trend generated from 2016 land use

The plots of the observed and simulated monthly stream flow trend obtained under the land use scenarios in the study shows that the stream flow trends are similar for the four scenarios that vibrates in phase as the observed data. The plots have demonstrated that there were high stream flows in 1987 as compared with those of 1997. This could be associated with the decrease in area covered by forest. Decreased forest cover enhances decrease in infiltration, low evapotranspiration and high surface runoff. All these factors combined contributed to increase in stream flows. Conversion of forest covers for agricultural and grassland could have resulted to decrease of water in the soil and thus affecting the river's base flow. This change in land cover likely decreased the infiltration of water into the soil, resulting in reduced or no flow in streams during the dry season(Castillo *et al.*, 2012).

Rapid changes in stream flows brings about immediate effects to environmental services that depends directly or indirectly on river water. Four scenarios: 1, 2, 3 and 4 representing simulated discharges based on 1987, 1997, 2016 and 2030 land use in the same order, were in the study to determine the changes in stream flows. Table 4.4 represents the quantile values obtained from the simulated flows and their percentage changes. Median values for the river discharge were used to observe the changes in stream flows. Figure 4.6 is a boxplot presentation showing the rate of flow rises and falls for the study area in four scenarios of study.

Table 4. 4 Quantile Comparison

Description	Year				Percentage Change		
	1987	1997	2016	2030	1997	2016	2030
Minimum	0	0	0	0	0	0	0
Quantile 1	0.0385	0.0429	0.0375	0.0373	11.46	-12.53	-0.6
Median	0.1724	0.1783	0.1694	0.1691	3.42	-4.99	-0.18
Quantile 3	0.52	0.5509	0.511	0.5103	5.95	-7.24	-0.14
Maximum	4.772	4.809	4.788	4.788	0.78	-0.44	0
T-test		0.0543412	0.0509	0.068			

In 1997, the median flow for the discharge increased by 3.42% from the base year (1987). During this period, the flow increased from 0.1724 m^3/ s to 0.1783 m^3/s. In 2016, there was a decrease of flows by 4.99 %. In this period, the flow decreased from 0.1783 m^3/s to 0.1691 m^3/s. It is expected that in the year 2030, there will be a decrease of flows by 0.18 %.This means that the flows will decrease from 0.1694 m^3/s to 0.1691 m^3/s.

According to Mango *et al.* (2006) on analysis of the effects of LULC on Mara river flows, model results indicated that any conversion of forest to agriculture or grassland adversely affected runoff at critically low-water times of the year such as droughts. This is likely to result in increased peak flows and associated hillslope erosion, .The net impact of these events is increased vulnerability of the basin to future climate change within the river basin.

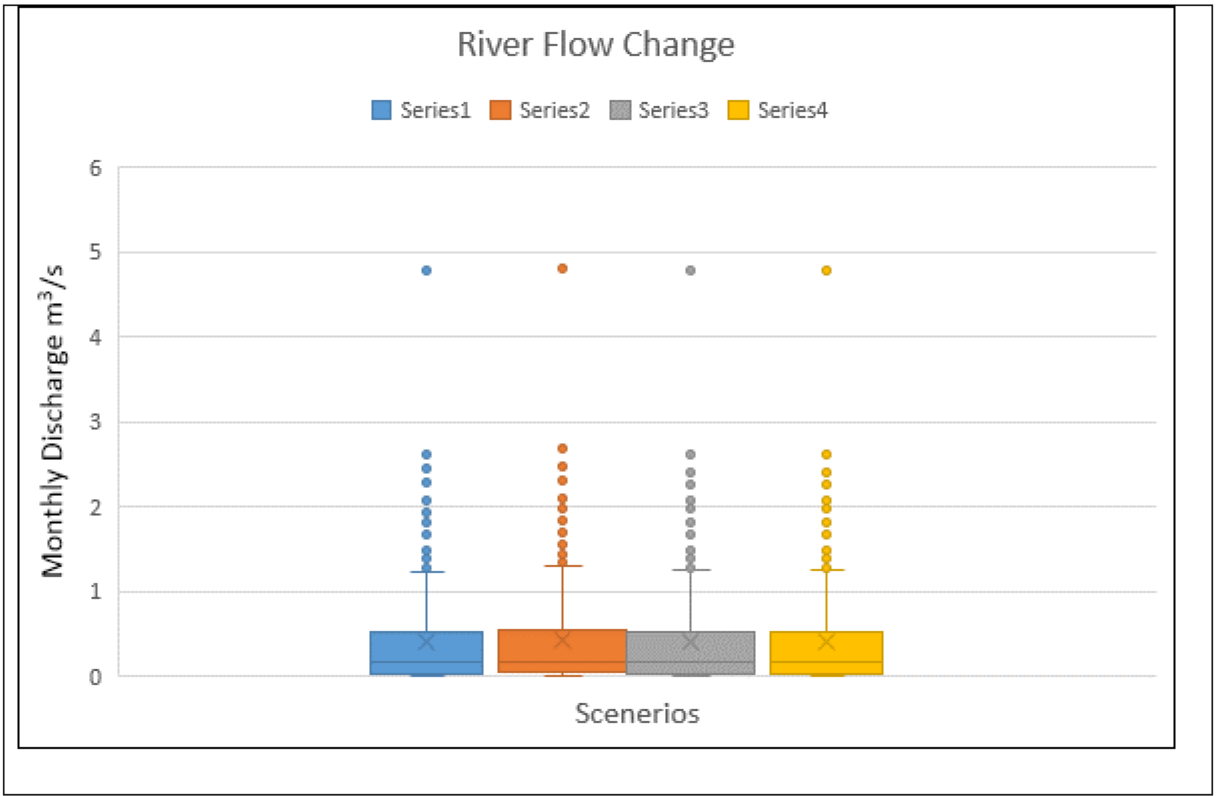


Figure 4. 6 River flow based on 1987, 1997, 2016 and 2030 land use

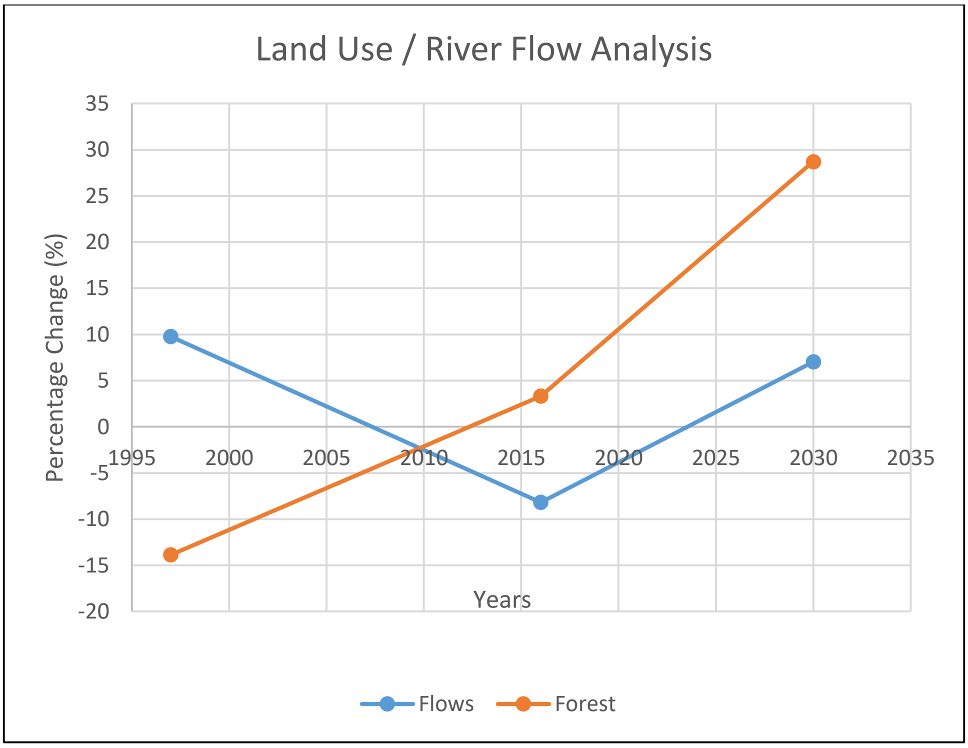


Figure 4. 7 Land Use River flow analysis

Land Use and Land Cover change can either reduce or increase river discharge. In this study, the baseline year is 1987 whereby all the changes in stream flows were based on it. Figure 4.7 shows the comparison of the percentage changes in forest cover with that of the stream flow. According to the simulated flows based on 1997 land use classification, it was found that there is increased river flows by 9.8%. The increase in flows was attributed to the decrease in the forested area. In 1997, there was a decrease in area under forest by 13%. This resulted to increase in surface runoff mainly due to less infiltration. Though there was increase in grassland and shrubs cover, it did not have any significant contribution in increasing the infiltration.

Based on the land use cover for 2016, simulation results indicate a decrease in stream flow by 8%. The increased forest cover in the catchment could be linked to the decrease in stream flows. From the comparison made between the land use and land cover change, the results shows that there was increased forest cover by 3% as compared to 1997 river flows and forest cover.

Prediction of land cover change in the period 2030 by increasing the forest cover is expected to result in reduction of surface runoff and increase in base flow due to increased infiltration. The simulation results shows that river flows and forest covers would increase by 7% and 29% respectively in the year 2030. These flows are mainly contributed by lateral and ground water recharge.

4.4 Calibration, Validation and Sensitivity Analysis

In most watershed modeling projects, model output is compared to the corresponding measured data on assumption that all error variance is contained within the predicted values and that observed values are error free (D. N. Moriasi *et al.*, 2007).The SWAT model discharge rates were calibrated and validated for different scenarios . Calibration process of physical based distributed model before it is used in simulation of flows in a hydrological process is important to reduce the uncertainties that may result during prediction. During this study, calibration process involved comparing the observed and simulated flows generated from the SWAT model. Discharge for Mkurumudzi river gauge station between the period 1982 to 1995 were used for calibration and then validated for flows using 1996 to 2011 discharge data. SWAT- P software was used for calibration in order to achieve good P- factor, R-factor, NSI, R^2 and PBIAS value. Table 4.5 shows model performance for flows in the years under consideration. Though the R^2 value is considerably low, statistical relationships to check model accuracy were based on results of PBIAS and NSE. Results of the two statistical indices indicate that SWAT Model can mimic natural flow of the river system and therefore it can be used for modelling of Mkurumudzi River catchment.

Table 4. 5 Model performance

Year	Calibration			Validation		
	PBIAS	R^2	NSE	PBIAS	R^2	NSE
1987	5.97	0.30	0.87	4.97	0.25	0.84
1997	8.82	0.31	0.81	8.23	0.26	0.74
2016	4.97	0.30	0.89	4.53	0.25	0.86
2030	4.96	0.30	0.89	4.51	0.25	0.86

Different parameters were subjected to sensitivity analysis. Parameters that are factors of surface run off, soil, land use, lithology, ground water, base flow, were tested. These parameters influence the availability of water storage capacity in the hydrological model. In this model, four parameters were used to adjust the simulated values closer to the observed. The following were found to be the most sensitive parameters:

I. The curve number (CN)
II. Ground water delay
III. Base flow alpha factor
IV. Depth of water in the aquifer
V. Soil hydraulic conductivity
VI. Available water capacity of the soil.

Sensitivity analysis is an important activity in development of a model. This activity involves examining the input parameters in an analytical manner. SWAT model has many input parameters that require to be calibrated. The parameters include streamflow, sediment and environmental purposes. In this study SWAT –CUP model was used to analyze the sensitivity of the parameters in the catchment. SWAT cup model has two types of sensitivity analysis. They are global sensitivity and One- at – a – time sensitivity analysis. In global sensitivity analysis, multiple regression system method is used to determine sensitivity of the parameters. Use of the Latin hypercube regresses is used to obtain parameters against the objective function values. One – at – a time sensitivity analysis involve varying one parameters while the other parameters are kept constant. Global sensitivity analysis was employed in this study.

SUFI-2 uses t – stat values and P-values in assessment of the sensitive parameters. The t-stat values for a most sensitive parameter has a large absolute value. P-value measures the significance of sensitivity of a parameter; P-values that are close to zero are the most significant parameters. Table 4.6 has the t-Stat values and P-Values for the parameters for the parameters used to analyze the sensitivity. From the analysis, soil available water content and CN2 were the most sensitive parameters in the catchment hydrology. Base flow alpha factor and soil hydraulic conductivity had the lowest sensitivity values hence had little effect on the catchment hydrology.

Table 4. 6 Parameter sensitivity

No.	Parameter Name	t - Stat	P - Value
1.	Available water capacity of the soil (SOL _ AWC)	35.76	0.00
2.	Curve number (CN2)	-21.37	0.00
3.	Threshold depth of water in the shallow aquifer (QWQMN)	-0.43	0.67
4.	Ground water delay (GW_DELAY)	0.29	0.77
5.	Soil hydraulic conductivity (SOL_K)	0.11	0.91
6.	Base flow alpha factor (ALPHA_BF)	0.03	0.98

4.5 Impact of LULC on Stream Flow

Based on the simulation results, the impacts of changes in land cover were experienced in the catchment area. According to the streamflow simulation results based on the four scenarios, it is evident that deforestation led to increase in surface runoff. On the other hand, the resultant increase in streamflow was associated with increased forest cover. Conversion of forest cover into cropland and urban land increases the demand of water for irrigation and domestic use. The general increase in water requirements in key sectors of the economy implies enhanced water abstraction from Mkurumudzi River. Considering reduced infiltration, this research flags this as another contributor towards the decreased stream flows.

Future year considered in this study is 2030. The assumption of increasing the current forest cover by 10 % as per the government of Kenya policy shows that there would be slight decrease in streamflow. The increase in forest cover would also gather for the land conversion for agriculture as it is expected that the population will increase. To ensure that there is sufficient decrease in surface runoff, this study recommends an increase in forest cover by at least 10 %.

4.6 Future Land Conversion

CLUE-s model combines a statistical description of land use with scenarios of changes in the demand for regional commodities to model the possible pathways of future land use development. Present land use was used in determining the possible future land use conversion. Future land use conversion for Mkurumudzi river catchment future were simulated from the CLUE-s model as shown by table 4.7.

The results from the conversion shows that grassland often makes place for agricultural activities while expansion of agricultural land occurs simultaneously at the forest frontier. An extreme example is shifting cultivation: for this land use system the same location is mostly not used for periods exceeding two seasons as a consequence of nutrient depletion of the soil. Not all land use changes are possible or realistic (e.g., arable land cannot be converted into primary forest directly) and many land use conversions follow a certain sequence (Willemen, 2002).

Table 4. 7 Table Future land use conversion

Present Land Use	**Future Land Use**			
	Forest	Agriculture	Grassland	Shrubs
Forest	+	-	-	-
Agriculture	-	+	+	-
Grassland	+	+	-	+
Shrubs	+	+	-	-

The + ve means Conversion possible and –ve means conversion not possible

4.7 Causes of Land Degradation

Land degradation is a human induced or natural processes which results to negative impacts to land functions in an ecosystem. The current status of land resources and its use patterns are the result of many highly interlinked factors including natural, socio-economic, policy and those related to agricultural practices(Tefera *et al.*, 2002) .Mkurumudzi river catchment is facing land degradation which results to the changes in the river flows. The major causes of these land use changes are deforestation, overgrazing and desertification.

1. Deforestation

   Forests helps in binding up soil particles. In Mkurumudzi Catchment cutting of trees has adversely affected the soil and land surface cover. The removal of the natural vegetation for fuel wood, agriculture and industry is increasing at an alarming rate and this is causing serious land degradation on 579 million ha of which 50% is located in Asia, followed by South America with 17%. It is estimated for example that only 4 to 6% of Ethiopia is now forested where once it was 40%; another example is Ivory Coast which lost more than 50% of its forest in less than 3 decades (Gabriels and Cornelis, 2009).

2. Overgrazing

Overexploitation of pasture in the catchment is resulted from increase in livestock population. Overgazing occurs when animals concentrate on one particular area, which leads to depletion of the vegetation cover resulting to soil erosion and increased surface run off. Soil degradation in Patagonia, Argentina is attributed to the heavy grazing pressure associated with the sheep monoculture in the region (Gabriels and Cornelis, 2009)

3. Desertification

   Desertification is a land degradation process that occur in arid, semi-arid and dry sub – humid areas. Factors that contribute to desertification are climatic variations and human activities. Human induced activities include mismanagement of forest and overgrazing while climatic variations include weather and climate change variations. Desertification in the catchment has resulted to degradation of vegetation cover and increased soil exposure.

4.8 Land Degradation Interventions

Economy of the study area is based on agriculture. Development and management of water resources is necessary especially in areas where there is competition of natural resources. Changes in land management practices will affect the users directly or indirectly. Different adaptation measures towards environment conservation can be applied in areas greatly affected by effects of distribution of ecological processes change. The need for protecting water resource and ensuring sustained and effective utilization of water resource is a times taken as a conflicting management function. Defining the main causes of deforestation in the area before implementation of these measures is important. Catchment management plans and strategies should be developed to help resolve on potential conflicts which might arise. The following are adaptation measures that can be adopted towards catchment conservation:

1. Catchment Management Practices

Catchment management practices involves management of land and surface water as a system. People have different interests on land and water and it is important if they work together by identifying the problems and issues they encounter and agree on what best should be put into practice.

A catchment facing deforestation results to excessive water runoff while areas with forests experience slow water movement. This is because the leaves and other organic matter that are found on the forest floor helps in absorbing water from heavy rains. This water is then released to the soil slowly. Deforestation can lead to catastrophic flooding, as water runoff is no longer constrained by the plant roots.

Overgrazing and intensive farming destroy humus and vegetation that protect soil against erosion. Eroded soil can absorb a lot of water. This makes the soil more likely to slip. In addition, the natural flow of water into streams can be interrupted.

Forestry Commission Wales, through the BetterWoodlandsforWales(BWW) grant scheme, have supported farmers who are working together to help address the effects of climate change through woodland creation and management ('Case Study : Adaptation – new woodland planting in West Dunbartonshire', 2007)

It is the mandate of the relevant institution to ensure that best land use management practices are enacted it this catchment. These activities may include, planting trees, avoiding cultivation around the riverbanks, ban cutting of trees for charcoal and logs.

2. Alternative Livehoods

The community is tasked with engaging in income generating activities to sustain their livelihoods. This is done with the aim of reducing deforestation. These activities should not involve destroying the environment. For example, the government can supply fruit trees to the farmers and introduce bee keeping. The government will be the custodian of ensuring that they buy these fruits from the farmers.

Study for changes and cropping pattern to identify the best land use option is important. Training and capacity building for improved land use practices should be introduced. This will increase the investments returns from agricultural products hence reducing the need for clearance of vegetation to pave land for agriculture.

3. Payment for Ecological Services (PES)

Payment for Ecological Services (PES) involves payment of natural resource in support to conservation of the ecosystem. These include taxing the heavy water consumers to pay for the ecology. This money will be used for the conservation of the environment i.e planting trees. This payment encourage landowners to improve on land use management practices.

The concept involve sensitizing the public on the benefits and important of conserving the ecosystem. The central idea of PES is that the stewards of the ecosystem services should be compensated by those who benefit (Grima et al., 2016). Upstream water users practicing land use management practices towards conservation of river flows should benefit by downstream water users.

Certain smallholder farmers in parts of sub-Saharan Africa engage in conservation agriculture and participate in agroforestry ecosystem services schemes that generate additional on-farm revenues through payment for ecosystem services (Benjamin and Sauer, 2018). According to Grima et al. (2016), Payment for Ecosystem Service in Latin America has been implemented in the aim of protection of the water shed. This is due to high demand for water that has resulted to increased water shortages.

4. Contributions towards Environment Conservation

Multinational organizations have been the major contributors towards investments in ecosystem conservation. Multinational Corporations are key drivers of economic liberalization in the context of globalization and as thus, many countries, including Least Developed Countries (LEDCs), have opted for their investments (Angeline, 2016). These organizations may help inform of giving out money or by themselves organizing ecological conservation programs. They may also create public awareness and conduct educational programs through media.

Chapter 5: Conclusion & Recommendation

5.1 Conclusion

Supervised classification of images in remote sensing to identify different LULC changes and use of SWAT model for hydrological modelling are effective methods for studying effects of LULC changes on river flow. From this study, it was noted that agricuulture is the major current land use practices in the catchment affecting the river flows. The study to determine the changes in the LULC clearly showed that changes in forest cover were the major LULC change experienced in the catchment..Most of the undesirable changes were brought about by human activities that do not comply with the development policies of the region. These changes in LULC in turn influences the stream flow regime of Mkurumudzi River. Modelling provided insight into understanding future river flow change and helps formulation of alternative land based intervention measures in response to the changed conditions to guide in decision making for better management of the water resources as advocated for in the concepts of integrated water resources management (IWRM).

5.2 Recommendation

Flow alteration can affect habitat availability in headwater streams and influence the functioning of ecosystems that depend on these waters in the downstream. Due to the undesirable land use and land cover changes experienced in the catchment, which involved the forest encroachment to pave way for agricultural activities, more sustainable development plans is required to be implemented. From the study, the vision 2030 aim of increasing the forest cover by 10% will bring positive impacts to the catchment even though there is an assumption that there would be an increase in agricultural land. Focusing on assessment of specific effects of land use change on river flows and formulation of the most suitable alternative measures to maintain water supply for domestic, agricultural, industrial and environmental flows in which the economy of the country is based is of great beneficial. Conservation of remaining forest areas and increase in forest cover is important to prevent further changes in the seasonal distribution of flows and its effects on downstream ecosystems. The government should consider applying policies that will affect directly or indirectly the development of the study area. The catchment stakeholders should optimize the utilization of the water being abstracted to ensure that water is available for future use. The success of hydrological studies of a water shed depends on the availability of data. In this study and most of other studies conducted by other researchers, problems of scarcity of data limits the accuracy of results obtained.

The following studies are recommended to be studied in future:

- Sufficient spatial and temporal data should be acquired for best modelling output results.
- Study the contribution and effects of climate change on the hydrology of the catchment.
- Assess the willingness of the water users to implement proposed catchment adaptive measures.

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Appendices: Budget

Item No.	Description	Units	No.	Cost per Unit (USD)	Total Cost (USD)
1	Climate Data	Sum	1	632	632
2	Streamflow Data	Sum	1	526	526
3	Landsat Data	Sum	1	474	474
4	Consultation	Sum	1	95	95
5	Internet	Sum	1	105	105
6	Transport	Sum	1	1,213	1,213
8	Research Registration Fee	Sum	1	11	11
TOTAL					**3,056**