MODELLING OF KANGIMI DAM WATERSHED HYDROLOGICAL PROCESSES USING GIS AND SWAT MODEL

UMAR Shamsuddeen Bello
(B.Eng. WREE, A.B.U)
P16EGWR8042

DEPARTMENT OF WATER RESOURCES AND ENVIRONMENTAL ENGINEERING,
FACULTY OF ENGINEERING,
AHMADU BELLO UNIVERSITY,
ZARIA, NIGERIA

DECEMBER, 2019

DECLARATION

I declare that the work in this dissertation entitled “**Modelling of Kangimi Dam Watershed Hydrological Processes Using GIS and SWAT Model**” has been performed by me in the Department of Water Resources and Environmental Engineering. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

Umar Shamsuddeen Bello ______________________ ______________________ ____________

Signature Date

CERTIFICATION

This dissertation entitled "**Modelling of Kangimi Dam Watershed Hydrological Processes Using GIS and SWAT Model**" by Umar Shamsuddeen Bello meets the regulations for governing the award of the degree of Master of Science in Water Resources and Environmental Engineering of the Ahmadu Bello University, and is approved for its' contribution to knowledge and literary presentation.

Dr. M.A. Ajibike
Member, Supervisory Committee   Signature   Date

Dr. B.K. Adeogun
Member, Supervisory Committee   Signature   Date

Dr. M.A. Ajibike
Head of Department   Signature   Date

Prof. Sadiq Z. Abubakar
Dean School of Postgraduate Studies   Signature   Date

DEDICATION

This dissertation is dedicated to my caring parentsAlhaji Umar Bello, and Hajiya Aisha Umar Bello whose support has been a driving force.

ACKNOWLEDGEMENT

My deepest and greatest gratitude goes to He who begins the beginning before the beginning began for His infinite mercies and kindness in making this study a huge success. May His peace and blessings be upon the last prophet, Muhammad (S.A.W), his entire house hold family and those that follow his footsteps until the last day.

I would like to express gratitude to my day-to-day supervisors of this work Dr. B.K. Adeogun and Dr. M.A. Ajibikefor their timely corrections and guidance through the various stages of this process and countless hours of reflecting, reading, encouraging, and most of all patience throughout the entire process despite their busy schedule. I also show my sincere appreciations to Dr. BadruddeenSaulawaSani and Prof. A. Ismail, Dr. Mujaheed, Dr. Umar Alfa, Dr. (Mrs) Fatima, and Prof. Donatus Adie for their words of encouragement. I would like to express my special gratitude to my motivator Dr. Mohammed IsmailaSani who motivated me a lot and encouraged me to be focus on my work. The topic was new to me, but his guidance, patience, enthusiasm and critical inputs during many decision-making processes were very much appreciated.

My profound appreciation goes to my lovely parents Alhaji Umar Bello and Hajia Aisha Umar Bello for their moral and financial support, my brothers and sisters Al-Amin, Usman, Abdussamad, Ubaidullahi, Abubakar, Ummalkhari, Aisha, Fatima, Maryam, Sadiya, Hafsat and Shamsiya. Their love and support made the success of this effort inevitable. I'm very proud to be part of such a family

I would like to thank Dr. Saminu, Dr. Haruna, Flt. Offr. Nasiru (rtd) and all the staffs of Civil Engineering, Nigerian Defence Academy Kaduna. It would have not been possible for me to carry out this work without the collaboration with Mrs. Charity and Kaduna State Water Board staffs for the data and information they gave me pertaining the Dam watershed.

I appreciate all my relatives and friends especially Usman, Sadik,Abdurrahman, Timta, Umar,EngrMuntaka, Engr Mustapha, Abdullahi (Junior),AliyuLadan, Snr. Ibro, Mahmud, Alof, Daddy,Lukman, Abdulganiyu, Saleem,Alkafor their enormous support and prayers. I also like to appreciate a fatherand a mentor Rear AdmiralIsah Muhammad (rtd) for his advice.

ABSTRACT

This study focused on application of physically based hydrological model, Soil and Water Assessment Tool (SWAT) interfaced with ARCGIS software over the Kangimi dam sub-watershed, located in Kangimi river sub-basin, in Igabi Local Government Area, about 37km away from Kaduna metropolis, Kaduna State, Nigeria.The watershed was delineated with 10 sub-basins, 39 hydrological response units (HRUs) were defined, which are areas with similar land use, soil, and slope characteristic, the watershed has a total surface area of 349.94km^2 and a corresponding perimeter of 156.82km.The maximum and minimum elevation in the study area were determined to be 784m and 512m respectively.The program SUFI-2 in SWAT-CUP package was used for sensitivity analysis, the parameters found to be most sensitive are curve number (CN2), threshold water depth aquifer (GWQMN) followed by, soil available water capacity (SOL_AWC),groundwater delay time (GW_DELAY), groundwater ‘‘revaporation’’ coefficient (ESCO), effective hydraulic conductivity (SOL_K) and base flow alpha factor (ALPHA_BF.gw) as relative to the determination of surface runoff.The model was executed from 1979 to 2014using SCS curve number method for estimation of surface runoff, Hargreaves method for potential evapotranspiration and Variable-storage method for channel routing.The calibration and validation of the model produced good simulation results based on the objective functions (p-factor=0.77, r-factor=0.71) and (p-factor=0.83, r-factor=0.75) for calibration and validation respectively, after achieving 500 simulations. The model performance was evaluated and found to be very good for both calibration and validation period of historical discharge datawith R^2 and NSE to be 92% and 82%, for calibration, and 93% and 86%, for validation respectively. The watershed hydrology was simulated in response to different LULC and climate changes, the surface runoff, evapotranspiration, contribution of groundwater to surface runoff, deep aquifer recharge and total average annual water yield at the watershed outlet for the simulation period were 387.37mm, 509.3mm, 248.22mm, 15.19mm and 655.51mm respectively. This interesting performance obtained with the ArcSWAT model suggests that SWAT model could be a promising decision support tool for sustainable management of water resources.

TABLE OF CONTENTS

CONTENTS **PAGES**

Cover Page i

Declaration ii

Certification iii

Dedication iv

Acknowledgement v

Abstracts vi

Table of Contents vii

List of Figures x

List of Tables xi

List of Symbols and Abbreviations xii

CHAPTER ONE: INTRODUCTION 1

1.1 Background **1**

1.2 Statement of Research Problem **3**

1.3 Justification **3**

1.4 Aim and Objectives **4**

1.5 Scope **4**

1.6 Limitations of the Research **5**

1.7 Study Area **5**

CHAPTER TWO: LITERATURE REVIEW **8**

2.1 Introduction **8**

2.2 Hydrological Processes **8**

2.3Hydrological Models **11**

2.3.1 Hydrological Model Classification 11

2.4. Standard Hydrological Equations **13**

2.5 SWAT Model Description **16**

2.5.1 Summary of SWAT Historical Development 19

2.5.2 GIS-SWAT Interface Development 20

2.5.3 SWAT Applications 21

2.5.4 SWAT Calibration and Validation 21

CHAPTER THREE: MATERIALS AND METHODS **26**

3.1 Introduction **26**

3.2 Materials **26**

3.2.1 Creation and Collection of Databases 26

3.2.2 Spatial Datasets 26

3.2.2 3 Digital Elevation Model (DEM) 26

3.2.2.2 Land Use Land Cover Data 27

3.2.2.3 Soil Data 27

3.2.3 Temporal Datasets 28

3.2.3.1 Meteorological Data 28

3.2.3.2 Hydrological Data 28

3.2.4 Projected Coordinate System 28

3.3 Key Procedures Used during the Modelling Process 29

3.3.1 Dem (Watershed Delineation) 30

3.3.2 Creating the Hydrological Response Units (HRUs) 30

3.3.4 Write Input Weather Data Table 31

3.3.5 ArcSWAT Setup and Run 31

3.3.6 Swat Output 32

3.4 Streamflow Calibration, Validation and Sensitivity Analysis Using SWATCUP 32

3.4.1: Key Steps in Streamflow Calibration, Validation and Sensitivity Analysis UsingSWATCUP 33

CHAPTER FOUR: RESULTS AND DISCUSSIONS 36

4.1 General 36

4.2 GIS Inputs and Watershed Delineation 36

4.3 Hydrological Response Units (HRUS) 42

4.4 Model Calibration, Sensitivity Analysis and Validation 44

4.5 Land Use and Land Cover Changes and their Impact on the Study Area 51

4.6 Water Balance Components 52

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS 56

5.1 Conclusions 56

5.2 Recommendations 57

Contributions to Knowledge 59

References 60

Appendices 65

LIST OF FIGURES

Figure 1.1: Geographic Map of the Study Area 6

Figure 2.1: Diagram of the Natural Water Cycle (without human alterations) 9

Figure 2.2; Water Balance Representation 14

Figure 2.3: The Schematic of SWAT development history and model adaptations 19

Figure 2.4 Example of SWAT Manual calibration flowchart 24

Figure 3.1: The Work Flow of the Modeling Process 29

Figure 4.1 (a): The DEM, Stream Network and Sub-basins Numbered 37

Figure 4.1. (b): Digital Elevation Model (DEM) of Kangimi Watershed 37

Figure 4.2: Delineated Land Use/Cover Map 39

Figure 4.3: Delineated Soil Map 40

Figure 4.4: Derived slope Map 41

Figure 4.5: Extracted part of the Topograhic Watershed Report 41

Figure 4.6: The Hydrological Response Unit (HRUs) 43

Figure 4.7: The Extracted part of the Hydrological Response Units (HRUs) 43

Figure 4.8: Comparison of observed and simulated Streamflow for R2, NS, p-factor and r-factor Statistics during the Calibration Period. 48

Figure 4.9: Comparison of observed and simulated Streamflow for R2, NS, p-factor and r-factor Statistics during the Validation Period 49

Figure 4.10: 95PPU in SWAT-CUP for calibration period 50

Figure 4.11: 95PPU in SWAT-CUP for validation period 50

Figure 4.12: Percentage share of the land use/land cover (LULC) classes within the Kangimi Catchment from the 1975s up to 2013 51

Figure 4.13:Figure 4.13: Average annual water balance as a relative percentage to precipitation for (a)1975 LULC (b) 2000 LULC (c) 2013 LULC (d) 2013LULC/2020 PRO in the study area. 54

LIST OF TABLES

Table 1.1: Available Kangimi Reservoir Design Data 7

Table 2.1: Equations Mostly Used in Hydrological Models 16

Table 4.1: Land Use–Land Cover, Soil and Slope Classes Used in the Watershed 38

Table 4.2 Derived Soil Characteristics Delineated in the Catchment 40

Table 4.3Global Sensitivity Analysis result in SWATCUP 45

Table 4.4 Stream flow Calibration Parameter Values Used in ARCSWAT 46

Table 4.5 Statistical Evaluation of Simulated versus Observed Annual Stream Flow data 47

Table 4.6: Summary LULC of Kangimi Watershed for Different Period of Time 52

Table 4.7:Land Use and Land Cover Changes and their Impact on Hydrology of Kangimi Watershed 53

LIST OF ABBREVIATIONS

GIS - Geographic Information System

RS - Remote Sensing

SWAT - Soil and Water Assessment Tool

SWAT-CUP - Soil and Water Assessment Tool-Calibration Uncertainty Program

HRU - Hydrologic Response Units

ANN - Artificial Neural Networks

MUSCLE - Modified Universal Soil Loss Equation

SCS- CN - Soil Conservation Service Curve Number

(USDA- ARS)- United States Department of Agriculture - Agricultural Research Service

CRP Conservation Reserve Program

CRPDSS Conservation Reserve Program Decision Support System

NSE - Nash-Sutcliffe Efficiency

R^2 - Coefficient of Determination

RMSE - Root Mean Square Error

CIAT - Centre for Tropical Agriculture

DEM - Digital Elevation Model

EROS - Earth Resources Observation and Science

USGS - United States Geological Survey

FAO - Food and Agriculture Organization

HWSD - Harmonized World Soil Database

UTM - Universal Transverse Mercator
SUFI2 - Sequential Uncertainty Fitting 2
95PPU - 95 Percent Uncertainty
FRSD - Deciduous Forest/Woodland
WETN - Wetlands-Non-Forested
RNGE - Range Grasses
AGRL - Agricultural Land (Rain–fed crop land)
WATR - Water Bodies
BARR - Bare Areas
URML - Urban Areas (artificial surfaces)
Af14-3c-1 - Ferric Acrisol
I-Lc-Re-b-73 - Chromic Luvisol- EutricRegosol
I-Rd-79 - DystricRegosol
HYDGRP - Soil Hydrologic Group
SOL_ZMX - Maximum rooting depth
ANION_EXCL- Porosity fraction from which anions are excluded
SOL_BD1 Bulk- Density Moist
SOL_CBN1 - Organic Carbon
SOL_Z1 - Depth
SOL_AWC - Available water capacity of first soil layer
SOL_ALB - Soil Albedo
ALPHA_BF. - Base Flow Alpha Factor
GW_DELAY - Groundwater Delay Time

GWQMN - Threshold depth of water in shallow aquifer

CHAPTER ONE

INTRODUCTION

1.1 Background

Water is a vital element for survival of living things. It is an important factor for economic development and boosting growth of agriculture and industry particularly in the viewpoint of rapidly increasing population and urbanization. To deal with water management difficulties, one must analyze and quantify the different elements of hydrologic processes taking place within the area of interest. Apparently, this analysis must be carried out on a watershed basis because all these processes are happening within individual micro watersheds (Shimaa, 2015).

Hydrological processes and their local scattering have always direct impact to land use, weather, topography, and geology of watershed in addition to the impact of human activities. A watershed, comprises areas of land and channels and may have lakes, ponds or other water bodies. The application of a watershed model to simulate these processes plays a vital role in addressing a range of water resources and environmental and social issues (Omar, 2014).

Effective planning and management of water resource requires the use of watershed models for hydrological processes simulations. Hydrologic models offers a framework for making suitable decisions for sustainable management of soil and water resources in the watershed and have become an important tool for the study of hydrological processes. Nigeria is a developing country where part of the population are involved in agriculture, and with rural-urban migration. This demands for goodmanagement of water resource in order to meet the country’s growing water need. Amanagement method that is technically sound is most appropriate, hence the need for hydrological models for water resources assessment and development. (Ndulue*et al*., 2018)

Number of recent studies in Nigerian watersheds, particularly the Kaduna river basin, provide background information highly vital to the issue of water supply development, but lacks information about prevalent hydrological processes. Thus, a study on identification of prevalent hydrological processes is required to aid sustainable water resources management and planning in Nigeria (Abdurrasheed, 2016).

The use of remote sensing (RS) techniques and Geographic Information System (GIS) abilities has fostered and enhanced the elaborate use of watershed models globally. GIS is a practical tool for the effective management of large and complex database and to provide a digital representation of watershed characteristics used in hydrological modeling. It has added confidence in the accuracy of modeling by determining watershed characteristics, developing more suitable approach toward the watershed conditions, improving the effectiveness of the modeling process and ultimately enhancing the estimation abilities of hydrological modeling, (Bhuyan*et al*., 2003).

In this study, the GIS based watershed model Soil and Water Assessment Tool (SWAT), was applied, a spatial hydrological model which simulates the water flow and transport in a specified region ofdata structures. In view of this, the GIS interface provides the platform tostreamline GIS processes tailored towards hydrologic modeling.Among the widely applied hydrological models for flow prediction in recent time. SWAT is a river basin, or watershed, scale model which has the ability to simulate both the spatial heterogeneity and the physical processes occurring within smaller modeling units, known as Hydrologic Response Units (HRU) for the sustainable planning and management of surface water resources of rivers.

The choice of SWAT model was based on its clear advantage as a hydrological modelling tool that includes modularity, computational efficiency, ability to predict longtermimpacts as a continuous model (Van Griensven*et al*., 2006), and ability to use readily available global datasets, availability of a reliable user and developer support has contributed to its acceptance as one of the most widely adopted and applied hydrological models worldwide (Gassman*et al*., 2007).

1.2 Statement of problem

In real terms, it has been tedious and costly to determine several parameters that interplay in hydrological processes in Kangimi watershed, for instance variables like runoff, sediments loads, temperature, solar radiation, land use and land cover changes on the environment are very difficult to measure in the field.

Sufficient information/data about hydrological processes is lacking. Lack of such information will have negative impacts on the distribution of water in time and space for various uses in the community.The problem of increasing water scarcity is complex, high quantity of the runoff water is being used by farmers in addition to the high losses.

Recently, it was reported that six communities downstream of Kangimi dam have raised the alarm over appearance of cracks on the dam embankment as a result of heavy rainfall.

Good management decisions using hydrological model are often based ongood data input and technical know-how. Therefore, it is very important to have bothreliable data and hydrological model.

The review of hydro-meteorological data availability and model analysis is required so that managers and decision makers would be able to know the confidence level when applying the model for management decisions.

1.3Justification

Within the Kangimi watershed, human activities have greatly affected the water resources management. The changing water quality and its associated quantity in the watershed has mainly resulted in land use change. Hydrological models have aided several management decisions in evaluating the impacts of variables like precipitation, land use changes and soil types on natural resources like water.Modeling the effects of continuousurban and agricultural development in Kangimi is vital for adaptive management of the watershed. Therefore, applying a reliable SWAT simulation of hydrological processes could provide a very useful insight into the potential effect of sediment deposition, water yield, quality and land-use change in the watershed which is especially important with regards to the prevalent high urban development inthe watershed. It is hoped that the findings from this research will motivate the policy makers and experts to formulate and implement effectivesustainable response to minimize the undesirable effects of thewatershed changes.

1.4 Aim and Objectives

The aim of the study is to model the hydrological processes of Kangimi dam watershed in order to develop an efficient decision framework to facilitate and plan the management of this important reservoir. The objectives are to:

I. Determine the Kangimi sub-watershed characteristics.
II. Determine the hydrologic sensitive parameters relative to the determination of surface runoff.
III. Calibrate and validate the ArcSWAT model for streamflow simulation.
IV. Determine the water yield at the watershed outlet using SWAT model.
V. Evaluate the model performance using quantitative statistics.

1.5 Scope

The study covers Kangimi River, small watershed which is a tributary of river Kaduna in Kaduna capital city in northern Nigeria; The analysis of hydrological process interactions and the assessment of water resources availability was focused on the dam watershed.

1.6 Limitation

Lack of sufficient hydro-meteorological data causes uncertainty in the design, management and assessment of water resources systems. Hydro- meteorological dataset that include precipitation, temperature (maximum and minimum), solar radiation, relative humidity and wind speed from global database were downloaded together with the historical data to make informed decisions.

Finally, the model is physically based, but remains full of assumptions and some of the parameters required are not measurable, or hardly so. Very strong assumptions of the system under analysis was made because of the lack of options to describe variability.

1.7 Study Area

The study area is located along river Kangimi 12.8km southeast of Maraba Jos in Igabi Local Government Area of Kaduna state as shown on figure 1.1. The sub watershed along river Kangimi lies between latitude 10°46‘and longitude 7°25' and serves as a tributary of river Kaduna in Kaduna town in Igabi Local Government area of Kaduna state, and falls within Niger river as major hydrological basin.

It was constructed in 1975 on the Kangimiriver, about 3 km upstream of its confluence with the Kaduna river. The watershed area of the Kangimi dam is about 365.17 km^2. The climate in the area is classified as tropical continental, with almost equal wet and dry seasons. Maximum daily temperatures ranges between 30^0 to 40^{0}C throughout the year, while minimum daily temperatures occasionally drop below 12^{0}C. (Abdurrasheed, 2016).

The rainfall in the area occurs between May and October. The rest of the year is dry. Relative humidity has a wide range of variations in dry season, the average is about 5%, while in the wet season it may be as high as 85%. The reservoir of Kangimi dam design data is given in table 1.1, the runoff factor is about 0.4 and the annual flowthrough the reservoir is about 11 million m^3. The reservoirhas a surface area of 692 ha and volume of 59million m^3 and a mean depth of 17 m. The estimatedmean retention time in the reservoir is 5–6 years. Thearea in the neighborhood of the Kangimi watershed represents pen plain, underlain by precambrian rocks of the basement complex comprising granites, and decomposedto give a non-uniform thickness of lateric soil,ranging from silty clays to coarse sand clays (Kemdirim, 2005).

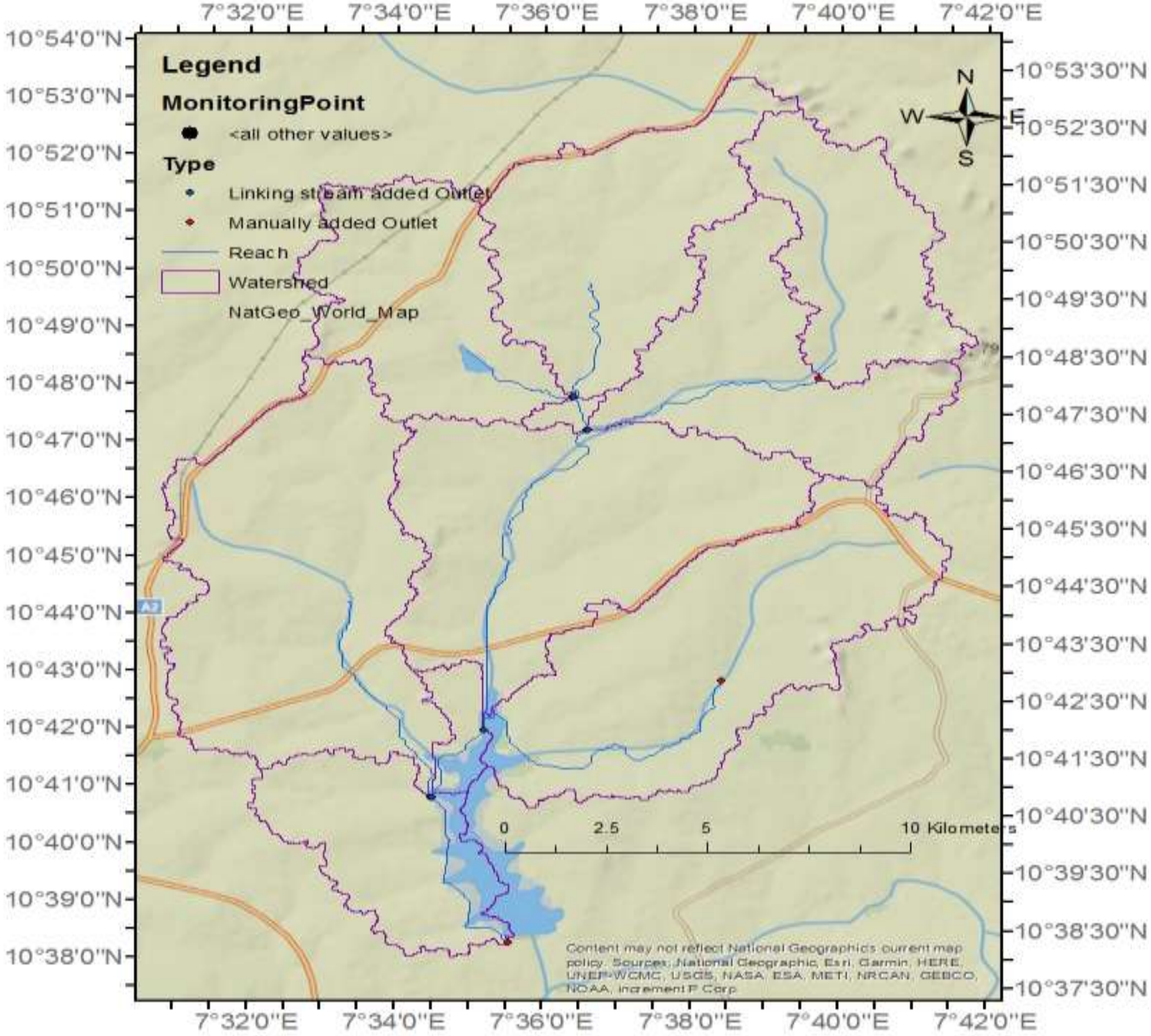


Figure 1.1: Geographic Map of the Study Area (Source: United State Geological Survey)

Table 1.1: Available Kangimi Reservoir Design Data

Reservoir design data	Unit	Quantity
Release for water supply	m^3/day	182,000
Daily projected requirement	m^3/day	50,227,500
Total storage volume	m^3	59,208,000

Kaduna river supply at low flow	m^3/day	45,500
Catchment area	km^2	365.19
Average annual discharge	m^3	74,010,000
Water available for supply and irrigation	m^3	43,172,500
Water supply	m^3	16,035,500
Irrigation	m^3	19,736,000
Distribution losses/surplus	m^3	7,401,000

Source: (Food Agricultural Organization NGA Dams; Extracted by Abdurrasheed, 2016).

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview on the basic terms which anchored hydrological modeling. After a brief description of the hydrological cycle, types of hydrological models and literature review of some research outputs of several authors in this field of study to support each step of the project.

2.2Hydrological Process

Hydrologic process can be defined as the natural system in which water moves between land, atmosphere and the ocean cyclically (Evans *et al.,* 2015) as shown in Figure 2.1. Human activities interrupt these cycles and the consequences of which now threaten the living existence of man on earth.

The hydrological cycle consists of a series of interactive, iterative processes which can besimplified and represented mathematically in a model. They are according to Uehlenbrook (2006):

(a) Precipitation,

(b) Interception (including, utilization by ecosystems, utilization by man and irrigation),

(c) Absorption into earth materials and uptake by plants (including percolation),

(d) Water movement from a shallow aquifer to a deep aquifer,

(e) Water losses in the form of evaporation, transpiration, and seepage,

(f) Surface flow and runoff, and

(g) Subsurface flow

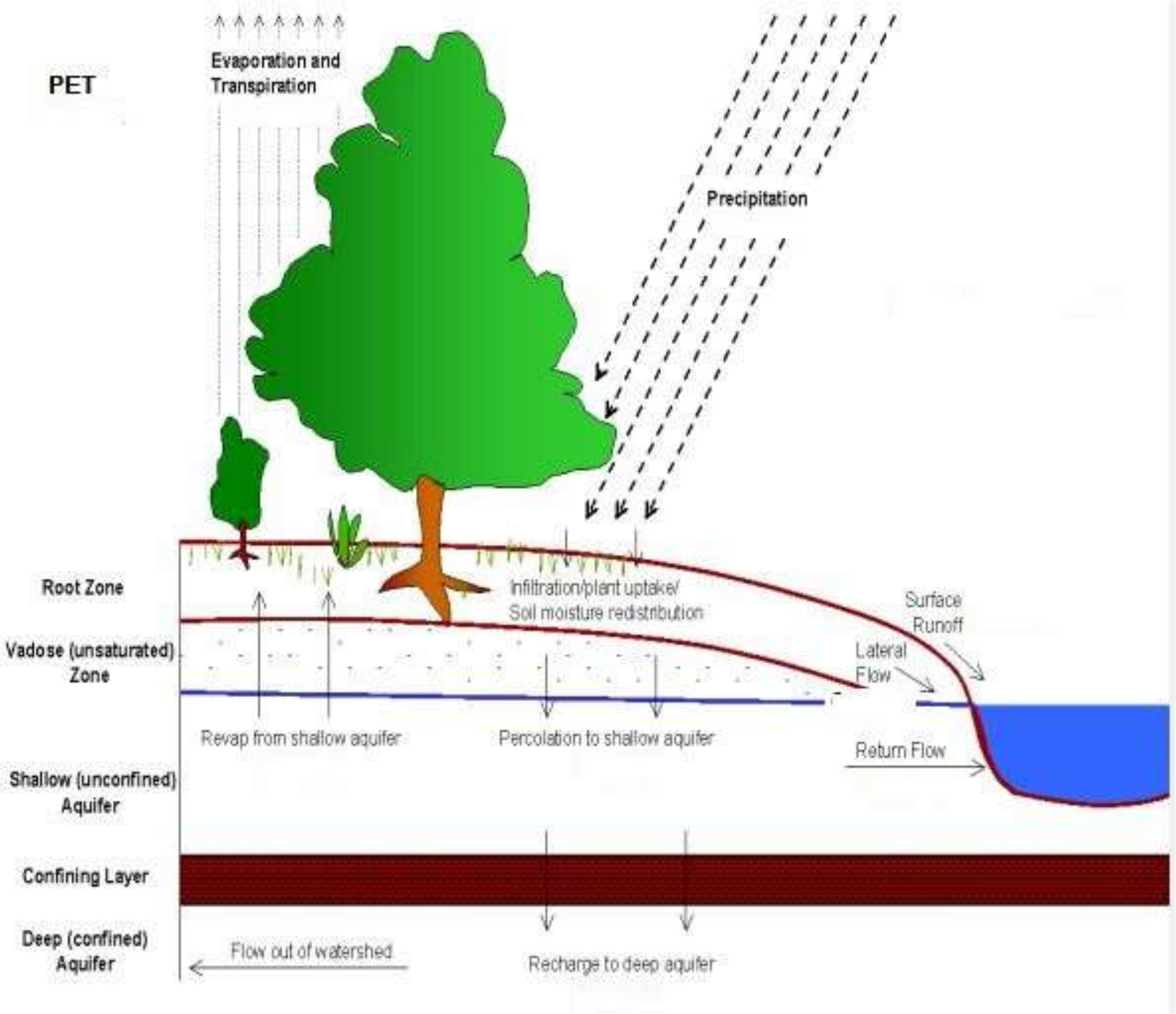


Fig. 2.1: Diagram of the natural water cycle (Extracted from ArcSwat).

Subsurface flow can be described as flow of water through earth materials. Most earth materials arenon-homogenous and then the flow path is dictated by the path of least resistance, determined bythe properties of these earth materials. Mass permeability of these materials determines resistance toflow.Traditionally groundwater and surface water hydrology are two separate areas of scientific study.Groundwater models are seldom used together with surface water models and vice versa. Modelsdepict a simplification of this configuration and distribution of the materials creating a flow pattern.

The hydrological cycle is a complex and dynamic system that is strongly interconnected with the energy and biogeochemical cycles (Hagemann, 2011; Pagano and Sorooshian, 2006). It describes the continuous movement and retention of water through and in the Earth’s spheres, driven by solar energy and gravitation (Brooks *et al.*, 2012). A general scheme of the hydrological cycle, its components and fluxes is depicted in Fig. 2.1. As it shown, major reservoirs as ice and snow, surface water, soil, groundwater, ocean and atmosphere are interconnected by physical processes such as precipitation, evaporation and runoff. These processes cover various spatial scales and are highly variable in time and space (Hagemann, 2011).

In general, atmospheric water vapour precipitates on the Earth’s surface, eventually flows as runoff to the ocean or inland water sinks while being transferred through the soil, the groundwater and/or surface water bodies, and finally evaporates again. Therefore, water fluxes and storageconditions are strongly interconnected and influenced by various climatic and physio-geographic factors. For instance, dependent on temperature, precipitation most commonly occurs as rain or snow, but also includes drizzle, sleet, hail, and in a broader sense fog, dew and frost. Besides temperature, also wind, topography, vegetation and physical obstructions determine the deposition and accumulation of snow and ice. Whether snowmelt and liquid precipitation infiltrate depends on various factors such as the moisture status of the soil, its maximum water-holding capacity, the network and size of pores within the soil matrix, the condition of the soil surface including the vegetation cover, as well as rainfall and snow melt rate (Blume*et al*., 2010). Additionally, human activities influence the hydrological cycle among others by building reservoirs, withdrawal from water storages, or land-use activities that modify vegetation and water bodies, which in turn influences for instance evapotranspiration and the distribution of snow (Brooks *et al*., 2012).

2.3Hydrological models

To gain a better understanding of hydrologic phenomena and how these are affected by changes in climate and land use, the complex hydrological cycle can be represented in simplified terms by mathematical models. A hydrological model is a mathematical model used to simulate river or stream flow and estimates water quality parameters such as suspended solids, turbidity, acidity, alkalinity etc. These models generally came into use in the 1960s and 1970swhen demand for numerical forecasting of water quality was driven by environmental legislation inthe United States and the United Kingdom. Computers are now more widelyaccessible, and powerful enough to significantly assist in modelling processes. There are numeroushydrological models and are developed or chosen for the particular problem based on the following four features:

Accuracy of the prediction, simplicity of the model, consistency of parameter estimates, and sensitivity of the results to changes in the parameter values.It is concluded that the choice of model is usually made on the basis of the time-frame availablefor development, input data resources, and various other factors such as the experience of the modeller. Also importantin determining the selection of model is whether it is distributed (i.e. capable of predicting multiplepoints within a river) or lumped. The groundwatercomponent may also be present in a model (Kim *et al.*, 2007).

Models often address individual steps modularly in the simulation process. Naturally subroutinesfor surface runoff include components for a land use type, topography, soil type, vegetation cover,precipitation and land management practice (regular agricultural activities e.g. pesticide or fertilizer application).

2.3.1 Hydrological model classification

The hydrological processes discussed in Section 2.2 are integrated to form awatershed model. Hydrological models provide the opportunity for well-structured basin-wide analyses of wateravailability and water demands, and offer a sound scientific framework for a coordinated management and planning, ensuring reasonable and equitable use of scarce and vulnerable water resources by stakeholders (Larse*et al*., 2001). He also noted that when combined with theGeographical Information Systems (GIS), models also provide a convenient platform for handling,compiling and presenting large amounts of spatial data essential to river basin management. Rainfall –runoff models have been developed in order to simulate the transformation from rainfall to runoff.

Domenico (1972) describes the following classifications of mathematical models:

(a) Models can be classified as *linear* or *nonlinear* where non linearity is associated with chaos and irreversibility, making it more difficult to study;

(b) The next classification category is *deterministic* or *probabilistic*, the latter also known asstochastic. Deterministic models are uniquely defined and parameterized, with a given set ofinitial conditions. On the other hand, stochastic models represent randomness, and probableoutcomes;

(c) Models can be either *static* or *dynamic* depending on whether the element of time is excluded orincluded in the model. Dynamic models often make use of difference equations or differentialequations. Artificial neural networks (ANN) are dynamic system models which mimic simplebiological nervous systems. In their current form they have the capacity to extract relationshipsin data and can represent highly complex, multi-dimensional and nonlinear relationships well,but do not spatially distribute watershed modelling systems;

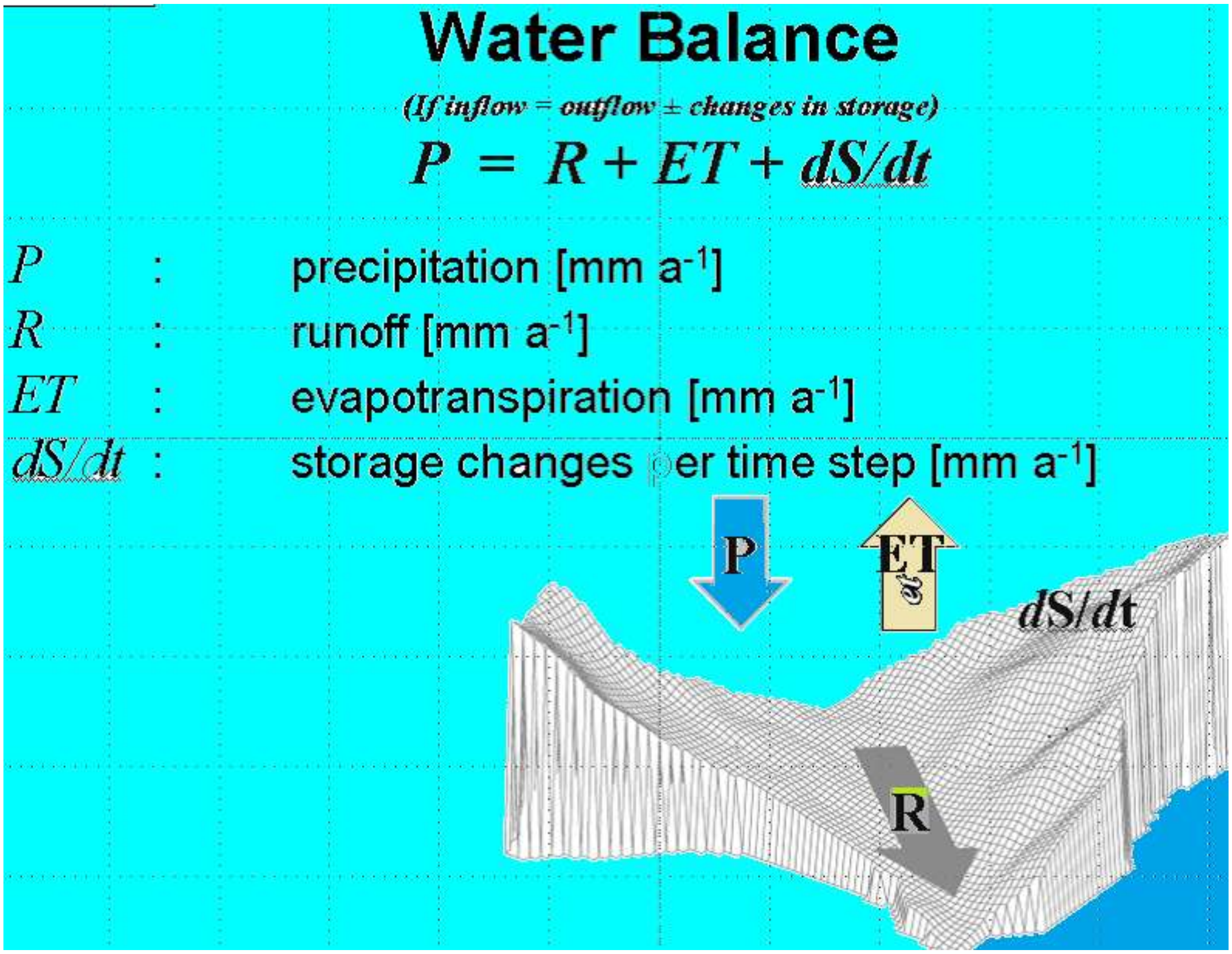
(d) Models can also be classified as either *lumped parameter* or *distributed parameter* models.Lumped models apply to homogenous states throughout the system, where distributed modelssignify varying states throughout the system, in which case parameters are in part representedby differential equations. Domenico (1972) discusses the uses of lumped or distributedparametermodels, each applicable to situations where detailed accuracy and scale willdetermine which should be used. The SWAT model uses a combination of both lumped (rainfallper sub basin) and distributed parameters for example, HRU combinations of unique soil,topography and land use characteristics. Lumping serves to reduce complexity and promoteexpediency and the distributed parameters are chosen to increase accuracy;

(e) A model is *physically based* if its parameters can be measured in the field. Physically basedmodels use equations in a modular way to replicate physical processes in the hydrological cycle.They can partly contain linear regression models, where constant, linear relationships areassumed between elements. Conceptual models, in contrast, do not require empiricalmeasurements.

(f) Stochastic, or data based models use mathematics and statistics to relate model inputs to model outputs. Neural networks, regression, transfer and system identification techniques are often used in this kind of model. Flood forecasting is the main use for data based models where rainfall and runoff are related to one another, and antecedent moisture conditions are considered, in real-time replication of real world hydrological systems.

2.4. Standard Hydrological Equations

Hydrological models comprises of number of equations, each signifying a different part of thehydrological cycle in mathematical interpretation as shown on figure 2.2. The surface energy balance and the water balance equations are the pillars supporting hydrological models. As with the actualhydrological cycle, each part is built on the next and errors in any part may affect the correctsimulation of the complete cycle.



Water Balance

(If inflow = outflow ± changes in storage)

$$P = R + ET + dS/dt$$

P : precipitation [mm a^{-1}]
R : runoff [mm a^{-1}]
ET : evapotranspiration [mm a^{-1}]
dS/dt : storage changes per time step [mm a^{-1}]

Figure 2.2; Water balance representation Source: Uhlenbrook (2006)

The water balance equation normally solved for catchments is given as;

$$P = R + ET + \frac{\Delta S}{\Delta t} \qquad (2.1)$$

Where;

P = Precipitation (mm),

R = Runoff (mm),

ET = Evapotranspiration (mm) and

$\Delta S/\Delta t$ = change in storage over time

Uhelenbrook (2006) lists the following storages in the hydrological cycle:

(a) Atmosphere

(b) Soil water / groundwater

(c) Oceans

(d) Ice caps, glaciers, snow

(e) Rivers, lakes

(f) Surface storage (interception)

(g) Biosphere

Water storage fluctuations are determined by precipitation, evaporation, transpiration, plant wateruptake, discharge, exchanges between surface water and groundwater, snow and ice melt. Thesewater fluxes between storages are of primary importance to hydrological studies.

Uhlenbrook (2006) also stated that the water balance does not stand in isolation for hydrologicalstudies, and is used in combination with the surface energy balance equation which representsevapotranspiration processes more accurately as given in Equation 2.2:

$$Rn = \lambda\mathrm{E} + \mathrm{H} + \mathrm{G} + \frac{\Delta S}{\Delta t} \qquad (2.2)$$

Where

Rn: Net radiation

λE: Latent heat (= evapotranspiration; ET)

H: Sensible heat

G: Soil heat flux

$\Delta S/\Delta t$: Change in storage

Assuming G and $\Delta S/\Delta t$ to be negligible: the equation can be further simplified to

$$Rn = \lambda E + H \tag{2.3}$$

The following sub models and equations are used in setting up SWAT models as summarized in Table 2.1 shown below (Uhlenbrook 2006;Neitsch et. al., 2005; Lewarne, 2009, Boluwade. 2010).

Table 2.1: Equations Mostly used in Hydrological Models

Equation	Use For
Penman-Monteith (Monteith 1965)	Simulates evapotranspiration
The Manning´s Roughness Coefficient	Used for Overland and Channel flow analysis to calculate the time ofconcentration in watersheds
The Soil Conservation Service (SCS) curve number method	It is a correlation between rainfall and runoff
Overland Flow Sediment Transport sub routines	This equation make use of the 2D total sediment load conservation equation
The Green &Ampt (1911) equation	This method assist in calculating infiltration
Darcy's law and the mass conservation of 2D laminar flow	They are used for groundwater saturated flow
The Richards equation	It has been used to estimate unsaturated flow
Lane´s Method	It is used to calculate transmission losses through leaching channel beds
The Modified Universal Soil loss equation (MUSLE)	Erosion study taking into account several factors like the erodibility, land cover, soil slope etc.

*(Modified from Boluwade, 2010)

2.5 SWAT Model Description

SWAT stands for Soil and Water Assessment Tool), a river basin or watershed, scale model developed by the United States Department of Agriculture - Agricultural Research Service (USDA- ARS). It is a continuous time model that operates on daily time steps and uses a command structure for routing runoff and chemical in large complex watersheds with varying soils, land use and management conditions over long periods of time (Neitch*et. al*., 2005).

In SWAT, a watershed is divided into multiple sub-watersheds, which are then further subdivided into Hydrological Response Units (HRUs) that consist of homogeneous land use, management, and soil characteristics. The HRUs represent percentages of the sub-watershed area and are not identified spatially within a SWAT simulation. The water balance of each HRU in the watershed is represented by four storage volumes: snow, soil profile (0-2meters), shallow aquifer (typically 2-20 meters), and deep aquifer (more than 20 meters).The soil profile can be subdivided into multiple layers. Soil water processes include infiltration, evaporation, plant uptake, lateral flow, and percolation to lower layers. Flow, sediment, nutrient, and pesticide loadings from each HRU in a sub-watershed are summed, and the resulting loads are routed through channels, ponds, and/or reservoirs to the watershed outlet. Detailed descriptions of the model and model components can be found in (Arnold *et al*., 1998 and Neitsch*et al.*,2002).

The estimation of surface runoff by the model uses the Soil Conservation Service (SCS) curve number method, (Arnold *et al*., 1998). This method is widely used for the prediction of approximate amount of runoff from a given rainfall event. It is mainly based on the soil properties, land use and hydrologic conditions. The SCS curve number equation is

$$Qsurf = \frac{(Rday - 0.2S)^2}{(Rday - 0.8S)} \tag{2.4}$$

Where Qsurf is the daily surface runoff (mm), Rday is the rainfall depth for the day (mm), and S is the retention parameter (mm).

The retention parameter S and the prediction of lateral flow by SWAT model are defined in Eq. (2.5):

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \tag{2.5}$$

Where S = drainable volume of soil water per unit area of saturated thickness (mm/day); CN = curve number.

SCS defines three antecedent moisture conditions: I – dry (wilting point), II – average moisture and III – wet (field capacity). The moisture condition I curve number is the lowest value the daily curve number can assume in dry conditions. The curve numbers for moisture conditions I and III are calculated with the Eqs. (2.6) and (2.7), respectively.

$$CN1 = CN2 - \frac{20(100 - CN2)}{(100 - CN2 + e\left(2.533 - 0.636 + (100 - CN2)\right)} \tag{2.6}$$

$$CN3 = CN2 * e\left(0.00673(100 - CN2)\right) \tag{2.7}$$

Where CN1 is the moisture condition I curve number, CN2 is the moisture condition II curve number, and CN3 is the moisture condition III curve number.

Lateral flow is predicted by

$$q_{lat} = 0.024\frac{(2SSC\sin\alpha)}{\theta_d L} \tag{2.8}$$

Where qlat = lateral flow (mm/day); S = drainable volume of soil water per unit area of saturated thickness (mm/day); SC = saturated hydraulic conductivity (mm/h); L = flow length (m), α = slope of the land, θd = drainable porosity.

The importance of SWAT over other hydrologic models already mentioned in this reportinclude the fact that input and output text files can be stored in a geodatabase (Neitsch*et. al*., 2008). Other advantage include its being an open source hydrologic model as showed on figure 2.3.

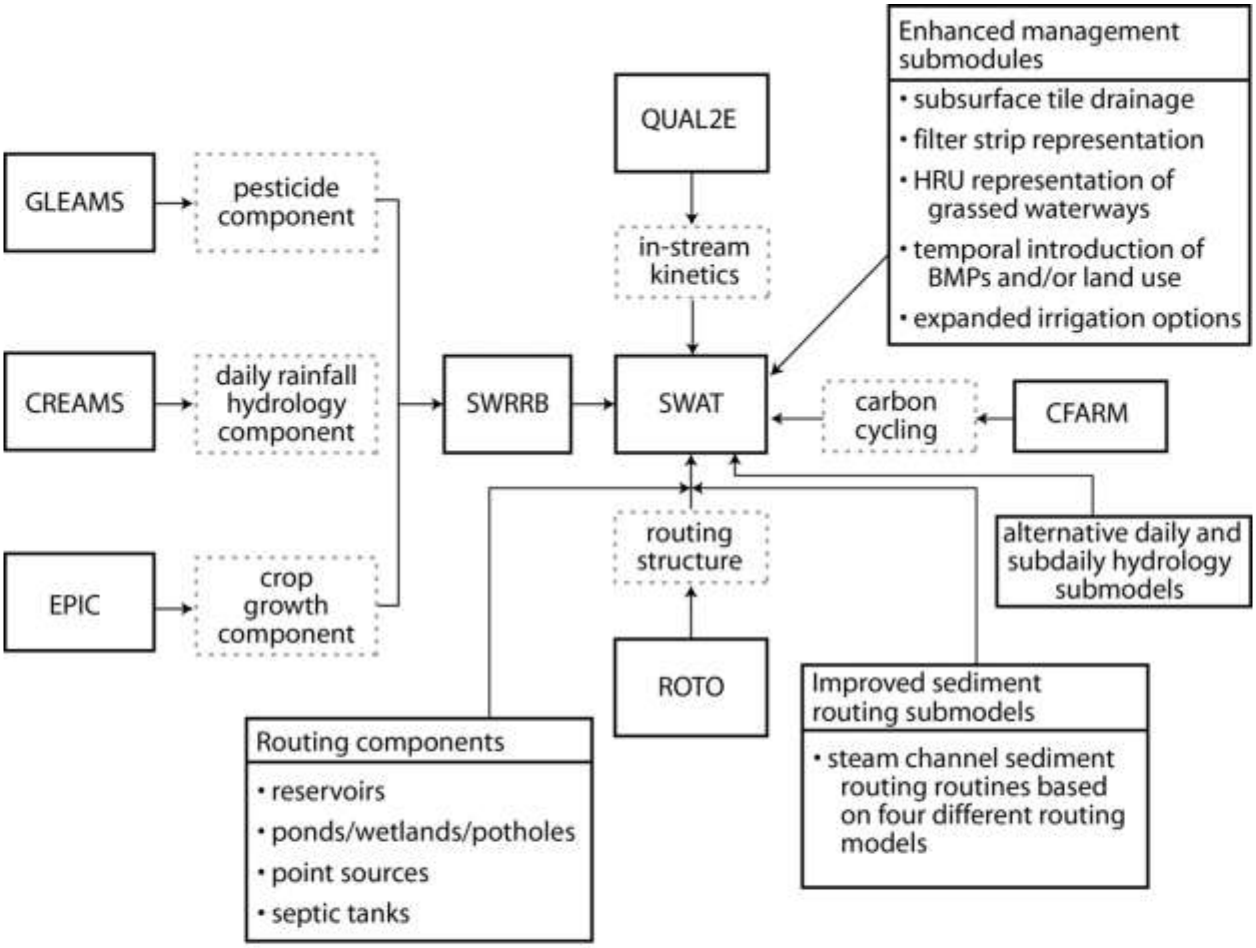


Figure 2.3: The Schematic of SWAT development history and model adaptations (modified from Gassman*et al*., 2007).Workflow of SWAT Modules.

2.5.1 Summary of SWAT Historical Development.

SWAT has undergone some substantial improvement since its conception in 1990s. Neitsch*et al.*, (2008) defined some of these developments as:

(1) SWAT94.2: Multiple Hydrologic Response Units (HRUs) were incorporated.

(2) SWAT96.2: Auto-fertilization and auto-irrigation added as management options; canopy storage of water incorporated; etc.

(3) SWAT98.1: Snow melt routines improved; in-stream water quality improved; nutrient cycling routines expanded; etc.

(4) SWAT99.2: Nutrient cycling routines improved, rice/wetland routines improved,reservoir/pond/wetland nutrient removal by settling added; bank storage of water in reach added; etc.

(5) SWAT2000: Bacteria transport routines added; Green &Ampt infiltration added; weather generator improved; etc.

(6) SWAT2005: Bacteria transport routines improved; weather forecast scenarios added; sub-daily precipitation generator added; etc.

2.5.2 GIS-SWAT Interface Development

It was an historical achievement when GIS was coupled with SWAT for easy manipulation of input data like the land-use, DEM, soil map, masking etc.ArcSWAT (Arc GISSWAT) is the latest available version which is used as an interface between ArcGIS and the SWAT model. A variety of other tools have been developed to support executions of SWAT simulations, including:

- The interactive SWAT (iSWAT) software which supports SWAT simulations using a Windows interface with an Access database;
- The Conservation Reserve Program (CRP) Decision Support System (CRPDSS) developed by Rao*et al*., (2006);
- The AUTORUN system used by (Kannan*et al*., 2007), which facilitates repeated SWAT simulations with variations in selected parameters;

- A generic interface (iSWAT) program (Abbaspour*et. al*., 2007), which automates parameter selection and aggregation for iterative SWAT calibration simulations.
- The SWATPLOT tool which is a standalone software developed also by theWaterbase group in 2009.

2.5.3 SWAT Applications

SWAT has been adjudged by researches as computationally efficient in its prediction. It has a reliabilitywhich confirmed in several areas around the world. SWAT model was applied in large scale to evaluate the hydrologicalprocesses in United States and European Union where there has being assessment of climate change or other impacts on the natural resources. (Gassman*et al*., 2007), Upper Indus River Basin by Khan *et al.*, (2014)and in other regions in Asia by Nasrin*et al.*, (2013) and Cindy and Koichiro (2012). It was tested and used in many regions of Africa by Fadil*et al*., (2011), Ashagre (2009) and Schuol*et al.*, (2008). It was also applied to simulate St. Joseph River watershed in US by Kieser*et al*., (2005). Swat model was used successfully to estimate the water balance components in South eastern Ethiopia by Shawul*et al*., (2013) and in Nigeria by Adeogun*et al*., (2014), Ndulue*et al*.,(2018).

2.5.4 SWAT Calibration and Validation

SWAT input parameters are process based and must be held within a realistic uncertainty range. The first step inthe calibration and validation process in SWAT is the determination of the most sensitive parameters for a givenwatershed or sub-watershed. The user determines which variables to adjust based on expert judgment or on sensitivity analysis. Sensitivity analysis is the process of determiningthe rate of change in model output with respect to changesin model inputs (parameters). It is necessary to identify keyparameters and the parameter precision required for calibration(Ma *et al.*, 2000). In a practical sense, this first step helps determine the predominant processes for the componentof interest. Two types of sensitivity analysis are generally performed: local, by changing values one at a time, andglobal, by allowing all parameter values to change. The two analyses, however, may yield different results. Sensitivity of one parameter often depends on the value of other relatedparameters; hence, the problem with one-at-a-time analysis is that the correct values of other parameters that are fixed are never known. The disadvantage of the global sensitivity analysis is that it needs a large number of simulations. Both procedures, however, provide insight into thesensitivity of the parameters and are necessary steps in model calibration.

The second step is the calibration process. Calibration is an effort to better parameterize a model to a given set of localconditions, thereby reducing the prediction uncertainty. Model calibration is performed by carefully selecting valuesfor model input parameters (within their respective uncertainty ranges) by comparing model predictions (output) for a given set of assumed conditions with observed datafor the same conditions. The final step is validation for thecomponent of interest (streamflow, sediment yields, etc.).Model validation is the process of demonstrating that a givensite-specific model is capable of making sufficiently accuratesimulations, although “sufficiently accurate” canvary based on project goals (Refsgaard, 1997).

Validation involves running a model using parameters that were determinedduring the calibration process, and comparing thepredictions to observed data not used in the calibration. Ingeneral, a good model calibration and validation should involve:

(1) Observed data that include wet, average, and dryyears

(2) Multiple evaluation techniques (Legates and McCabe, 1999; Boyle *et al*., 2000); (3) Calibrating all constituents to be evaluated; and

(4) Verification that other important model outputs are reasonable. In general, graphical and statistical methods withsome form of objective statistical criteria are used to determinewhen the model has been calibrated and validated.Calibration can be accomplished manually or using auto-calibration tools in SWAT (Van Griensven and Bauwens,2003; Van Liew*et al*. (2005) or SWAT-CUP (Abbaspour*et al*., 2007).

The metrics and methods used to compare observed data to model predictions are also important. Multiple graphical and statistical methods could be used, such as time-series plots, Nash-Sutcliffe efficiency (NSE; Nash and Sutcliffe, 1970), and percent bias. A general calibration flowchart for flow, sediment, and nutrients is shown in figure 2.4 to aid with the manual model calibration process.An extensive array of statistical techniques can be used to evaluate SWAT hydrologic and pollutant predictions; for example, (Coffey *et al.* 2004) describe nearly 20 potential statistical tests that can be used to judge SWAT predictions, including coefficient of determination (r^2), NSE, root mean square error (RMSE), nonparametric tests, t-test, objective functions, autocorrelation, and cross-correlation. By far, the most widely used statistics reported for calibration and validation are r^2 and NSE. The r^2 statistic can range from 0 to 1, where 0 indicates no correlation and 1 represents perfect correlation, and it provides an estimate of how well the variance of observed values are replicated by the model predictions(Krause *et al*., 2005).NSE values can range between $-\infty$ to 1 and provide a measure how well the simulated output matches the observed data along a 1:1 line (regression line with slope equal to 1). A perfect fit between the simulated and observed data is indicated by an NSE value of 1. NSE values ≤ 0 indicate that the observed data mean is a more accurate predictor than the simulated output. Both NSE and r^2 are biased toward high flows. To minimize this bias, some researchers have taken the log of flows for statistical comparison or have developed statistics for low and high flow seasons(Krause *et al*., 2005).

Automatic calibration and uncertainty analysis capability is now directly incorporated in SWAT2009 (Gassman*et al*., 2010) via the SWAT-CUP software developed by Eawag (2009). A number of previous SWAT application projects report automated calibration/validation and uncertainty analysis using SWAT-CUP.

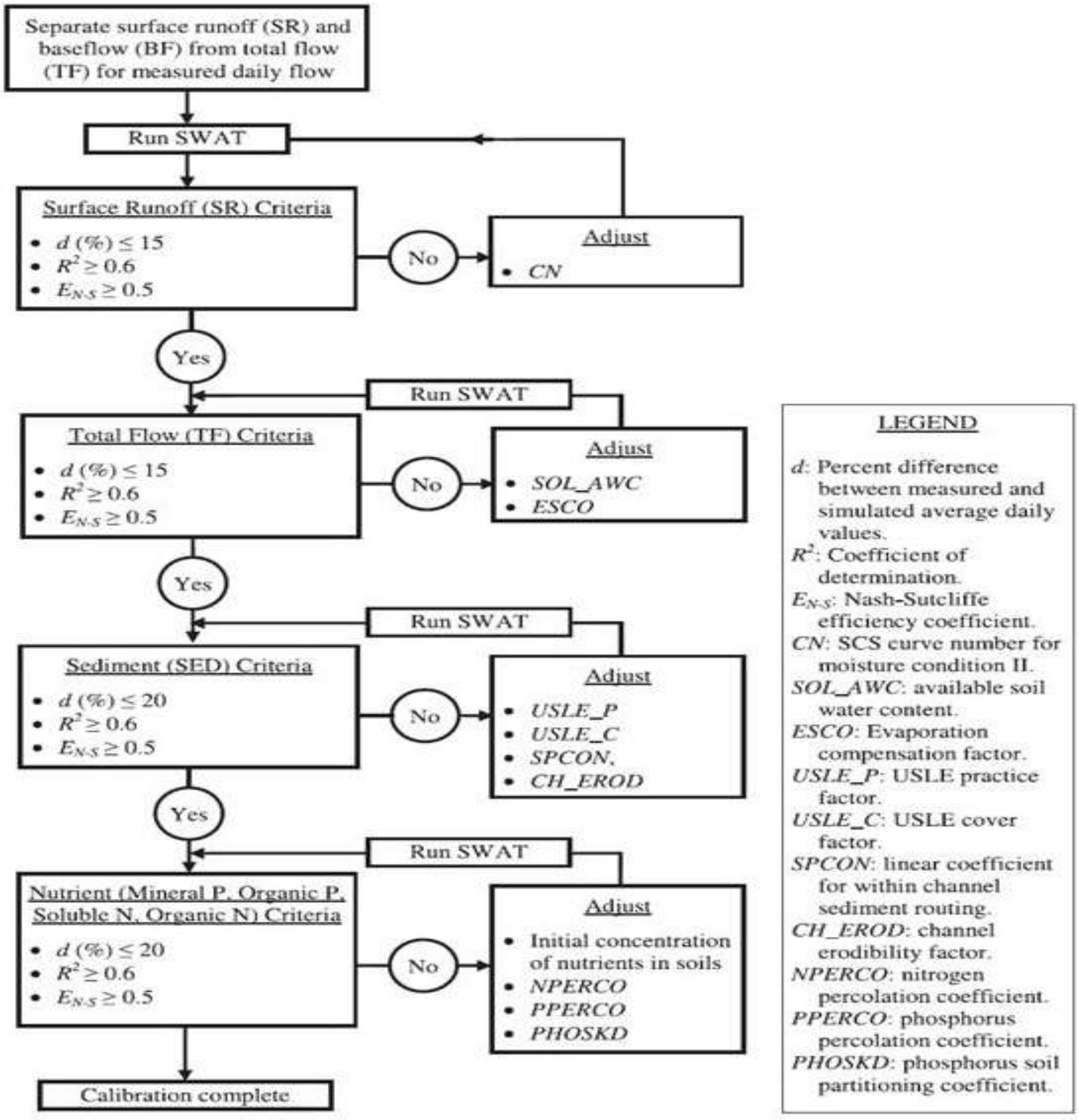


Figure 2.4 Example of SWAT manual calibration flowchart (from Engel *et al.*, 2007; modified from Santhi*et al.*, 2001).

SWAT-CUP software package uses the SUFI-2 algorithm (Abbaspour*et al*., 2004, 2007) for model calibration, validation, sensitivity, and uncertainty analysis.This algorithm maps all uncertainties (parameter, conceptual model, input, etc.) on the parameters (expressed as uniformdistributions or ranges) and tries to capture most of the measured data within the 95% prediction uncertainty (95PPU) of the model in an iterative process. The 95PPU is calculated at the 2.5% and 97.5% levels of the cumulative distribution of an output variable obtained through Latin hypercube sampling. For the goodness of fit, as we are comparing two bands (the 95PPU for model simulation and the band representing measured data plus its error), the first author coined two indices referred to as ‘‘P-factor’’ and ‘‘R-factor’’ (Abbaspour*et al*., 2004).

The P-factor is the fraction of measured data (plus its error) bracketed by the 95PPU band and varies from 0 to 1, where 1 indicates 100% bracketing of the measured data within model prediction uncertainty (i.e., a perfect model simulation considering the uncertainty). The quantity (1-P-factor) could hence be referred to as the model error. For discharge, we recommend a value of >0.7 or 0.75 to be adequate. This of course depends on the scale of the project and adequacy of the input and calibrating data. The R-factor on the other hand is the ratio of the average width of the 95PPU band and the standard deviation of the measured variable. A value of <1.5, again depending on the situation, would be desirable for this index (Abbaspour*et al*., 2004, 2007). These two indices are used to judge the strength of the calibration and validation. A larger P-factor can be achieved at the expense of a larger R-factor. Hence, often a balance must be reached between the two. In the final iteration, where acceptable values of R-factor and P-factor are reached, the parameter ranges are taken as the calibrated parameters.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Introduction

This chapter broadly deals with the hydrological description and analysis of the study area.Soil and Water Assessment Tool (SWAT) is applied to model the hydrology of Kangimi Dam watershed in Kaduna river basin.The methodologies used for this study include hydrological modelling, temporal and spatial dataset used in the simulation are given in the following section with details as showed on figure 3.1.

3.2 Materials

3.2.1 Creation and Collection of Databases

The simulation of the water balance of an area by ArcSWATmodel requires a large amount of spatial and time series datasetsin order to establish the water balance equation. The mainsets of data used are briefly explained below.

3.2.2 Spatial Datasets

The topography, land use/land cover and soil characteristics are physiographical datasets which defines the land features of any areaand the most requirement of the hydrological model. The inputpart of SWAT model includes a section from land features inthe form of DEM, land use and soil.

3.2.2.1 Digital Elevation Model (DEM)

The SRTM DEM of 90 m resolution (HTML: CGIARCSI) wasdownloaded from the International Centre for Tropical Agriculture (CIAT) website (http://srtm.csi.cgiar.org/) and processed for the extraction of flow direction,flow accumulation, stream network generation and delineationof the watershed and sub-basins. The topographicparameters such as terrain slope, channel slope or reach lengthwere also derived from the DEM. From the present studyArcSWAT model, the Kangimi Dam watershed covers an area of 349.94 km^2 with an elevation ranging from 512m to 784 m. The whole watershed is segmented in a total number of 10 sub-basinsdepending on topographic characteristics.

3.2.2.2 Land Use Land Cover Data

Changes in land use and vegetation affect the hydrological processes and its influence is a function of the density of plant cover and morphology of plant species.Land-use data (West Africa Land Use Land Cover Time Seriestwo-kilometer (2-km) resolution land use land cover (LULC) 2013) with 26 classes of land-use representation was constructed by USGS Earth Resources Observation and Science (EROS) and was downloaded from https://eros.usgs.gov/westafrica. The land use classes were converted from original land use classes to SWAT classes and defined using a lookup table.

3.2.2.3 Soil Data

The soil map, was obtained mainly from the United Nation Food and Agriculture Organization (HTMAL: FAO-AGL, 2003) and extracted from harmonized digital soil map of the world (HWSD v1.1) which can be downloaded from the link http://www.fao.org/nr/land/soils/digital-soil-map-of-the-world/. The database provides for 16,000 different soil mapping units containing two layers (0 - 30 cm and 30 - 100 cm depth). For this study soil samples from different locations within the watershed area were collected from two different layers (0 - 30 cm and 30 - 100 cm depth) and analyzed in soil laboratory Nigerian Defence Academy Kaduna and used to validate the model parameters.

3.2.3 Temporal Datasets

The climate data are required by ArcSWAT to provide the moisture and energy inputs that control the water balance and determine the relative importance of the different component of the water cycle. Rivers in the hydrological regimes may differ significantly in their runoff response to changes inthe driving variables of temperature and precipitation.

3.2.3.1 Meteorological Data

The long term meteorological datasets of precipitation,temperature, wind speed, solar radiation and relative humidityare required for the hydrological modeling. For SWAT model,the records of precipitation and temperature are the minimummandatory inputs and the other parameters are optional. The observation data for Kangimi Dam site weather station within the study area for thirty five years (1979-2014) were obtained, from Kaduna State Water Board, Kaduna State together with three additional stations; the databases were downloaded and processed with respect to the model input format.

3.2.3.2 Hydrological Data

For calibration and validation, hydrological datasets of Kangimi river flow are required. The data have been collected from the concerned agency, Kaduna State Water Board. A long term flow data were gauged at Ribako (located in 33390 2500 N, 73 180 1500 E) which is a very close control point Upstream the KangimiDam. The historic daily flow data were available for the period 1983–1990 for both calibration and validation of flow simulation.

3.2.4 Projected Coordinate System

The requisite spatial datasets were all processed from the Geographic Coordinate Systems (WGS 1984) to projected coordinate system WGS 1984 UTM Zone 32N, the Transverse Mercator

Projection, the project area falls between Zone 32 of Northern Hemisphere. The GIS data was masked by a “Focus Mask” which was clipped to the study area.

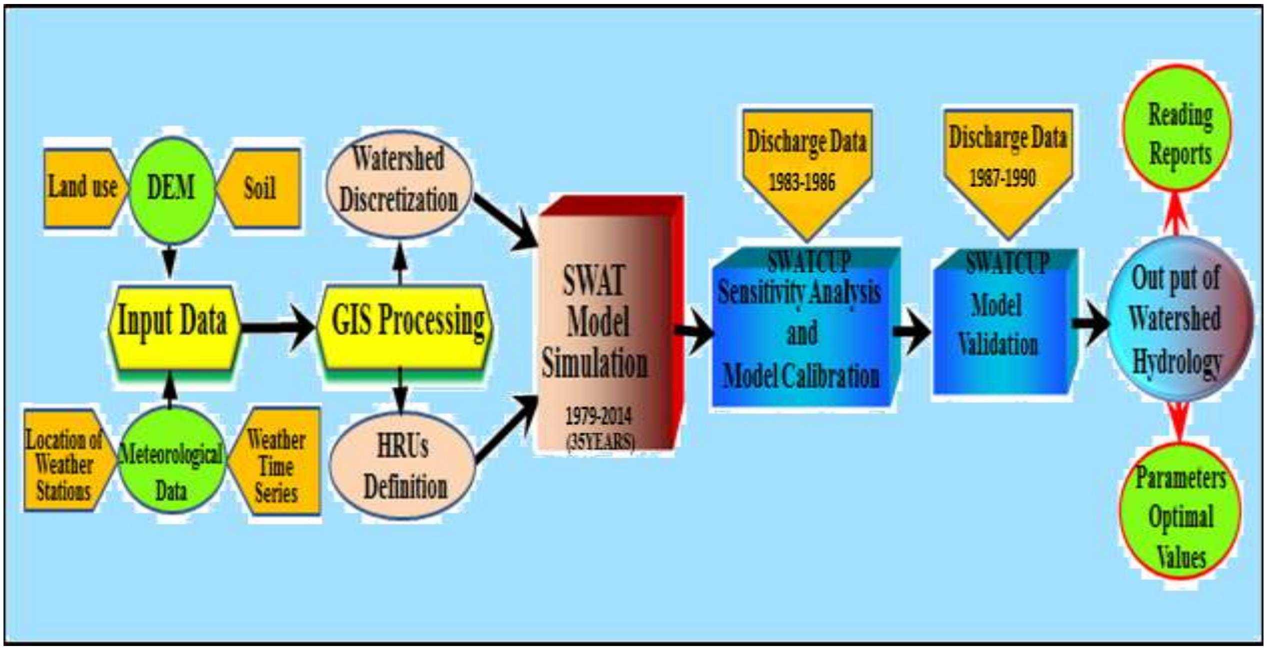


Figure 3.1: The Work Flow of the Modeling Process. (Source: Shimaa, 2015, Modified and adopted)

3.3 Key Procedures Used during the Modelling process

- Loading the ArcSWAT extension
- Delineation of the watershed and defining the HRUs
- (Optional) Editing SWAT databases
- Defining the weather data
- Applying the default input files writer
- (Optional) Editing the default input files
- Setting up (requires specification of simulation period, PET calculation method, etc.) and run SWAT
- (Optional) Applying a calibration tool

- (Optional) Analyzing, plot and graph SWAT output

3.3.1 DEM (Watershed Delineation)

Hydrologic modeling of Kangimi Dam watershed was carried out using the ArcSWAT version 2.3.4. The workflow used for this study is given in figure 3.3 above. To start the ArcSWAT Interface.ArcMapwas started and an empty document was opened, On the Tools menu, Extensions was clicked and 3 extensions were checked for ArcSWAT to run: Spatial Analyst, SWAT Project Manager and SWAT Watershed Delineator. To start the Automatic Watershed Delineation (AUD), the Automatic Watershed Delineationitem from the Watershed Delineationmenu was clicked. The Watershed Delineation dialog opens the DEM,after a few minutes. The name of the elevation map grid isdisplayed in the DEMtext box on the Automatic Watershed Delineation (AWD)dialog box as shown in appendix 1. It is very important for the 'Elevation Units' to be in meters, as it was set in meters. The 'Mask' may bemanually selected or from the file if there is a shapefile that already demarcate the area of interest, the mask was selected as a shapefile. The first part of the watershed delineation iconwas then run. This took some few minutes. The threshold size for sub-basins is set next by area in hectares. It can be set by area, in variousunits such as sq km or hectares, or by number of cells. Now the second run button todelineate the stream network was clicked. In order to complete the whole process,there is need to define the outlet of the watershed. Also, a prepared shapefilecould beused or manually done. The ArcSWAT interface mark the AUD done and enables the second step as everything was okay as shown in Appendix 2.

3.3.2 Creating the Hydrological Response Units (HRUs)

This step determines the details of the Hydrological Response Units (HRUs) that are used by SWAT. This is basically dividing the watersheds into smaller pieces each of which has a particular soil/landuse (crop)/slope range combination. The landuse and soil maps were imported and look-up tables for the landuse classes (from the global landuse classes) and for the soil (from global soils) were reclassified respectively as shown in appendix 3. The slope of each sub-basin is created by an intermediate point for slopes to divide HRUs. The HRU feature class button was checked and the overlay command added the land-use, soil and slope layers to project file.

After these operations, the HRU definition specifies criteria for land use, soil and slope to be used in determining the CN Grid values. One or more unique combinations can be created for each sub-basin where runoff was simulated separately for each HRU and routed to the stream channel. HRUs distribution command accesses the dialog box used to definethe number of HRUs created within each sub-basin in the watershed. This Step is now reported as done as shown in appendix 4 and now available as various reports concerning the sub-basin, topographic and HRUs properties.

3.3.4 Write Input Weather Data Table

Weather data time series for precipitation, temperature (maximum and minimum), solar radiation, relative humidity and wind speed was used to update the global weather data for weather generator file prepared from the local climatic condition of the area. TheSWAT manual gives the procedure to follow in providing the weather generator file. These dataset serves as input to Write SWAT Input Table.The Input menu contains the commands which generate the ArcSWATgeodatabase files used by the interface to store input values for the SWAT model. The Weather Stations command was checked to loadsweather station locations and data for use. Appendix5 displays the Write Input menu.

3.3.5 ArcSWAT Setup and Run

This step involves the setting of the simulation period (start and finish date) and the selection of the weather sources from the SWAT data base. The option to choose the methods for the estimation of surfacerunoff (Curve Number or Green and Ampt method), channel water routing (variable or Muskingum method), potential Evapo-transpiration (Priestley,Penman-Monteith, Hargreaves) are available. SWAT was executed using the Runoff Curve Number method for estimating surface runoff from precipitation, the Hargreaves method for estimating potential evapo-transpiration generation, and the Variable-storage method to simulate channel water routing.

The model was simulated for three LULC types (1975, 2000 and 2013) from 01 January 1979 to 31 December 2014 which is the period of availability of climate data, it was also projected with the recent (2013LULC) type to year 2020 to determine the impacts on the water balance components.Modeling data for the first 3 years were used to warm up the model while those from 1983 to 1986 were used for the calibration and 1987 to 1990 for validation of the model. All the necessary files needed to run SWAT were written at this level and the appropriate selection of weather sources done before running the ArcSWATexecutables as showed in appendix 7.

3.3.6 SWAT Output

SWAT output the results achieved from the simulation and saved it in Microsoft access database and later used statistically by other software like SWATCUP and Excel for analysis.

3.4Streamflow Calibration, Validation and Sensitivity Analysis Using SWATCUP

The SUFI-2 algorithm (Abbaspour*et al.,* 2004, 2007) in the SWAT-CUP software package (Abbaspour, 2011) was used for model calibration, validation and sensitivity analysis. This algorithm maps all uncertainties (parameter, conceptual model, input, etc.) on the parameters (expressed as uniformdistributions or ranges) and tries to capture most of the measured data within the 95% prediction uncertainty (95PPU) of the model in an iterative process.

To calibrate the model the following general approach was used:

After setting up the model within ArcSWAT 2012, the model was calibrated and validated using the SUFI-2 algorithm in SWAT-CUP (version 5.1.6.2), basicallyfollowing the guidelines of (Abbaspour*et al.,* 2007). As the SUFI-2 program withinthe SWAT-CUP software was utilized for parameter optimization. Theuncertainty band represented by the 95PPU was used to account for the modeling uncertainty, and is quantified as the p-factor,which measures the ability of the model to bracket the observed hydrograph with the 95PPU. Finally, the p-factor is simply the fraction enveloped by the 95PPU. Hence, the p-factor can be between 0 and 1, where 1 means a 100% bracketing of the measured data. The width of the 95PPU is calculated by the r-factor. The r-factor divides the average distance between the lower and upper percentile with the standard deviation of the measured data. The r-factor ranges from 0 to infinity, and should be below 1, implying a small uncertainty band. The final parameter ranges are estimated and a detailed description of the single parameters is given in Arnold *et al*., (1998).

3.4.1: Key Steps in Streamflow Calibration, Validation and Sensitivity Analysis Using SWATCUP

The programme was started by pressing the SWATCUPicononthedesktop, a new project and SWAT “TxtInOut” directory was located. Any file with “TxtInOut” in the name string would be acceptable by the programme, an icon on choose SWAT version was clicked to select version of SWAT and computer processor.

Next is to select a program from the list provided (SUFI2, GLUE, ParaSol, MCMC, PSO) where SUFI2 was chosen, a man was given to the project and saved to project folder. The program creates the desired project directory and copies there all TxtInOut files from the indicated location into the SWATCUPprojectdirectory.Italsocreatesadirectorycalled"Backup" inthe same SWATCUPprojectdirectory and copies all SWAT TxtInOut file there. Theparametersin the files in the Backup directory serve as the default parameters and do not changed during the calibration process.

The model was calibrated based on the variables from output.rch, output.hru and output.sub after the file was clicked and activated, under the Calibration Inputs, the following files were edited Par_inf.txt , SUFI2_swEdit.def, File.cio, Observation files, Extraction files and Objective function files.

Next, after editingall the input files, "Save All" and "Close All" tasks were clicked. The run the programs in the Calibration window was checked in the order that they appear for complete execution. After the execution a calibration output was achieved that contains the result for the first iteration. The same procedure was repeated for second and third iterations before a better result was achieved. Global sensitivity analysis was carried out after each iteration.

For validation, the calibrated parameter ranges "without any further changes" were used to run an iteration (with the same number of simulations as used for calibration). To perform validation in SUFI2, the files observed_rch.txt, observed_hru.txt, obsrved_sub.txt,extraction files, the file.cioand observed.txt were all edited with a set of new discharge data. Thereafter the calibrated parameter ranges were used to make one complete iteration (using the calibration button).

Based on parameters identified in and one-at-a-time sensitivity analysis, initial ranges are assigned to parameters of significance. In addition to the initial ranges, user-defined absolute parameter ranges are also defined for every SWAT parameter in SWAT-CUP where parameters are not allowed to be outside of this range.

Once the model is parameterized and the ranges are assigned, the model is run some 500 times for several parameters Van Liew*et al.*,(2005) etc. Great time saving could be achieved by using the parallel processing option of SWATCUP(Rouholahnejad*et al*., 2012).

The suggested new parameter ranges were modified by using one-at-a-time sensitivity analysis again. Another iteration is then performed. The procedure continues until satisfactory results were obtained (in terms of the p-factor and r-factor). Normally, three to five iterations are sufficient for satisfactory results, for these study three iterations were performed and found to be satisfactory. More detailed information could be found in Abbaspour*et al.,* (2004, 2007) and Rouholahnejad*et al.,* (2012). SUFI-2 allows usage of ten different objective functions such as r^2, Nash-Sutcliff (NS), and mean square error (RSR). In this study we used $R^2$and Nash-Sutcliff (NS) for discharge to ascertain the model performance.

Uncertainty in the model was addressed with the 95% prediction uncertainty (95PPU), which is the bandwidth between the 2.5% and 97.5% levels of the cumulative distribution output, resulting from Latin Hypercube sampling (Abbaspour*et al.,* 2007). The algorithm follows the principle that a single parameter produces a single model response while the propagation of the uncertainty of the parameter will result in the 95PPU; i.e.,the greater the parameter uncertainty the greater the model output uncertainty. The practical idea of the 95PPU is that the output bandwidth should cover most of the observation.

To quantify the model results, the p-factor give the percentage of data that is within the 95PPU, and the r-factor gives the thickness of the 95PPU (average thickness of the 95PPU band divided by the standard deviation of the observed data). Suggested but not firm values for these two statistics are p-factor>0.7 and r-factor<1.5 (Abbaspour*et al*., 2015). More details on SWAT-CUP and the SUFI2 algorithm can be found in Abbaspour*et al*., (2007). Other statistics to compare the best simulation with the observed data is the Nash-Sutcliffe efficiency coefficient (Nash and Sutcliffe, 1970), which is used to provide an idea of the performance of the calibration.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1General

This chapter will present and discuss results from the hydrological modeling including streamflow calibration, validation and the sensitivity analysis. These results includes various derived maps and tables which give very vital information about the watershed.

4.2 GIS Inputs and Watershed Delineation

All the GIS inputs have been projected to the Projected Coordinate System WGS 1984 UTM Zone 32N. The methodology as described in Chapter 3 was cautiously followed and executed. Figure 4.1(a) below shows the delineated watershed with the sub-basinsnumbered using the DEM as the background. A total of 10 sub-basins were derived after the AUD procedure with 10 outlets points for each sub-basin, the watershed has a total surface area of 349.94km^2 and a corresponding perimeter of 156.82km.The maximum and minimum elevation in the study area were determine to be 784m and 512m respectively as showed on figure 4.1(b).

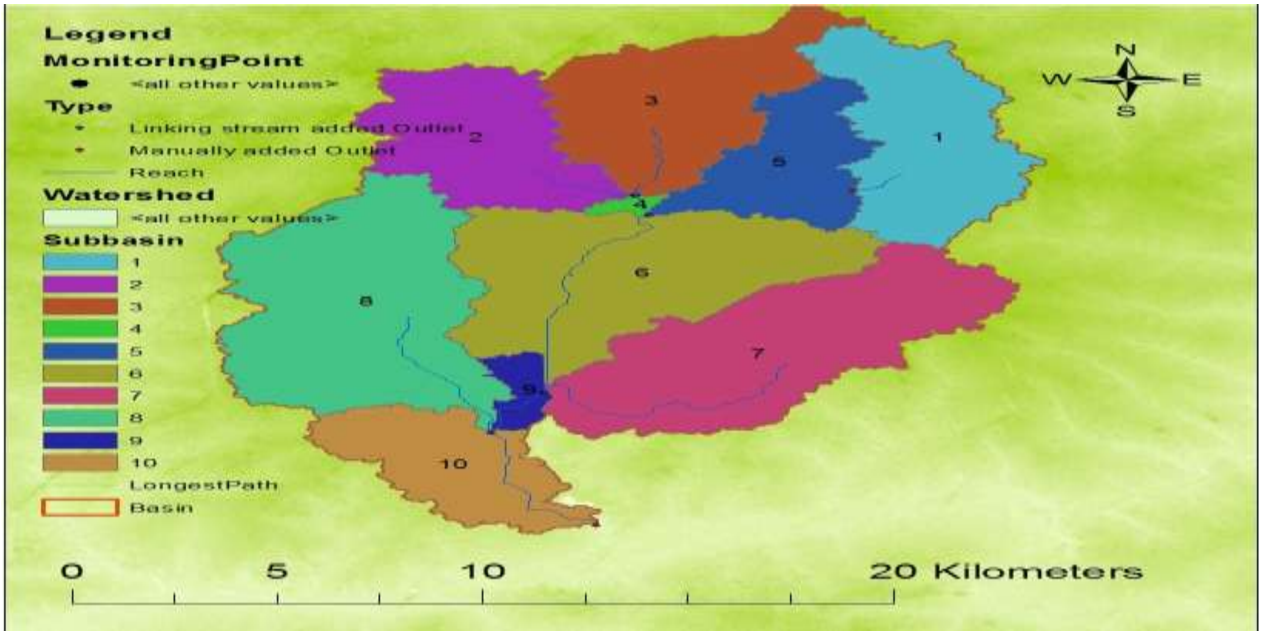


Figure 4.1(a): TheKangimiStream Network and Sub-basins Numbered.

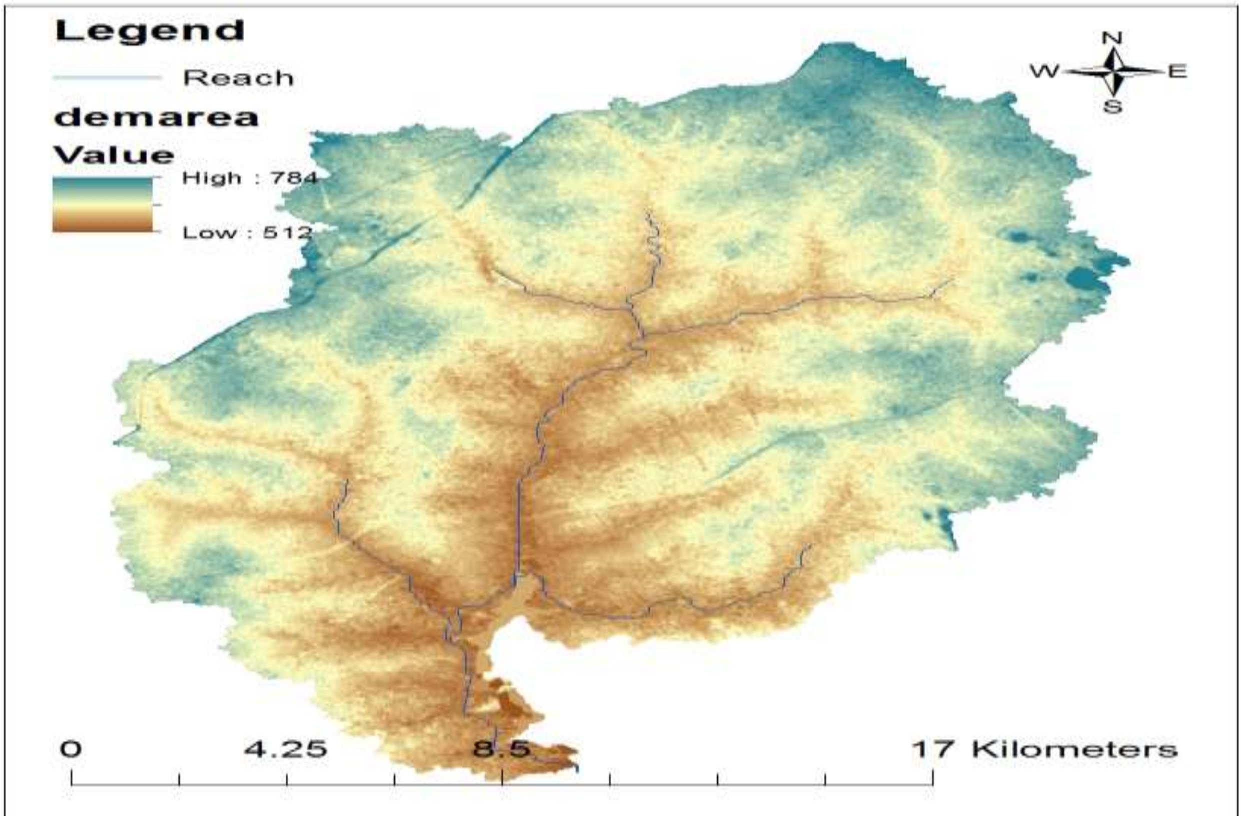


Figure 4.1. (b): Digital Elevation Model (DEM) of Kangimi Watershed

Table 4.1: Land Use–Land Cover, Soil and Slope Classes Used in the Watershed

Land-use SWAT Classes	**Class Description**	**% Watershed Area (1979-2014)**
FRSD	Vegetation	20.657
WETN	Wetlands floodplain	2.077
RNGE	Herbaceous vegetation (grassland, savannas)	4.198
AGRL	Agricultural Land (Rain–fed crop land)	60.748
WATR	Water bodies	1.853
BARR	Bare areas	1.131
URML	Urban Areas (artificial surfaces)	1.508
AGRR	Agricultural Land-Row crops	7.828
SOIL		
Af14-3c-1	Ferric Acrisol	80.298
I-Lc-Re-b-73	Chromic Luvisol- EutricRegosol	1.498
I-Rd-79	DystricRegosol	18.203
SLOPE		
0-5		0.30
5-15		92.46
15-30		6.76
30-999		0.47

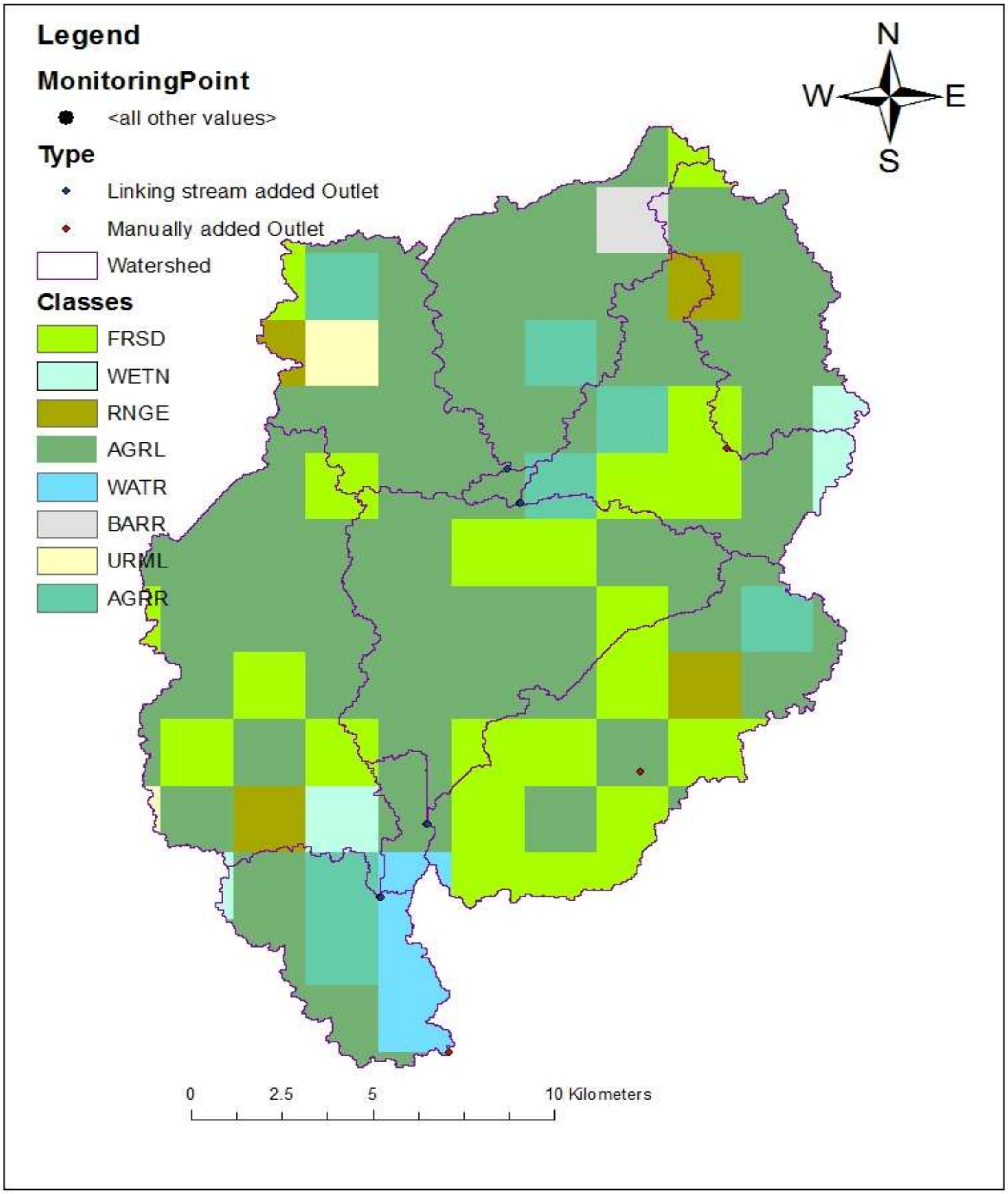


Figure 4.2: Delineated Kangimi land use/cover Map

Table 4.2 Derived Soil Characteristics Delineated in the Catchment

Soil name	Ferric Acrisol (1)	Chromic Regosol (2)	DystricRegosol (3)
HYDGRPSoil hydrologic group	C	D	D
SOL_ZMXMaximum rooting depth (mm)	750	550	550
ANION_EXCLPorosity fraction from which anions are excluded	0.5	0.5	0.5
SOL_CRKCrack volume potential of soil	0.5	0.5	0.5
Texture Texture of soil layers	clay/loam	loam	loam
SOL_Z1Depth (mm)	300	300	300
SOL_AWCAvailable water capacity of first soil layer (mm/mm)	0.144	0.098	0.098
SOL_BD1Bulk density moist (g/cc)	1.2	1.4	1.4
SOL_K1Ksat. (mm/h)	13.87	4.63	5.89
SOL_CBN1Organic carbon (weight %)	1.67	0.8	0.8
CLAY Clay (weight %)	38	25	20
SILT Silt (weight %)	26	40	40
SAND Sand (weight %)	36	35	40
ROCK Rock fragments (vol. %)	1.4	0	0
SOL_ALB Soil albedo (moist)	0.0224	0.1047	0.1047
USLE_K1Erosion K	0.2536	0.3037	0.2767
SOL_EC1Salinity (EC)	0	0	0

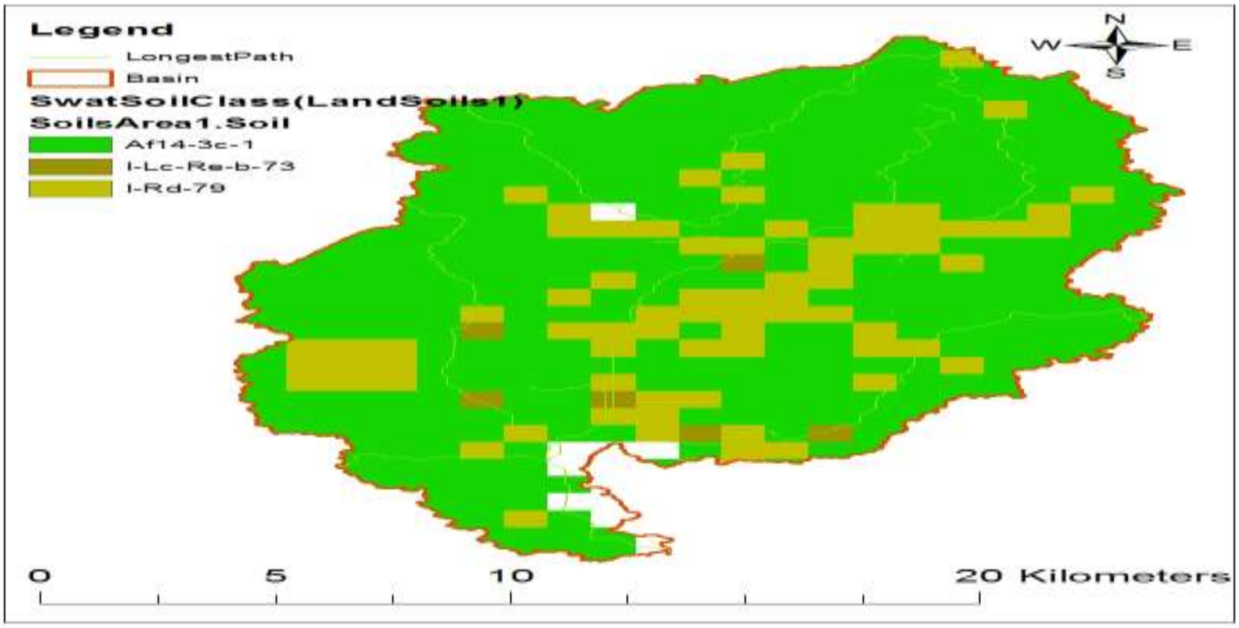


Figure 4.3: Delineated Soil Map

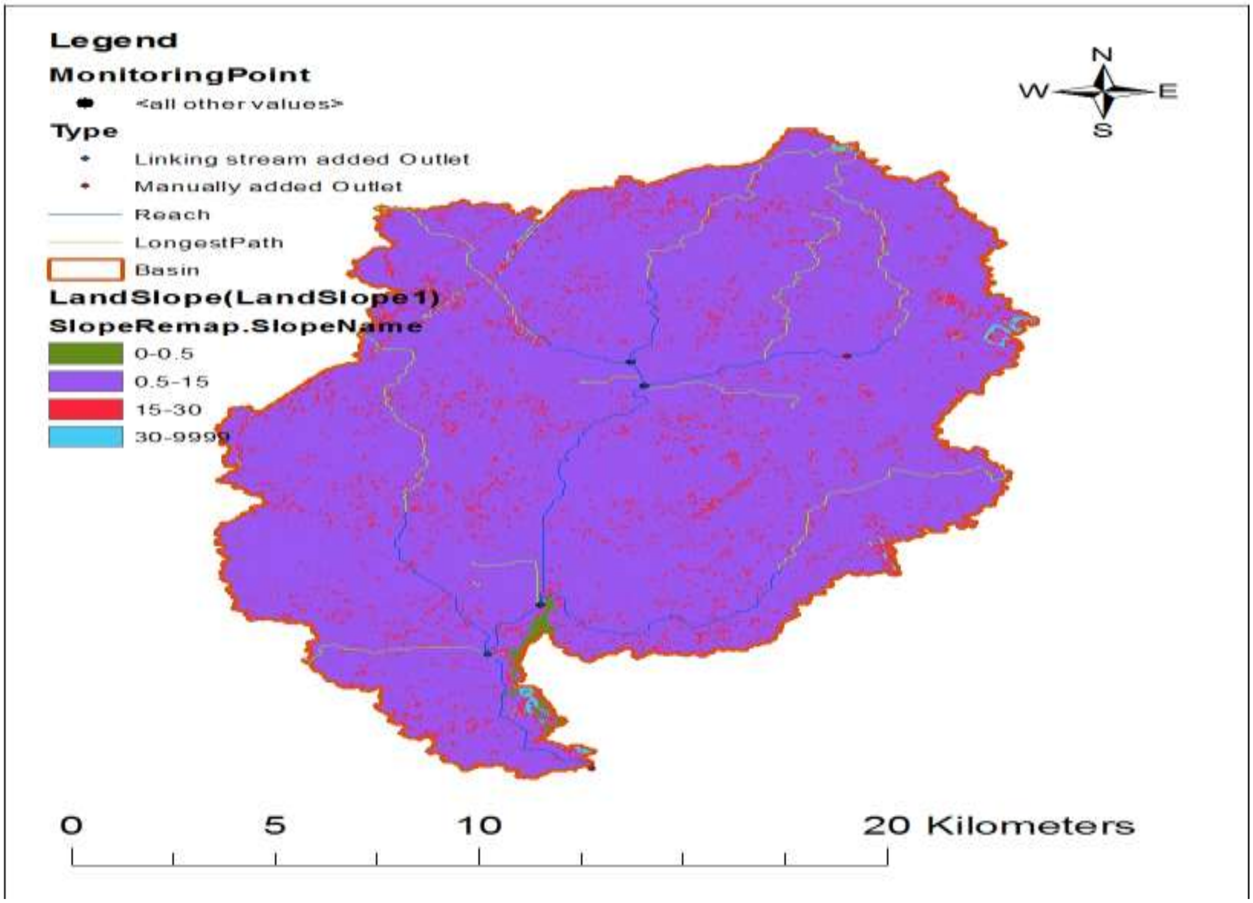
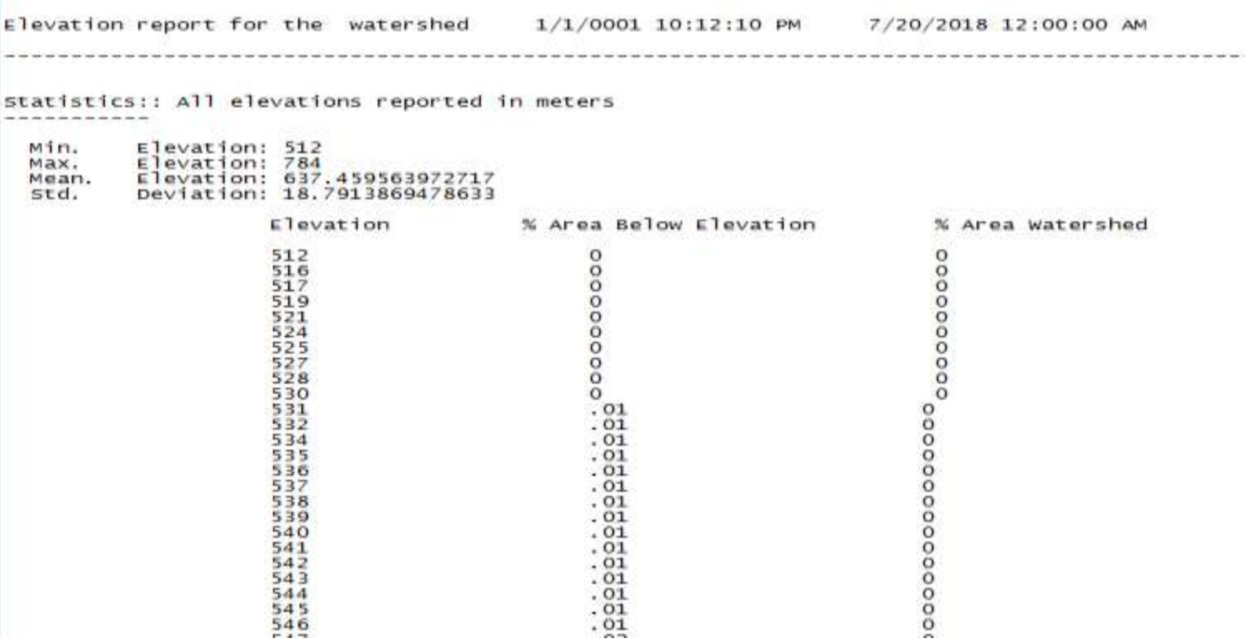


Figure 4.4: Derived Slope Map



```
Elevation report for the  watershed     1/1/0001 10:12:10 PM     7/20/2018 12:00:00 AM
------------------------------------------------------------------------------------------

Statistics:: All elevations reported in meters
-----------

  Min.     Elevation: 512
  Max.     Elevation: 784
  Mean.    Elevation: 637.459563972717
  Std.     Deviation: 18.7913869478633
                      Elevation          % Area Below Elevation        % Area Watershed

                      512                         0                          0
                      516                         0                          0
                      517                         0                          0
                      519                         0                          0
                      521                         0                          0
                      524                         0                          0
                      525                         0                          0
                      527                         0                          0
                      528                         0                          0
                      530                         0                          0
                      531                         .01                       0
                      532                         .01                       0
                      534                         .01                       0
                      535                         .01                       0
                      536                         .01                       0
                      537                         .01                       0
                      538                         .01                       0
                      539                         .01                       0
                      540                         .01                       0
                      541                         .01                       0
                      542                         .01                       0
                      543                         .01                       0
                      544                         .01                       0
                      545                         .01                       0
                      546                         .01                       0
```

Figure 4.5: Extracted part of the topograhic watershed report

Figures 4.2 and 4.3 shows the delineated landuse and soil map respectively. Figure 4.4 shows the slope map result after dividing the HRUs into those with the average of 0-10%. A few extraction of the topographic report can be seen in figure 4.5. Table 4.1 gives the summary of the landuse, soil type and slope bands of the watershed, while Table 4.2 shows the soil units extracted and completed by additional information from the soil properties.It is observed that Agicultural land and Ferric acrisol has the dominant area in the watershed for both the land use and soil classification. This is in precise agreement with the “ground truth” fact based on the supervised classification and soil test conducted in the area as recommended by Adeogun *et al*., (2014) that supervised classification of land use land cover and soil samples within the watershed should be analysed to validate the model parameters .

4.3Hydrological Response Units (HRUS)

Figure 4.6 showsthe results of HRUs. The numerical values are given in Figure 4.7 There are 39 HRUs derived from the HRU analyses. This shows that there are 5 different landuse classes in the watershed with Agricultural land being the dominant class. In general, the HRUs in figure 4.7 signify the classification of the watershed into hydrologic zones based on the hydrologic boundaries. In other words, the classifications give the response of these zones to recharge and discharge patterns based on water level trends, depth to water, hydrological and hydrogeological environments.

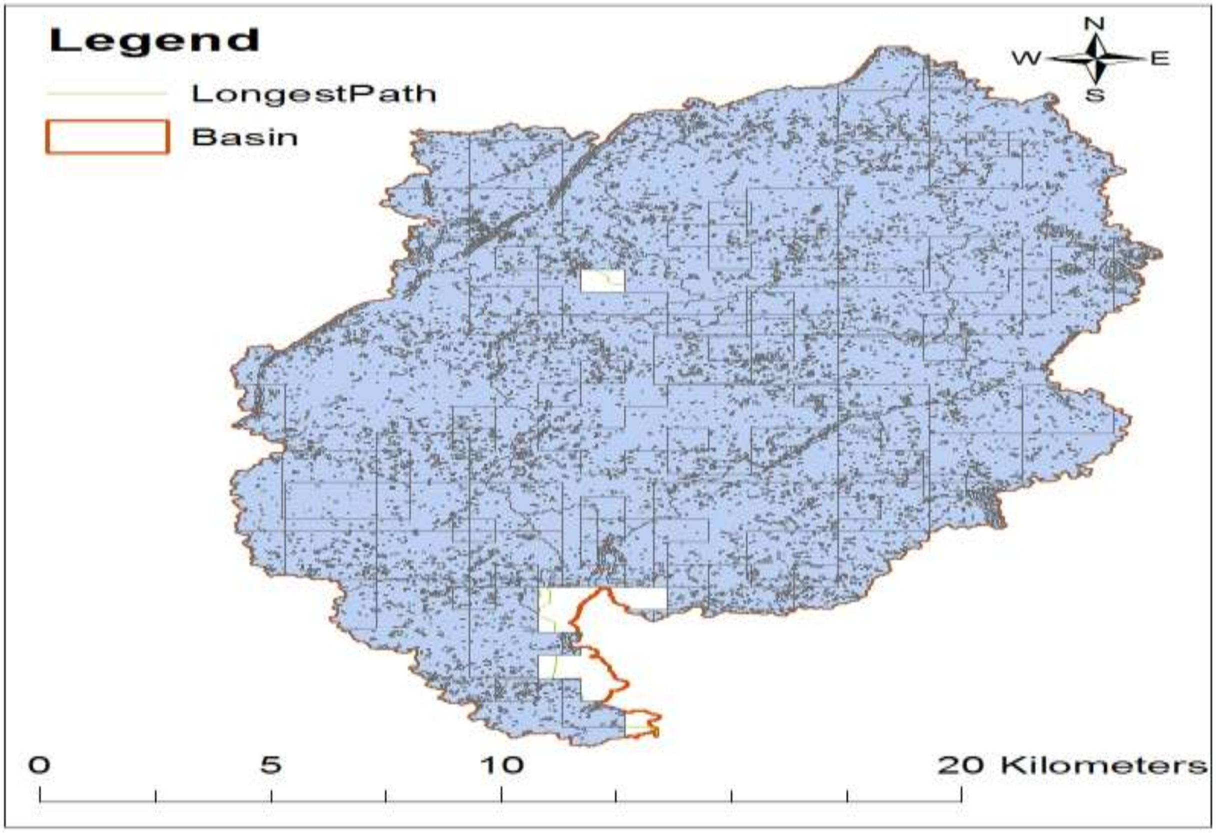
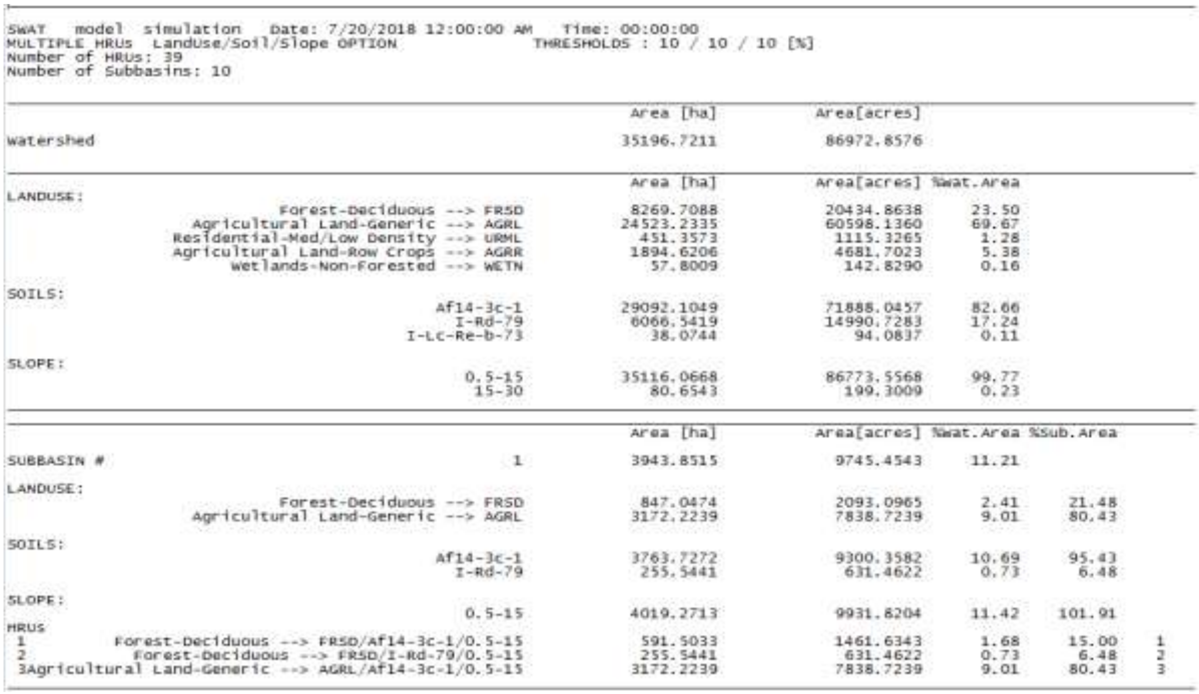


Figure 4.6: The Hydrological Response Unit (HRUs) Results



```
SWAT   model  simulation   Date: 7/20/2018 12:00:00 AM   Time: 00:00:00
MULTIPLE HRUs  Landuse/Soil/Slope OPTION              THRESHOLDS : 10 / 10 / 10 [%]
Number of HRUs: 39
Number of Subbasins: 10

                                                                 Area [ha]         Area[acres]

watershed                                                       35196.7211          86972.8576

                                                                 Area [ha]         Area[acres] %Wat.Area
LANDUSE:
                               Forest-Deciduous --> FRSD         8269.7088          20434.8638     23.50
                      Agricultural Land-Generic --> AGRL        24523.2335          60598.1360     69.67
                    Residential-Med/Low Density --> URML          451.3573           1115.3265      1.28
                    Agricultural Land-Row Crops --> AGRR         1894.6206           4681.7023      5.38
                          Wetlands-Non-Forested --> WETN           57.8009            142.8290      0.16

SOILS:
                                               Af14-3c-1        29092.1049          71888.0457     82.66
                                                 I-Rd-79         6066.5419          14990.7283     17.24
                                            I-Lc-Re-b-73           38.0744             94.0837      0.11

SLOPE:
                                                  0.5-15        35116.0668          86773.5568     99.77
                                                   15-30           80.6543            199.3009      0.23

                                                                 Area [ha]         Area[acres] %Wat.Area %Sub.Area

SUBBASIN #                                             1         3943.8515           9745.4543     11.21

LANDUSE:
                               Forest-Deciduous --> FRSD          847.0474           2093.0965      2.41     21.48
                      Agricultural Land-Generic --> AGRL         3172.2239           7838.7239      9.01     80.43

SOILS:
                                               Af14-3c-1         3763.7272           9300.3582     10.69     95.43
                                                 I-Rd-79          255.5441            631.4622      0.73      6.48

SLOPE:
                                                  0.5-15         4019.2713           9931.8204     11.42    101.91
HRUS
 1            Forest-Deciduous --> FRSD/Af14-3c-1/0.5-15          591.5033           1461.6343      1.68     15.00     1
 2              Forest-Deciduous --> FRSD/I-Rd-79/0.5-15          255.5441            631.4622      0.73      6.48     2
 3Agricultural Land-Generic --> AGRL/Af14-3c-1/0.5-15            3172.2239           7838.7239      9.01     80.43     3
```

Figure 4.7: The Extracted part of the Hydrological Response Units (HRUs)

4.4 Model Calibration, Sensitivity Analysis and Validation

Model calibration and validation are vital for simulation process, which are used to assess model prediction results. This is to reduce the uncertainty associated with the model prediction. Streamflow calibration and validation were based on the observed flow data collected by Kaduna State Water Board at Ribako gauge station upstream the Kangimi Dam on Kangimi river. The available measurements were used for comparison with the predicted results in order to test the SWAT simulation efficiency.

Calibration took place monthly where outflow data existed from 1983 to 1986 and then the parameters were validated from 1987 to 1990. After achieving a reasonable runoff data, the same value of calibrated hydrological parameters was used for validation. The SUFI2 algorithm within SWAT-CUP software was used for calibrations by realizing 500 simulations for the most sensitive parameters.

Parameter sensitivities are determined by calculating the following multiple regression system which regresses the Latin hypercube generated parameters against the objective function values (in file goal.txt) as showned in appendix A11:

$$G = \alpha + \sum_{i=1}^{m} \beta_i b_i$$

A t-test is then used to identify the relative significance of each parameter. The sensitivities given are estimates of the average changes in the objective function resulting from changes in each parameter, while all other parameters are changing. This gives relative sensitivities based on linear approximations and, hence, only provides partial information about the sensitivity of the objective function to model parameters. According to (Abbaspour et al., 2015) the larger, in absolute value, the value of t-stat, and the smaller the p-value, the more sensitive the parameter. In this study, CN2, GWQMN, SOL_AWC, followed by GW_DELAY, ESCO, SOL_K, and ALPHA_BF are the most sensitive parameters as shown on table 4.3.

Table 4.3Global Sensitivity Analysis result in SWATCUP

ParameterName	t-stat	P-Value
1: Curve number	-1.294377763	0.243116791
2: Base flow Alpha factor	0.587964599	0.577999068
3: Available water capacity of the first soil layer	0.538852442	0.110844576
4:Groundwater delay time	0.324837891	0.756331164
5:Groundwater revaporation coefficient	-0.205673432	0.104523675
6:Effective hydraulic conductivity	0.103472211	0.098474644
7:Threshold depth of water in shallow aquifer	0.085266666	0.934823424

The CN2 determines the amount of precipitation that becomes runoff and the amount that infiltrates, followed by (GWQMN) affect the amount of groundwater flow and control the emergence of groundwater into the unsaturated soil zone.(SOL_AWC) is a layer-specific parameter describing the maximum water that can be held in a soil layer between saturation andwilting point. SOL_AWC determines the movement of water within the soil profiles. Groundwater delay time(GW_DELAY), (ESCO) is used for modifying the depth distribution to meet soil evaporative demand and accountsmainly for the effect of capillary action and threshold water depth aquifer, Base flow alpha factor (ALPHA_BF.gw)has a characteristically rapid response of runoff to rainfall. These parameters were adjusted to bring simulated values close to the observed values as shown in table 4.4. This result is in agreement found by similar study of Ndulue*et al.*, (2018), confirming that these parameters are crucial for stream flow calibration.

Table 4.4 Stream Flow Calibration Parameter Values Used in ARCSWAT

S. no.	Parameters	Description	Fitted value	Minimum value	Maximum value
1	r__CN2.mgt	Curve number	-0.184342	-0.212561	-0.005619
2	v__ALPHA_BF.gw	Base flow alpha factor	0.849888	0.566410	1.133366
3	r_SOL_AWC (1).sol	Available water capacity of first soil layer	0.098	0.098	0.144
4	v__GW_DELAY.gw	Groundwater delay time	32.608788	-69.638748	251.710648
5	v__ESCO.hru S	Groundwater ‘‘revaporation’’ coefficient	0.84	0.84	1.00
6	r__SOL_K.sol	Effective hydraulic conductivity	0.54	-0.7	0.8
7	v__GWQMN.gw	Threshold depth of water in shallow aquifer	2.242123	1.298533	2.519649

The model calibration for various water balance components yielded good result, the graphical representation between simulated and observed monthly flows during calibration period is showned on the appendix 14A. For the flow calibration result, the average flow for the simulation period is 1.13 m^3/s whereas the average observed flow during the same period is about 1.46 m^3/s. The peak flow is observed in the month of september 1985 and the lowest flow is received in the month of july 1984. The simulation results show a very good match with peak and low flow periods depending on the meteorological datasets received from KSWB.

For validation period, the result of flow shows a good correlation of observed and model simulated as denoted in appendix 15. The mean flow for the simulation is 1.12 m^3/s while the mean observed flow during the same period is about 1.39 m^3/s. The results suggest that the model can be used topredict the average annual values of river flow.. The statistical evaluation of simulated versus observed annual stream flow data is summarized in Table 4.5

Table 4.5 Statistical Evaluation of Simulated Versus Observed Annual Stream Flow Data

Coefficient	Calibration Period (1983-1986)		Validation period (1987-1990)	
	Obs. Flow m^3/s	Sim. Flow m^3/s	Obs. Flow m^3/s	Sim. Flow m^3/s
Mean	1.46	1.13	1.39	1.12
R^2	0.92		0.93	
NSE	0.82		0.86	
RSR	0.77		0.77	
PBIAS	23.0		19.0	

The statistical evaluation showed a very good match between the monthly observed and simulated river discharge. The values of Coefficient of Determination (R^2) for both calibration and validation recognize the accuracy of the results as shown in fig. 4.9 and 4.10. The value R^2 test stands 0.92 and 0.93 for calibration and validation respectively. It indicates that model results produced for the flow are very good for both periods. According to NS method, the model results 0.82 for calibration and 0.86 for validationare quite acceptable as reported by Neitsch, (2005).

Many studies with the SWAT related R^2 and NS values ranged from 0.4 to 0.9 and 0.3 to 0.9 respectively, depending on the drainage area of basin, the time interval of the simulation and the available database.Ndulue *et al.*, (2018) obtained R^2 and NSvalues of (0.53 and 0.74) and (0.61 and 0.59) inthe calibration and validation of SWAT, respectively, for the Hydrological modelling of upper Ebonyi watershed using the SWAT model, using a time series of data to simulate the model. Adeogun *et al.*,(2014) obtained R^2 and NSvalues of (0.76 and 0.71) and (0.72 and 0.78) inthe calibration and validation of SWAT, respectively for the GIS-based hydrological modelling of upstream watershed of Jebba reservoir in Nigeria using SWAT model. Shimaa, (2015) obtained R^2 and NSvalues of (0.93 and 0.80) and (0.85 and 0.75) inthe calibration and validation of SWAT, respectively for the hydrological modeling of the Simly Damwatershed (Pakistan) using GIS and SWAT model. Therefore, these suggest strong agreement between the simulated and observed stream flow during this period, based on the performance criteria stated above.

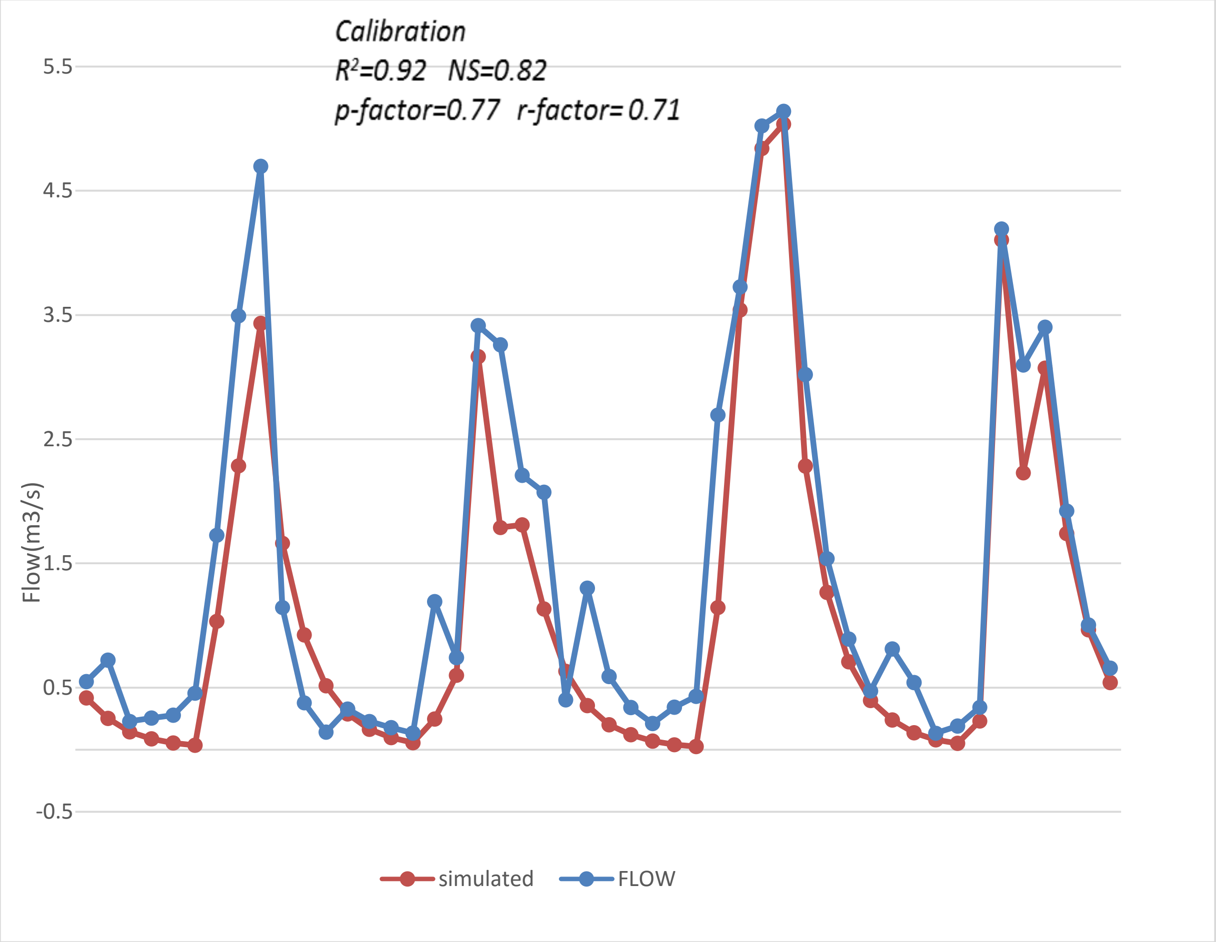


Figure 4.8 Comparison of monthly observed and simulated streamflow for R2, NS, p-factor and r-factor statistics during the calibration period (1983-1986)

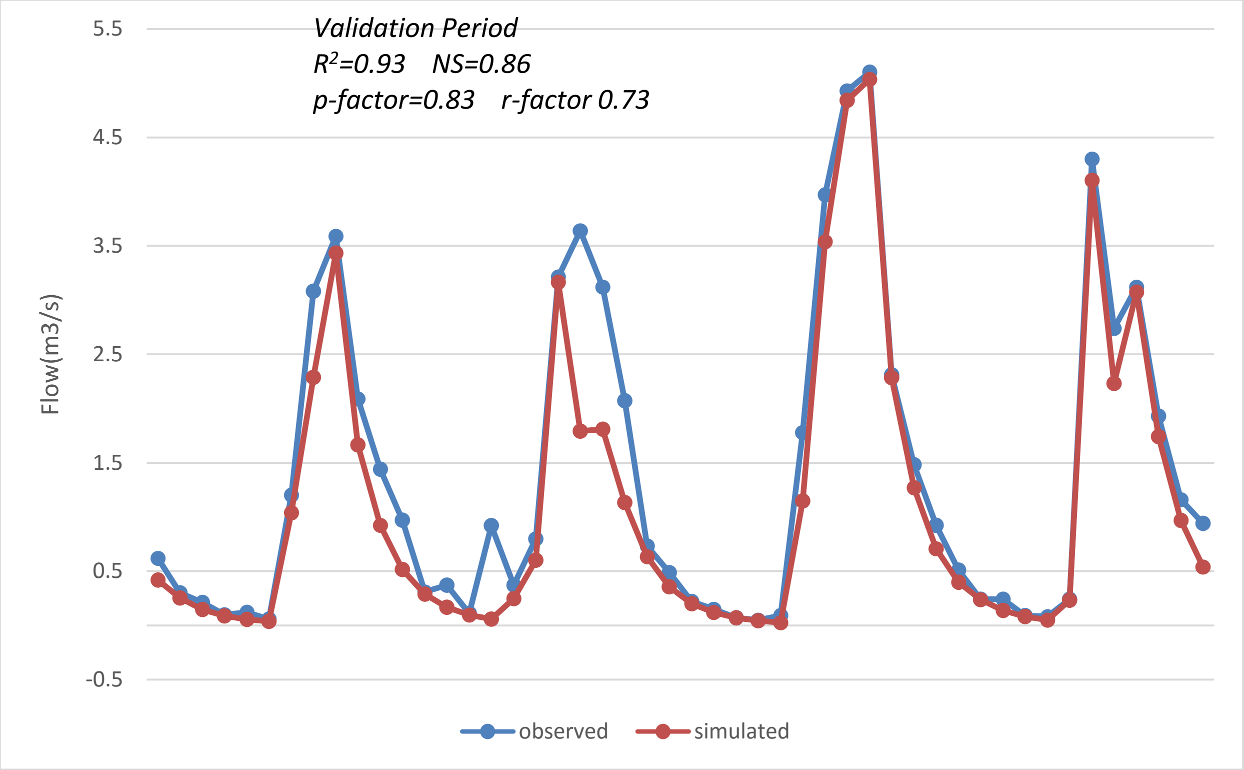


Figure 4.9 Comparison of monthly observed and simulated Streamflow for R^2, NS, p-factor and r-factor statistics during the Validation period (1987- 1990)

The simulation underpredict the peak values of flow experienced in the month of July, August and September as shown in figure 4.9. It is clear that if more reliable precipitation and temperature data sets of the meteorological stations with good special coverage of the study area are available, the results of the model could be equally improved with excellent accuracy. The underprediction of flow during peak events by the SWAT model has been reported in many studies, (Jayakrishnan *et al*., 2005), (Gassman *et al*., 2007) and (Fadil *et al*., 2011)

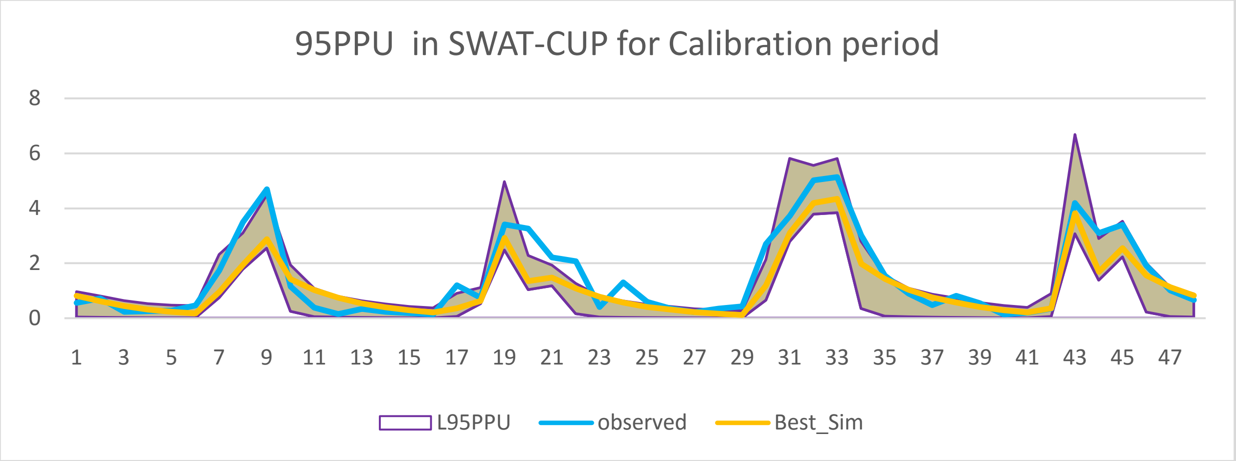


Figure 4.10: 95PPU in SWAT-CUP for calibration period

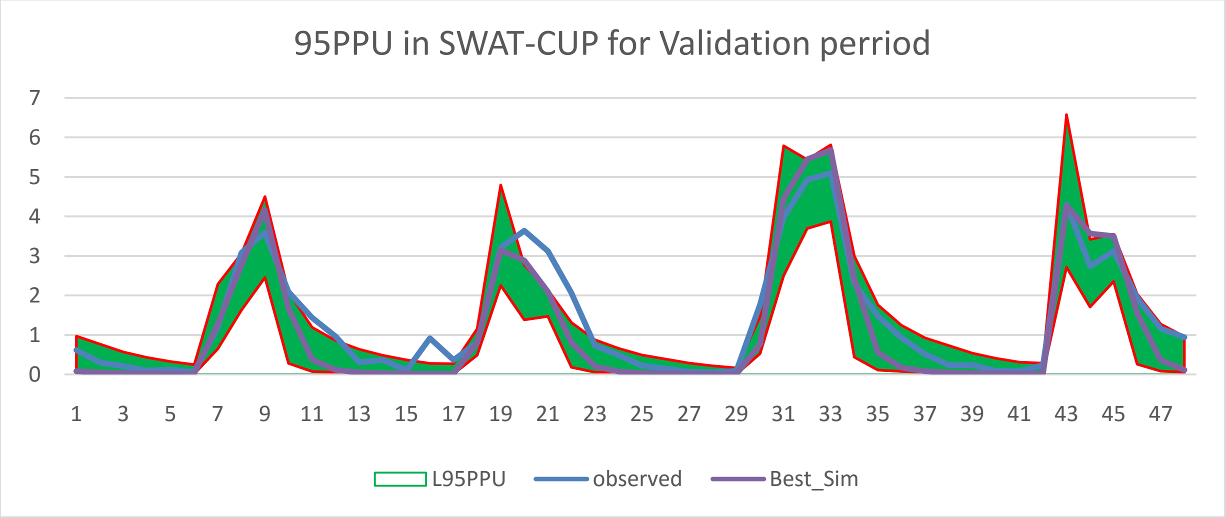


Figure 4.11: 95PPU in SWAT-CUP for validation period

As SUFI-2 is iterative, each iteration results in a reduction of parameter uncertainties, this algorithm maps all uncertainties (parameter, conceptual model, input, etc.) on the parameters (expressed as uniform distributions) and tries to capture most of the measured discharge within the 95% prediction uncertainty (95PPU).To quantify the model results, the uncertainty statistics p-factor give the percentage of data that is within the 95PPU, and the r-factor gives the thickness of the 95PPU (average thickness of the 95PPU band divided by the standard deviation of the observed data). Suggested but not firm values for these two statistics are p-factor>0.7 and r-factor<1.5 (Abbaspour *et al*., 2015). The 95PPU is illustrated in figure 4.10 and 4.11 which shows the model performed satisfactorily in terms of the p-factor and r-factor for simulation period as reported by other published studies of (Abbaspour *et al*., 2015).The uncertainty of the simulations represented by the 95PPU band are generally low.

4.5 Land Use and Land Cover Changes and their Impact on the Study Area

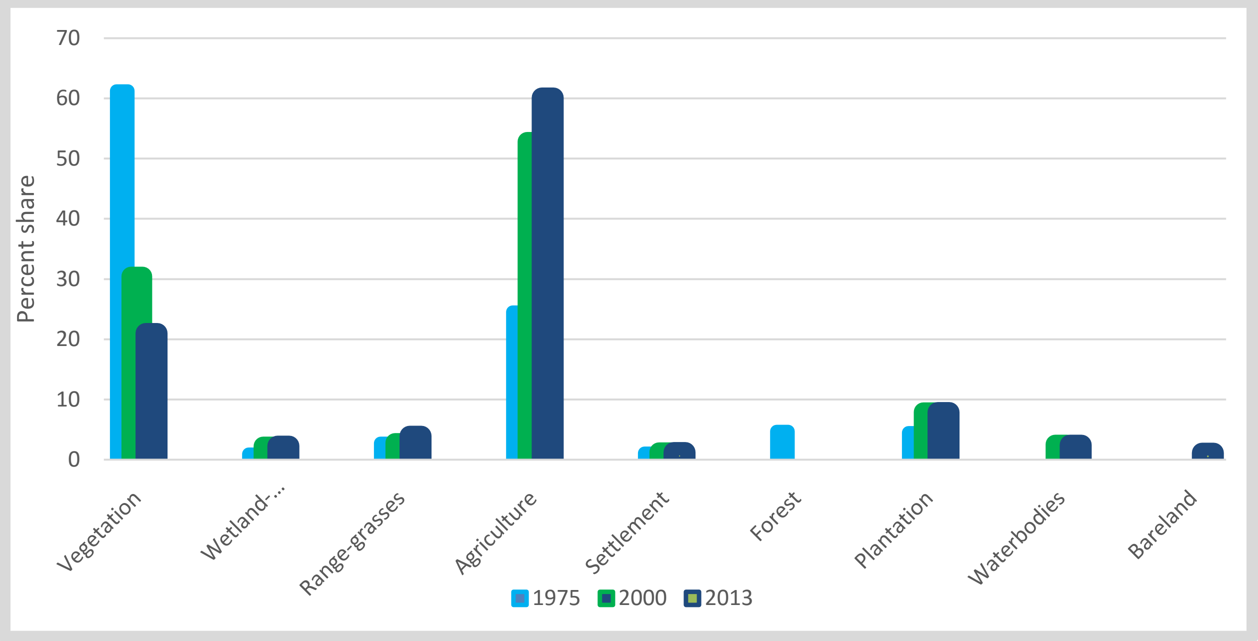


Figure 4.12: Percentage share of the land use/land cover (LULC) classes within the Kangimi Catchment from the 1975s up to 2013

Figure 4. 12 displays the percentage changes among the LULC classes from the 1975s up to 2013, in contrast to the classes' spatial representation shown in (appendix 9, 10 and 11). In this study, savanna is classified as vegetation which has the highest share (61.3%), followed by agricultural land of (24.58%), while wetland-floodplain (0.96) takes the lowest share as at 1975. It is clearly seen that, the share of agricultural land increased significantly from 1975 to 2013, which is in good agreement with the land use practice of the area. The increase shift of the wetland in the catchment could be attributed to an increase in agricultural land as shown in Table 4.6.

Table 4.6: Summary Land Use Land Cover of Kangimi Watershed for Different Period of Time.

SWAT Code		Area Coverage (Hectare)						
	LULC type	1975	% share	2000	%share	2013	%share	% change(1975-2013)
FRSD	Vegetation	21564.48	61.3	10826.35	30.45	7450.02	20.98	-40.32
WETN	Wetland-floodplain	341.29	0.96	806.76	2.25	806.75	2.26	1.3
RNGE	Range grasses	1000.75	2.78	1000.75	2.8	1399.67	3.93	1.15
AGRL	Agricultural land	8733.37	24.58	18733.97	52.81	21300	60.11	35.53
URML	Settlement	411.39	1.14	446.68	1.24	446.68	1.23	0.09
FRST	Forest mixed	1315.48	4.7	0	0	0	0	0
AGRR	Agricultural row crops	1633.08	4.54	2827.74	7.9	2827.74	7.89	3.35
WATR	Water bodies	0	0	357.59	2.55	357.59	2.46	0
BARR	Bare soil	0	0	0	0	411.39	1.14	0
	Total	**34999.84**	**100**	**34999.84**	**100**	**34999.84**	**100**	

4.6 Water Balance Components

In order to deal with water management issues, it is ideal to analyze and quantify the different elements of hydrological processes occurring within the area of interest. Wateryieldisoneof the significant parameters estimated by themodelforefficient watermanagementandplanningofthestudy area. The SWAT model estimated other relevant water balance components in addition to the monthly flow. Sathian and Syamala (2009) stated that the most vital elements of water balance of a basin are precipitation, surface runoff, lateral flow, base flow and evapotranspiration. Among these, all the variables, except precipitation, need prediction for quantifying as their measurement is not easy. The average annual basin values for different water balance components and LULC type where simulated by the model as shown in Table 4.7 and calculated as a relative percentage to average annual rainfall in Fig. 4.13.

Table 4.7:Land Use and Land Cover Changes and Their Impact on Hydrology of Kangimi Watershed.

Hydrology LULC Type	Simulation from 1979-2014 1975	2000	2013	2020 Projection
Precipitation; mm	1198.5	1198.5	1198.5	1281.6
Surface runoff; mm	345.2	377.87	387.37	388.87
Evapotranspiration; mm	504.4	510.7	509.3	593.8
Tile flow; mm	0	0	0	0
Lateral flow; mm	5.02	4.58	4.49	4.74
Soil water; SW (mm)	17.5	15.59	15.19	14.97
Total water yield; mm	654.43	654.06	655.51	646.24
Contribution of GW to streamflow Q(mm)	286.71	255.77	248.22	237.77

The relative change of annual stream flow and sediment load could be due to land use land cover and climate dynamics of Kangimi dam watershed shows higher influence over sediment yield than stream flow as shown in Table 4.7.Mean annual stream flowin the watershed for 1975-2000LULC and 2000-2013LULC scenario was increased by (8.65- 10.89%). The main contributing reasons for this change are the expansion of serious agricultural lands and expansionof bare land and this in turn made the catchment prone to surface runoff.

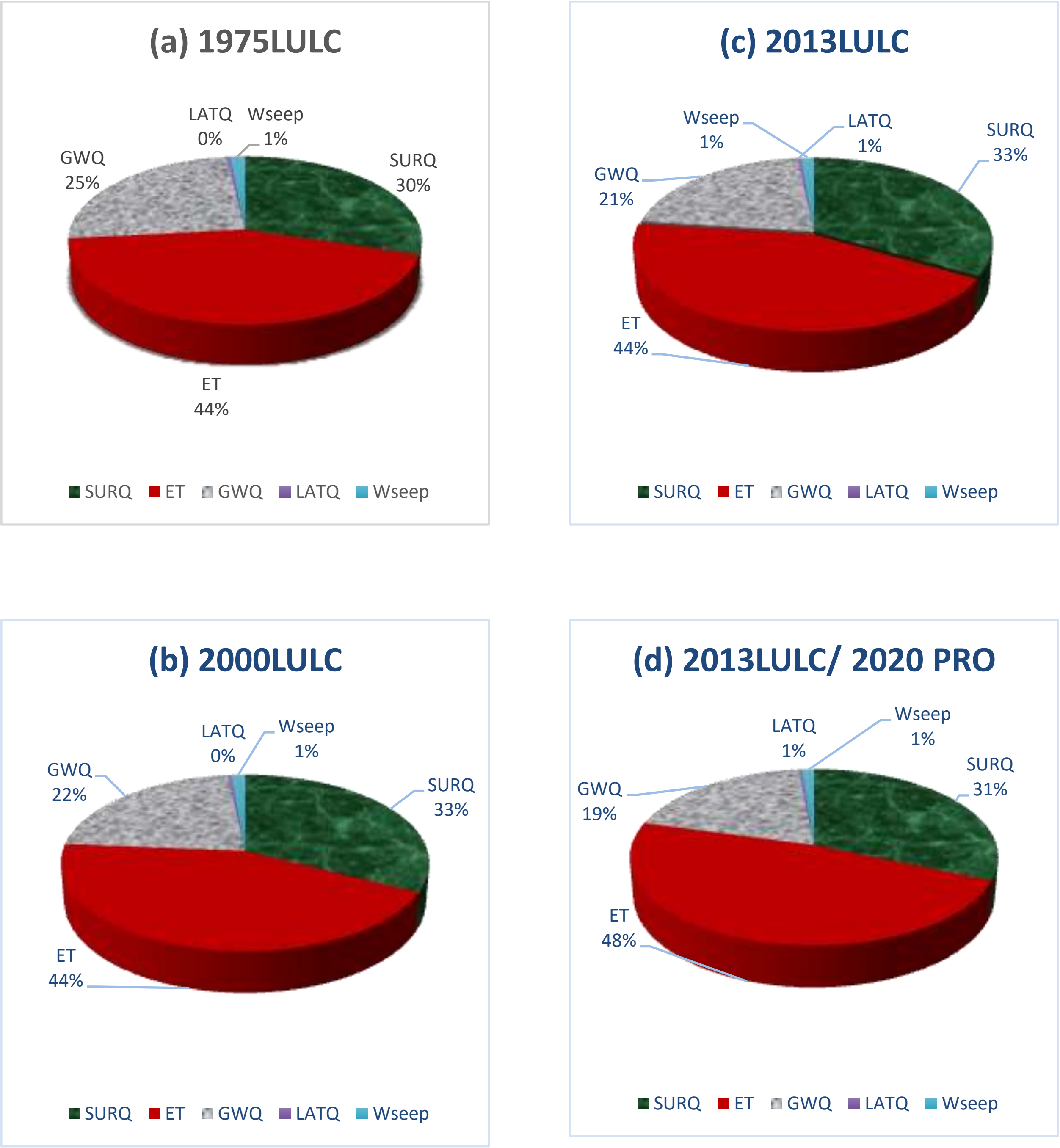


Figure 4.13: Average annual water balance as a relative percentage to precipitation for (a)1975 LULC (b) 2000 LULC (c) 2013 LULC (d) 2013LULC/2020 PRO in the study area

From figure 4.13 actual evapotranspiration ET (about 44%) contributed a larger amount of water loss from the watershed for all three LULC scenarios and increased to (48%) when projected to simulation year 2020. High evapotranspiration rate simulated could be attributed to high temperature and the type of vegetation cover present in the studyarea. Lateral flow has a nil percentage (0%) for the two scenarios but increased to (1%) for 2013LULC type and when projected to year 2020 , thismightbe due tothelowlevelofinfiltration ofwaterwithincreasing development anditsassociatedimpervioussurfaceresultingin increased surface runoff, it can also be attributed to the shallow terrain slope of the watershed as asserted by Shimaa, (2015) that in sloping terrain, the major contributor of river flow is lateral flow while shallow sloping terrain, its impact is very marginal.Groundwater contributionto stream flow (GW_Q) is the water from the shallow aquifer that returns to the reach during the time step and it varies widely among streams. There is a significant decrease in the average annual contribution of groundwater as a relative percentage to precipitation for all the three LULC type and projection. Totalwateryield(WYLD)is the amount ofstreamflowleavingthewatershedoutletamidthe time step.Basedon Table 4.7,it was observed thatasignificantpart of theprecipitationreceivedbythewatershedislostas stream flow. Thetotalannualwateryieldfor the simulation period waspredictedtobe 655.51mm and 646.24mm for the projection period. The decrease in the water yield during the projection period could be attributed to decrease in groundwater contribution to stream flow. Deep aquifer recharge is alsovery low for all the three scenarios with average of (1%) of the total rainfall forthe simulated period and projection.The low deep aquifer value indicate that the water-yieldingpotentialofdeepaquifersinthewatershedwillbe quite small.

The study yields crucialinformation about the response of Kangimi dam for rainfall events of the watershed. In many cases, rainfall events result in floods, and well-calibrated and well-validated SWAT model forrainfall will be helpful in flood inundation modeling as simulated stream flow is input for the flood inundation modeling. The findings of the present study can also be useful in forecasting runoff response during rainfall events. R^2

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

Watershed models have become a main tool in addressing a wide spectrum of water resources and environmental problems. The present study comprises the application of hydrological model to simulate the hydrological response of Kangimi dam watershed. The hydrological model selected for modeling stream flows in the watershed is theArcSWAT interface implemented in the ArcGIS software,soil and water assessment tool (SWAT).The SWAT model has been well-documented asan effective water resources management tool. From the results achieved the following conclusions are made:

i. The Kangimi Dam watershed has 10 sub-basins with a corresponding outlets points with their climate data and channel characteristics, for all of these sub-basins 39 hydrological response units (HRUs) were defined, which are areas with similar land use, soil, and slope characteristic.the watershed has a total surface area of 349.94km^2 and a corresponding perimeter of 156.82km.The maximum and minimum elevation in the study area were determined to be 784m and 512m respectively.

ii. The program SUFI-2 in SWAT-CUP package was used for calibration/uncertainty analysis, validation, and sensitivity analysis. The program SUFI-2 in SWAT-CUP package was used for sensitivity analysis, The parameters found to be most sensitive are curve number (CN2), threshold water depth aquifer (GWQMN) followed by, Soil available water capacity (SOL_AWC),Groundwater delay time (GW_DELAY), Groundwater ‘‘revaporation’’ coefficient (ESCO), Effective hydraulic conductivity (SOL_K) and Base flow alpha factor (ALPHA_BF.gw) as relative to the determination of surface runoff.

iii. The model was calibrated for river discharge. Only readily available data were used for model setup as well as calibration and validation. The calibration and validation of the model produced good simulation results based on objective funtions with (p-factor=0.77, r-factor=0.71) and (p-factor=0.83, r-factor=0.75) for calibration and validation respectively.

iv. The water balance component were simulated in response to different LULC and climate changes, the surface runoff, evapotranspiration, contribution of grounnwater to surface runoff, deep aquifer recharge and total average annual water yield at the watershed outlet for the simulation period were 387mm, 509.3mm, 248.22mm, 15.19mm and 655.51mm respectively.

v. The efficiency of the model has been tested by coefficient of determination, Nash Sutcliffe Efficiency (NSE) in addition to another two recommended statistical coefficients: Percent Bias and RSR-observation standard deviation ratio. On monthly basis the coefficient of determination and Nash and Sutcliffe Efficiency (NSE) were 92% and 82%, for calibration, and 93% and 86%, respectively, for validation periods, which indicate very high predictive ability of the model.

5.2 Recommendations

The efficiency of the model has been evaluated by a strong calibration (from 1983 to 1986) and validation (from 1987 to 1990) results produced by it.

i. The model can be used successfully to predict the volume inflow to Kangimi Dam when gauging stations are installed at each subbasin for both climatological and hydrological data collections, so as to facilitate the storage and efficient water management.The present study is also useful to hydrology environment as a detailed study on the sensitivity parameters that has been carried out.

ii. Land Use Land Cover change occur predominantly within the Kangimi watershed, and this in turn has local effects on the water balance components over the area. There should be better understanding and determination of the different land use land cover changes and watershed hydrological processes that could assit in optimal use of the dam reservoir.

iii. Most of the GIS data used for this study were obtained through the open geoportal of some global organisations with relatively low resolutions. Hence, there is high believe that obtaining the data locally may enhance the images' resolution and subsequently the ARCSWAT results. Other licensed GIS interface like the MWSWAT or ArcView versions of SWAT could be used and compare with ARCSWAT results.

iv. Finally, the evaluation of the Watershed Modeling System (WMS) which is a complete graphical modeling environment for all levels of watershed hydrology and supports other hydrologic models like the HEC-1, HEC-HMS, TR-20, TR-55, Rational Method, NFF, MODRAT, OC Rational, HSPF, xpswmm, and EPA-SWMM should also be used to model this watershed. WMS also consists of powerful tools to automate modeling processes such as geometric parameter calculations, automated basin delineation, cross-section extraction from terrain data, GIS overlay computations (CN, rainfall depth, roughness coefficients, etc.), etc. It would recommended to compare the results with ARCSWAT.

CONTRIBUTIONS TO KNOWLEDGE

- This research has been able to apply physical hydrological GIS based model (ArcSWAT) to model the hydrology of Kangimi Dam watershed with good performance (R^2) and (NSE) were 92% and 82%, for calibration, and 93% and 86%, for validation period respectively.
- The Runoff Curve Number method, Hargreaves method, and Variable-storage method are the most suitable methods for estimating surface runoff from precipitation, potential evapo-transpiration generation and channel water routing of Kangimi dam watershed respectively.
- Kangimi Dam hydrology was simulated in response to different LULC and climate changes, the surface runoff, evapotranspiration, contribution of grounnwater to surface runoff, deep aquifer recharge and total average annual water yield at the watershed outlet for the simulation period were 387mm, 509.3mm, 248.22mm, 15.19mm and 655.51mm respectively.
- The relative change of annual stream flow and sediment load due to land use land cover and climate dynamics of Kangimi dam watershed shows higher influence over sediment yield than stream flow. Mean annual stream flow in the watershed for 1975-2000LULC and 2000-2013LULC scenario was increased by (8.65- 10.89%).
- On a general scale, ArcSWAT shows interesting performance, therefore these suggests that SWAT model could be a promising decision support tool to predict water balance and water yield in other watersheds in Kaduna, Nigeria for sustainable water resources management.

REERENCES

Abbaspour, K.C., (2011). SWAT-CUP4: *SWAT calibration and uncertainty programs—a user manual.*Swiss Federal Institute of Aquatic Science and Technology, Eawag.

Abbaspour, K. C., Vejdani, M., and Haghighat, S.,(2007). SWATCUP calibration and uncertainty programs for SWAT. In Proc. Intl. *Congress on Modelling and Simulation (MODSIM'07)*, 1603-1609. L. Oxley and D. Kulasiri, eds. Melbourne, Australia: Modelling and Simulation Society of Australia and New Zealand.

Abbaspour, K. C., Johnson, A., and Th van Genuchten, M.,(2004). *Estimating uncertain flow and transport parameters using a sequential uncertainty fitting procedure*. Vadose Zone J. 3(4):1340-1352.

Abbaspour K.C., Rouholahnejad E., Vaghefi S., Srinivasan R., Yang H., and Kløve B., (2015). *A continental-scale hydrology and water quality model for Europe: Calibration and uncertainty of a high resolution large-scale SWAT model*. J Hydrol 524:733–752

Abdurrasheed, S. A., (2016). *Numerical simulation of Kangimi reservoir sedimentation, Kaduna, Nigeria*. Master's Thesis.Ahmadu Bello University Zaria, Nigeria.

Adeogun A.G., Sule, B.F., Salami, A.W., and Okeola, O.G., (2014). '*GIS-based hydrological modeling using SWAT: case study of upstream watershed of Jebba reservoir in Nigeria*',Nigerian Journal of Technology, Vol. 33, No. 3, pp.351–358.

Arnold J.G., Srinivasan R., Muttiah R.S., Williams J.R., (1998).*Large area hydrologic modeling and assessment part I: model development*. JAWRA J Am Water ResourAssoc 34(1):73–89

Ashagre B.B., (2009).*SWAT to Identify Watershed Management Options*: Anjeni Watershed, Blue NileBasin, Ethiopia, Master's Thesis, Cornell University, New York.

Bhuyan S.J., Koelliker J.K., Marzen L.J., and Harrington J.R., (2003).*An integrated approach for water quality assessment of Kansas watershed, Environ*.Model.Software.473–484.

Blume, H.P., Brümmer, G.W., Horn, R., Kandeler, E., Kögel K., and Welp, G., (2010). *Scheffer/Schachtschabel: Lehrbuch der Bodenkunde. SpektrumAkademischer*Verlag, Heidelberg, Germany.

Boluwade A., (2010). *Hydrologic and Uncertainty Analysis of an ungauged watershed using MapWindow- SWAT*.MSc thesis, UniversitatJaume.

Boyle, D. P.,Gupta, H. V., and Sorooshian.S., (2000).*Toward improved calibration of hydrologic models: Combining the strengths of manual and automatic methods*. *Water Resour. Res*. 36(12): 3663-3674.

Brooks, K.N.,Ffolliott, P.F., Magner, J.A., (2012).*Hydrology and the Management of Watersheds,Wiley-Blackwell*, Oxford, UK.

CGIAR SRTM 90m Digital Elevation Data http://srtm.csi.cgiar.org/, Accessed on 4 July, 2018

Cindy S., and Koichiro O.,(2012).*Dam construction impacts on stream flow and nutrient transport in KaseRiver Basin,* Int. J. Civil Environ. Eng. IJCEE-IJENS 12 (3)

Coffey, M. E., Workman, S. R.,Taraba, J. L., andFogle, A. W.,(2004).*Statistical procedures for evaluating daily and monthly hydrologic model predictions*. Trans. ASAE 47(1): 59-68.

Domenico, P.A.(1972). *Concepts and models in groundwater hydrology*. New York: McGrawHill Book Company.

Eawag.(2009). SWAT-CUP.Dübendorf, Switzerland: Swiss Federal Institute of Aquatic Science and Technology. Available at: www.eawag.ch/organisation/abteilungen/siam/software/ swat/index_EN.

Engel, B., Storm, D., White, M., Arnold, J. and Arabi, M.,(2007).*A hydrologic/water quality modelapplication protocol.* J. American Water Resour. Assoc. 43(5): 1223-1236.

Evans, J., and Perlman, H., (2015).*The Water Cycle*.U.S. Department of the Interioir, U.S. Geological Survey.

Fadil, A., Rhinane, H., Kaoukaya, A., Kharchaf, Y., and Bachir, O.A., (2011). "*Hydrologic Modeling of the Bouregreg Watershed (Morocco) Using GIS and SWAT Model"*Journal of Geographic Information System vol 3, pp279-289.

Gassman, P.W., Reyes, M.R., Green, C.H., and Arnold, J.G. (2007). *'The soil and water*

assessmenttool: historical development, applications, and future research directions',
Transactions ofASABE, Vol. 50, No. 4, pp.1211–1250.

Gassman, P. W., Arnold J.G., Srinivasan R., and Reyes, M.,(2010).*The worldwide use of the SWATmodel: Technological drivers, networking impacts, and simulation trends*. In Proc. 21st Century Watershed Technology: Improving Water Quality and Environment. ASABE
Publication No. 701P0210cd. St. Joseph, Mich.: ASABE.

Hagemann, S., (2011).*The hydrological cycle: how observational data are able to improve climatemodels, Hamburg University Hamburg.*

Harmonized World Soil Database (2003). Food and Agri-culture Organization of the United
Nations, Rome www.fao.org/nr/water/docs/harm-worldsoil soil-dbv7cv..Pdf accessed on July 6, 2018.

Jayakrishnan, R., Srinivasan, R., Santhi, C., and Arnold, J.G., (2005). *Advances in the application*
*of the SWAT model for water resources management,*Hydrol. Process. 19 (3) 749–762

Kannan, N., White, S. M., Worrall, F., and Whelan, M. J.,(2007).Sensitivity analysis and identification of the best evapotranspiration and runoff options for hydrological modeling in SWAT-2000. J. Hydrol. 332(3-4): 456-466.

Kemdirim, E.C., (2005). *Studies on the hydrochemistry of Kangimi reservoir, Kaduna State,*
*Nigeria.*African Journal of Ecology, Afr. J. Ecol., 43, 7–13

Khan A.D., Shimaa M.G., Mauro Di Luzio, J.G., (2014).*Hydrological modeling of upper Indus*
*Basin and assessment of deltaic ecolog*y, Int. J. Modern Eng. Res. 4 (1) 73–85, indexed in ANED (American National Engineering Database). By ANED-DDL (Digital Data link) number is 02.6645/IJMER-AJ417385.

Kieser& Associates for Environmental Science and Engineering, (2005).*SWAT Modeling of the*
St. Joseph River Watershed, Michigan and Indian, Kieser& Associates Michigan Ave., Suite 300, Kalamazoo, Michigan 49007, 2005.

Kim, N.W., Chung I.M., Won Y.S., Lee J.,& Arnold J.G.,(2007). *Integrated modeling of surface waterand groundwater by using combined SWAT-MODFLOW*. Paper delivered at the 4th International SWAT Conference, Delft.

Krause, P., Boyle, D. P., and Base, F.,(2005).*Comparison of different efficiency criteria for hydrological model assessment*. Adv. Geosci. 5: 89-97.

Larse, A., Wilk, J., and Plermkamon, V., (2001).*Hydrological impacts of forest conversion to agriculture in a large river basin in northeast Thailand, hydrological processes*. Hydrol.Process. 15, 2729–2748 DOI: 10.1002/hyp.229

Legates, D. R., and McCabe, G. J.,(1999).*Evaluating the use of "goodness-of-fit" measures in hydrologic and hydroclimatic model validation*. *Water Resour. Res.* 35(1): 233-241.

Lewarne, M., (2009).*Setting up ArcSWAT hydrological model for the verlorenvlei Catchment*. Unpublished Master's Thesis. Stellenbosch University, South Africa.

Ma, L., Ascough J. C., Ahuja L. R., Shaffer M. J., Hanson J. D., and Rojas K.W., (2000). *Root Zone Water Quality Model sensitivity analysis using Monte Carlo simulation*. Trans. ASAE 43(4): 883-895.

Nash, J. E., and Sutcliffe, J.E.,(1970).*River flow forecasting through conceptual models*: Part I. Adiscussion of principles. J. Hydrol. 10(3): 282-290.

Nasrin Z., Sayyad G.A., Hosseini S.E., (2013).*Hydrological and sediment transport modeling in maroon dam catchment using soil and water assessment tool (SWAT)*, Int. J. Agron. Plant Prod. 4 (10) 2791–2795.

Ndulue, E.L., Ezenne, G.I., Mbajiorgu, C.C., Ogwo, V. and Ogbu, K.N. (2018) '*Hydrological modelling of upper Ebonyi watershed using the SWAT model'*, Int. J. Hydrology Science and Technology, Vol. 8, No. 2, pp.120–133.

Neitsch S.L., Arnold J.G., Kiniry J.R., Srinivasan R., and Williams J.R.,(2002).*Soil and water assessment tool user's manual. Version 2000*. GSWRL Report 02-02. Temple, Texas: Grassland, Soil &Water Research Laboratory.

Neitsch, S. L., Arnold, J. G., Kiniry J. R., and Williams, J. R.,(2008). *Overview of soil and water assessment tool (SWAT) model: Global Applications.*Published as Special Publication No. 4 by The World Association of Soil and Water Conservation (WASWC). http://waswc.soil.gd.cn, www.waswc.org

Neitsch S. L., Arnold, J.G., Kiniry J.R., Williams J.R., (2005).*Soil and water assessment tool theoretical documentation version*. Grass Land, Soil and Water Research Laboratory, Agricultural Research Service 808 East Blackland Road, Temple, Texas 76502; Blackland Research Centre, Texas Agricultural Experiment Station 720, East Blackland, Texas USA.

Omar, M., (2014).*Space-time variation of hydrological processes and water resources in Rwanda*. Phd Dissertation, UNESCO-IHE Institute for water education Delft, Netherland.

Pagano, T.C., Sorooshian, S., (2006).*Global water cycle (fundamental, theory, mechanisms)* Encyclopedia of Hydrological Sciences, 5.Wiley, Chichester, England.

Rao, M.G., Fan, J., Thomas, G.,Cherian, V., and Awawdeh,M., (2006).*A web-based GIS decision support system for managing and planning USDA'sConservation Reserve Program (CRP)*. Environ. Model.Soft. 22(9): 1270-1280.

Refsgaard, J. C. (1997). *Parameterisation, calibration, and validation of distributed hydrological models*. *J. Hydrol.* 198(1): 69-97.

Rouholahnejad, E.,Abbaspour, K. C., Vejdani, M., Srinivasan, R., Schulin, R., and Lehmann, A., (2012). *A parallelization framework for calibration of hydrological models*. Environ. Modelling Software 31: 28-36.

Santhi, C., Arnold J.G., Williams, J.R., Dugas, W.A., Srinivasan, R., and Hauck L.M., (2001). *Validation of the SWAT model on a large river basin with point and nonpoint sources*. J. American Water Resour. Assoc. 37(5): 1169-1188.

Sathian, K.K., Syamala, P.,(2009). *Application of GIS integrated SWAT model for basin level Waterbalance*.<http://www.csre.iitb.ac.in/~csre/conf/wpcontent/uploads/fullpapers.pdf>

Schuol J., Abbaspour K.C., Srinivasan R., and Yang H., (2008).*Modeling blue and green water availabilityin Africa at monthly intervals and sub basin level*, Water Resour. Res. 44 1–18.

Shawul, A., Alamirew T., Dinka M.O., (2013).*Calibration and validation of SWAT model and estimationof water balance components of Shaya mountainous watershed, Southeastern Ethiopia*,Hydrol. Earth Syst. Sci. Discuss 10 (2013) 13955– 13978, http://dx.doi.org/10.5194/hessd-10-13955.

Shimaa, M.G., (2015). *Hydrological modeling of Simly Dam watershed (Pakistan) Using GIS and SWAT Model.*Alexandria Engineering Journal (2015) 154.585-594.

Uehlenbrook S., (2006).*Catchment hydrology — a science in which all processes are preferential. Hydrological Processes,* HPToday, 20, 16, 3581–3585, DOI: 10.1002/hyp.6564

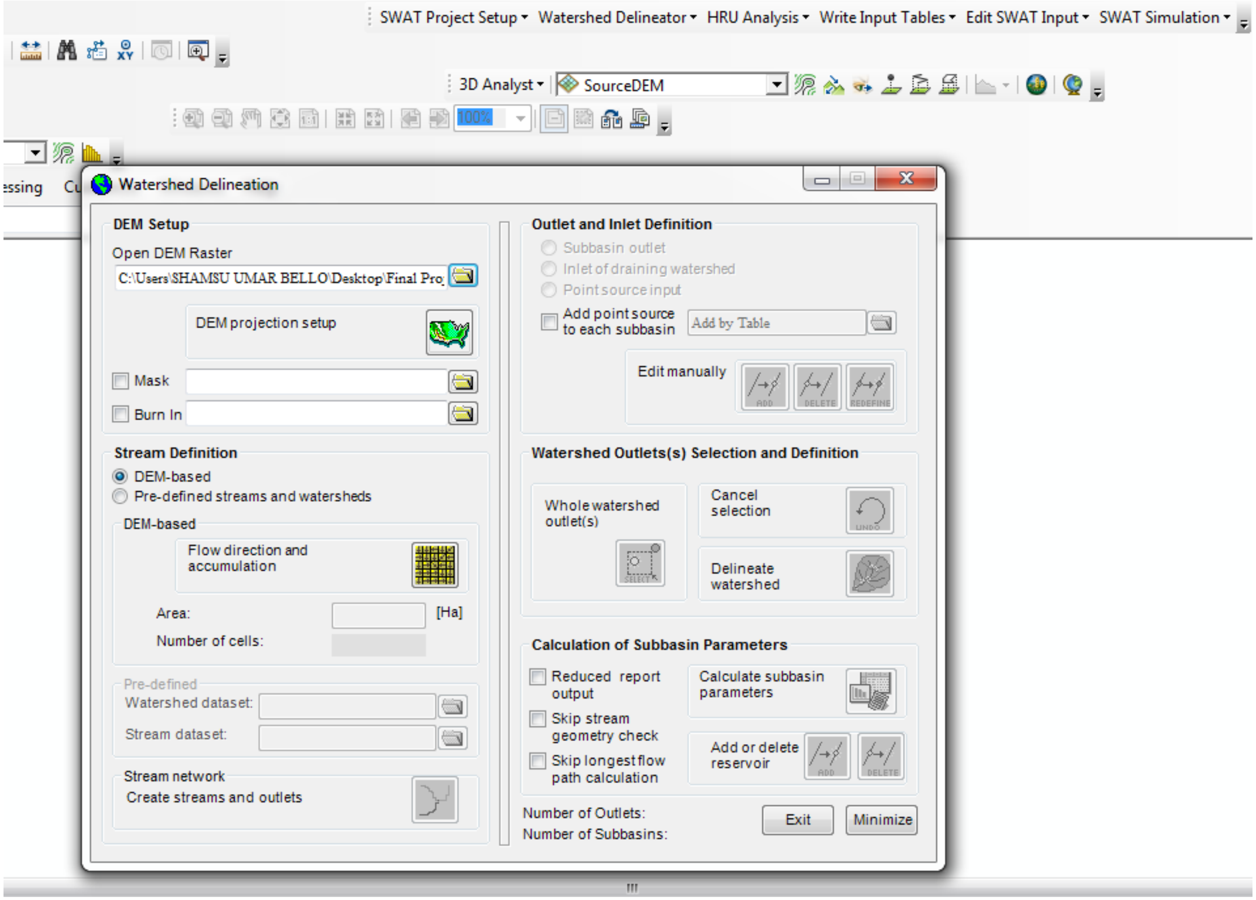
USGS Earth Resources Observation and Science (EROS) https://eros.usgs.gov/westafrica. Accessed on 6 July, 2018.

Van Griensven, A., Meixner, T., Grunwald, S., Bishop, T., Diluzio, M. and Srinivasan, R. (2006). *'A global sensitivity analysis tool for the parameters of multi-variable catchment models'*, Journal of Hydrology, Vol. 324, Nos. 1–4, pp.10–23, DOI: 10.1016/j.jhydrol.2005.09.008.

Van Griensven, A., andBauwens.W.(2003).*Multi objective auto calibration for semi distributed water quality models.* Water Resour. Res. 39(12): 1348-1356.

Van Liew, M.W., Arnold, J.G., and Bosch, D.D.,(2005). *Problems and potential of auto-calibratinga hydrologic model.* Trans. ASAE 48(3): 1025-1040.

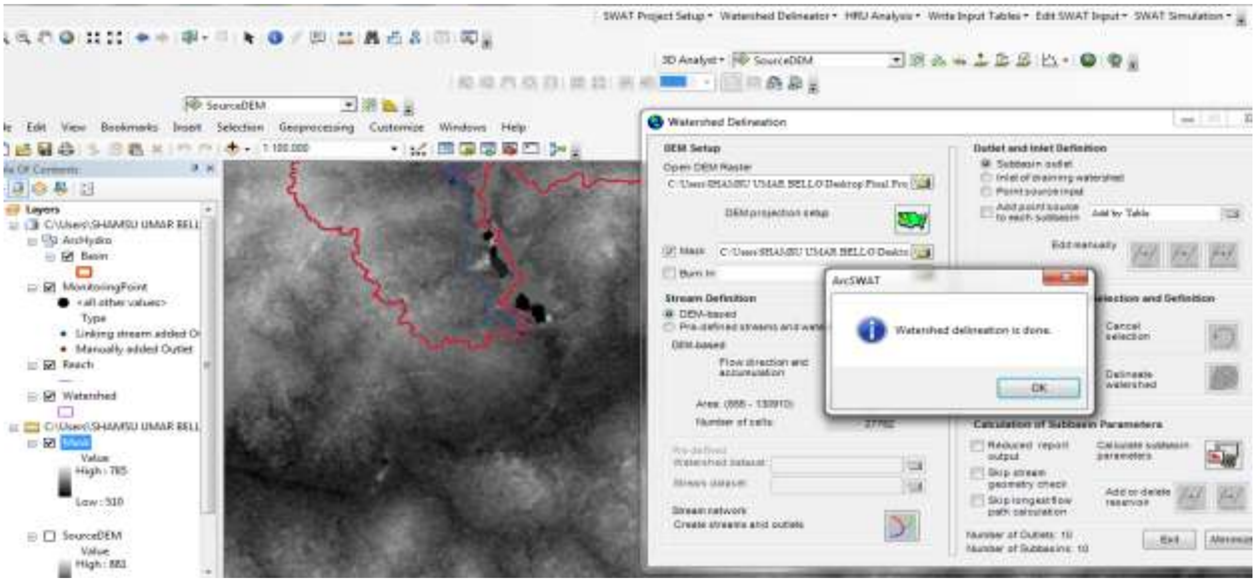
APPENDICES



Open DEM Raster: C:\Users\SHAMSU UMAR BELLO\Desktop\Final Pro

Stream Definition: ● DEM-based

Figure A1: The Automatic Watershed Delineation Procedure



Open DEM Raster: C:\Users\SHAMSU UMAR BELLO\Desktop\Final Pro

☑ Mask: C:\Users\SHAMSU UMAR BELLO\Deskto

● DEM-based

Area: (888 - 133910)

Number of cells: 27702

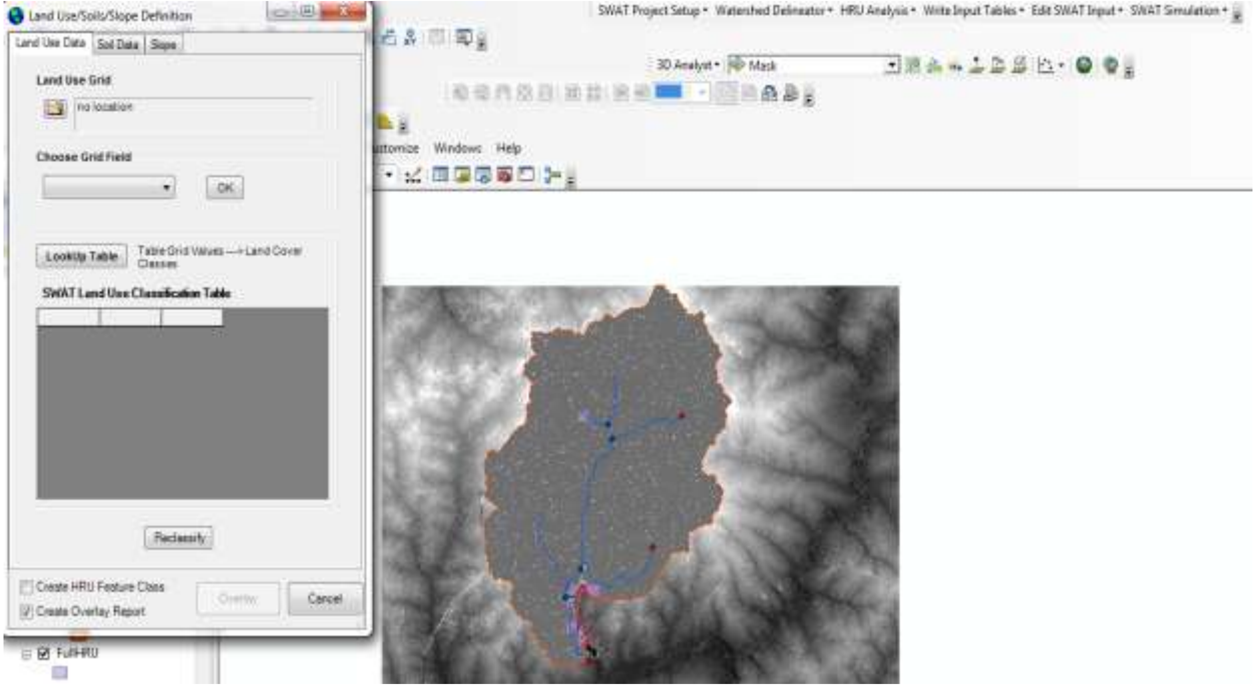
● Subbasin outlet

Watershed delineation is done.

Number of Outlets: 10

Number of Subbasins: 10

Figure A2: The Automatic Watershed Delineation Procedure Completed

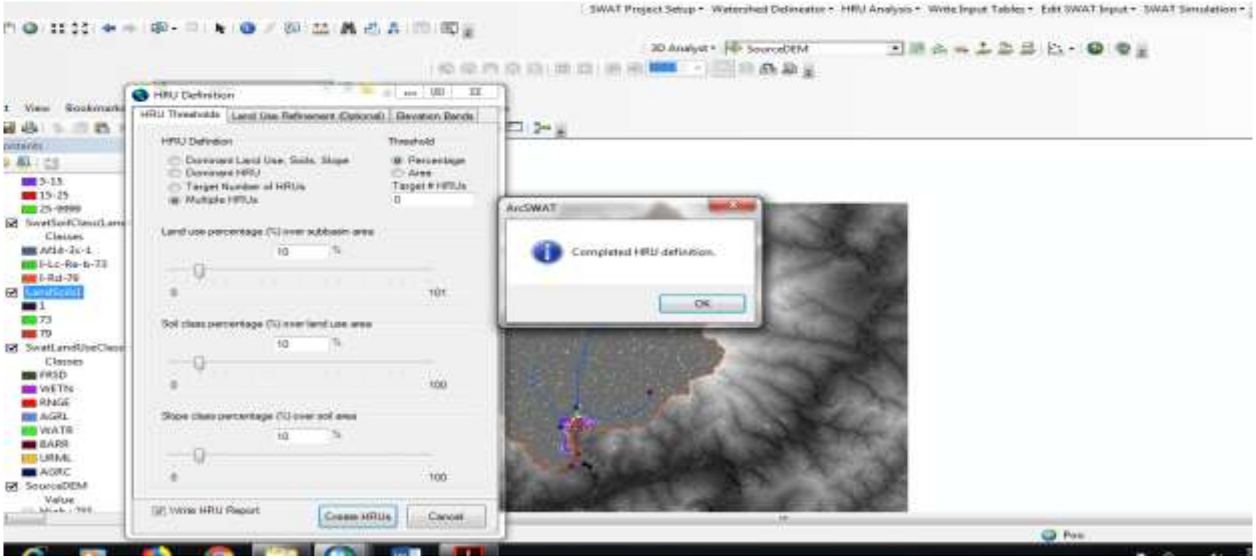


Land Use Grid: no location

☐ Create HRU Feature Class

☑ Create Overlay Report

Figure A3: The Hydrological Response Unit (HRUs) Procedure.



HRU Definition
○ Dominant Land Use, Soils, Slope
○ Dominant HRU
○ Target Number of HRUs
● Multiple HRUs

Threshold
● Percentage
○ Area

Target # HRUs: 0

Land use percentage (%) over subbasin area: 10 %

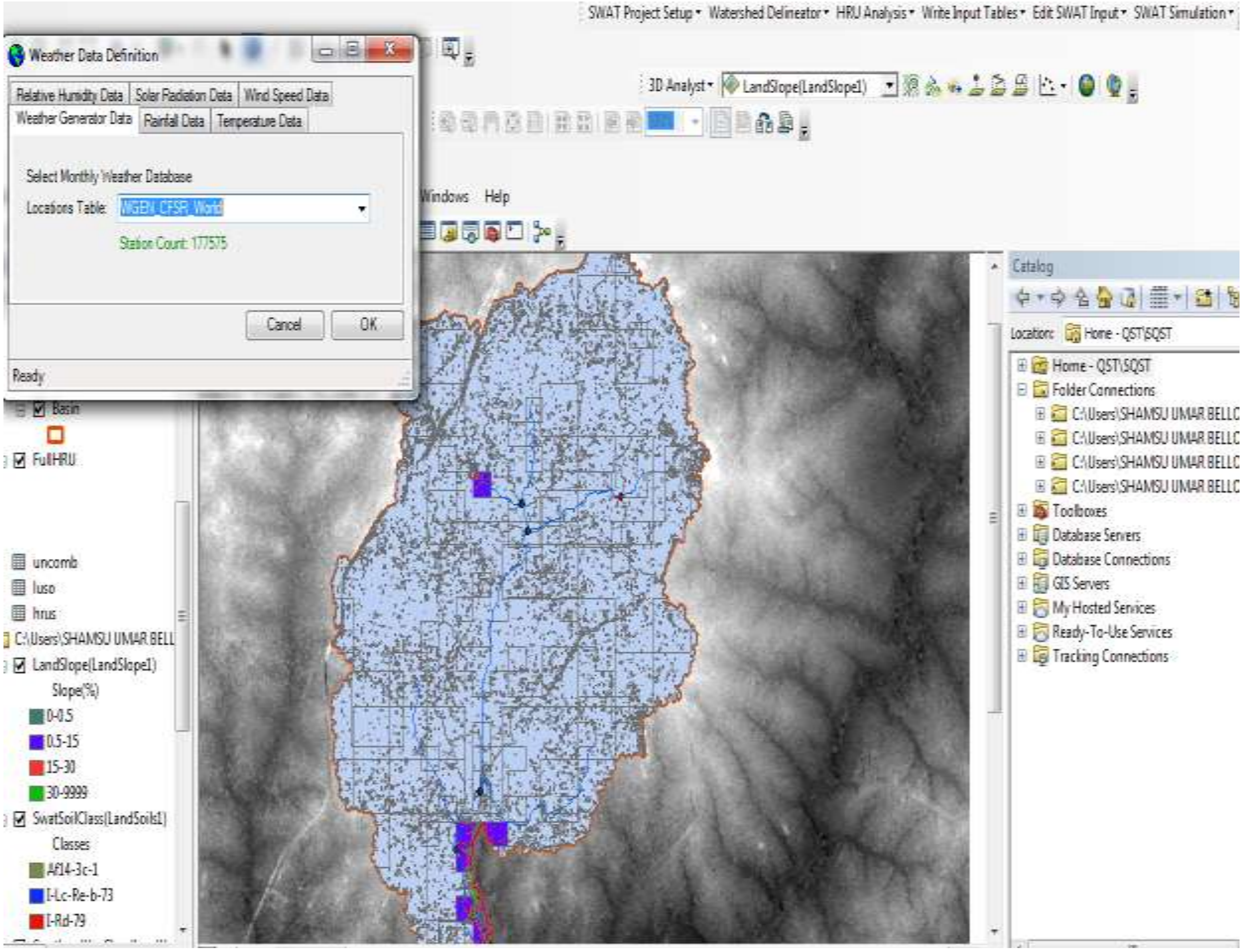
Soil class percentage (%) over land use area: 10 %

Slope class percentage (%) over soil area: 10 %

☑ Write HRU Report

Completed HRU definition.

Figure A4: Complete HRU Definition



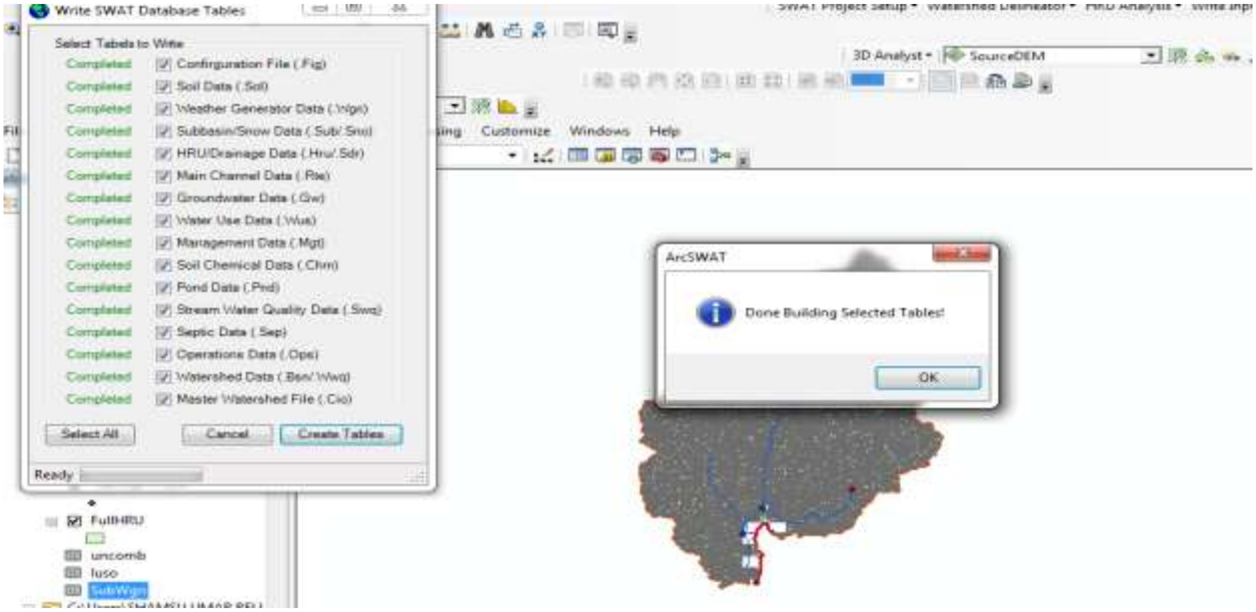
Select Monthly Weather Database

Locations Table: WGEN_CFSR_World

Station Count: 177575

Ready

Figure A5: Weather data definition procedure



Write SWAT Database Tables

Select Tabels to Write

Completed ☑ Configuration File (.Fig)
Completed ☑ Soil Data (.Sol)
Completed ☑ Weather Generator Data (.Wgn)
Completed ☑ Subbasin/Snow Data (.Sub/.Sno)
Completed ☑ HRU/Drainage Data (.Hru/.Sdr)
Completed ☑ Main Channel Data (.Rte)
Completed ☑ Groundwater Data (.Gw)
Completed ☑ Water Use Data (.Wus)
Completed ☑ Management Data (.Mgt)
Completed ☑ Soil Chemical Data (.Chm)
Completed ☑ Pond Data (.Pnd)
Completed ☑ Stream Water Quality Data (.Swq)
Completed ☑ Septic Data (.Sep)
Completed ☑ Operations Data (.Ops)
Completed ☑ Watershed Data (.Bsn/.Wwq)
Completed ☑ Master Watershed File (.Cio)

Select All | Cancel | Create Tables

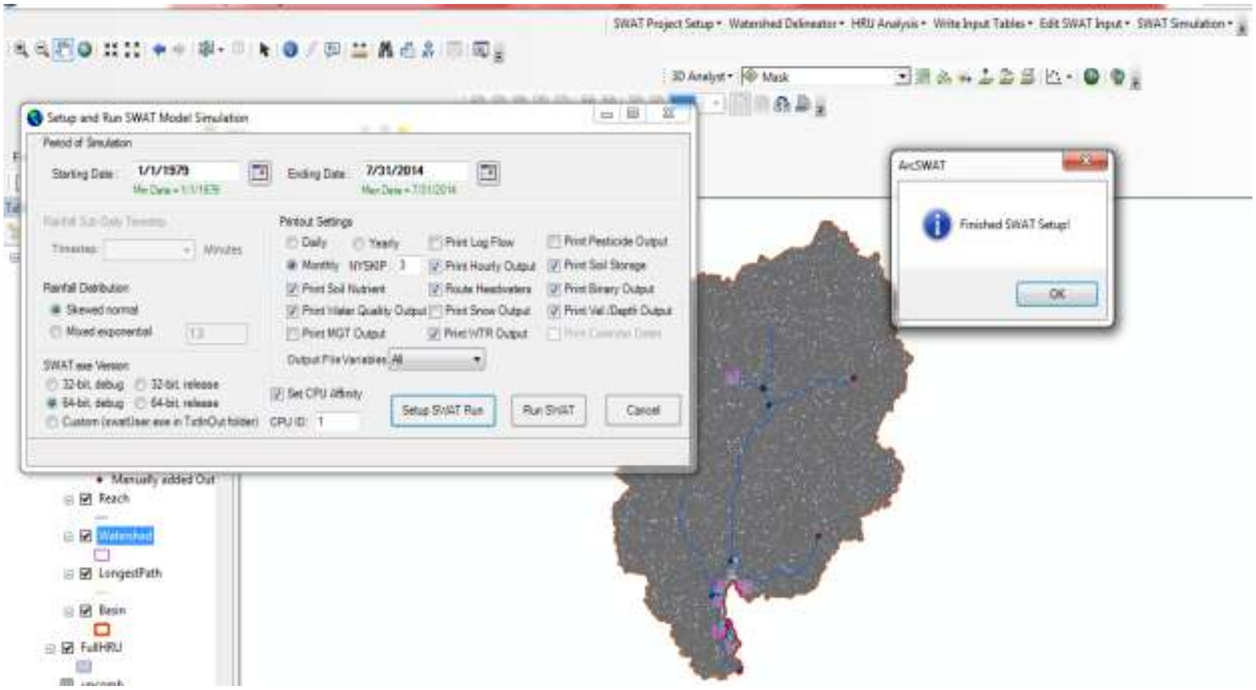
Ready

ArcSWAT

Done Building Selected Tables!

OK

Figure A6: Done writing selected tables



Setup and Run SWAT Model Simulation

Period of Simulation

Starting Date: 1/1/1979 Min Date = 1/1/1979

Ending Date: 7/31/2014 Max Date = 7/31/2014

Rainfall Sub-Daily Timestep

Timestep: Minutes

Rainfall Distribution

● Skewed normal
○ Mixed exponential 1.3

SWAT.exe Version

○ 32-bit, debug ○ 32-bit, release
● 64-bit, debug ○ 64-bit, release
○ Custom (swatUser.exe in TxtInOut folder)

Printout Settings

○ Daily ○ Yearly ☐ Print Log Flow ☐ Print Pesticide Output
● Monthly NYSKIP 3 ☑ Print Hourly Output ☑ Print Soil Storage
☑ Print Soil Nutrient ☑ Route Headwaters ☑ Print Binary Output
☑ Print Water Quality Output ☐ Print Snow Output ☑ Print Vel./Depth Output
☐ Print MGT Output ☑ Print WTR Output ☐ Print Calendar Dates

Output File Variables All

☑ Set CPU Affinity

CPU ID: 1

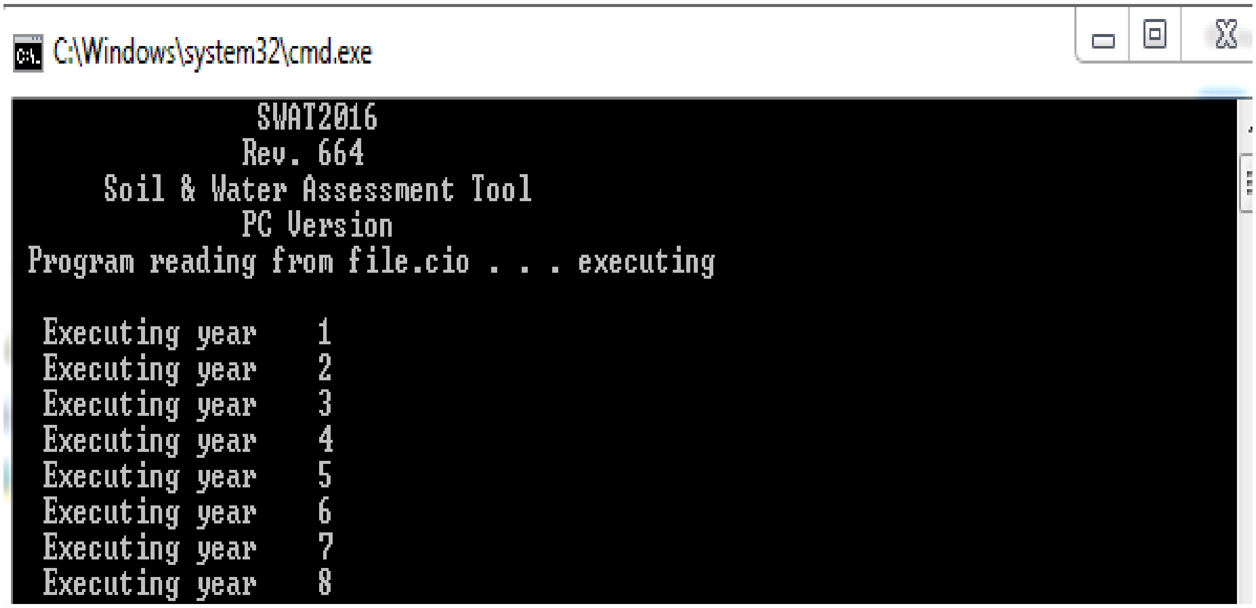
Setup SWAT Run | Run SWAT | Cancel

ArcSWAT

Finished SWAT Setup!

OK

Figure A7: Setup SWAT Run procedure



```
                 SWAT2016
                Rev. 664
      Soil & Water Assessment Tool
                PC Version
Program reading from file.cio . . . executing

 Executing year    1
 Executing year    2
 Executing year    3
 Executing year    4
 Executing year    5
 Executing year    6
 Executing year    7
 Executing year    8
```

Figure A8: SWAT Execution stage

Period of Simulation

Starting Date: 1/1/1980   Ending Date: 1/1/1990

SWAT run successful.

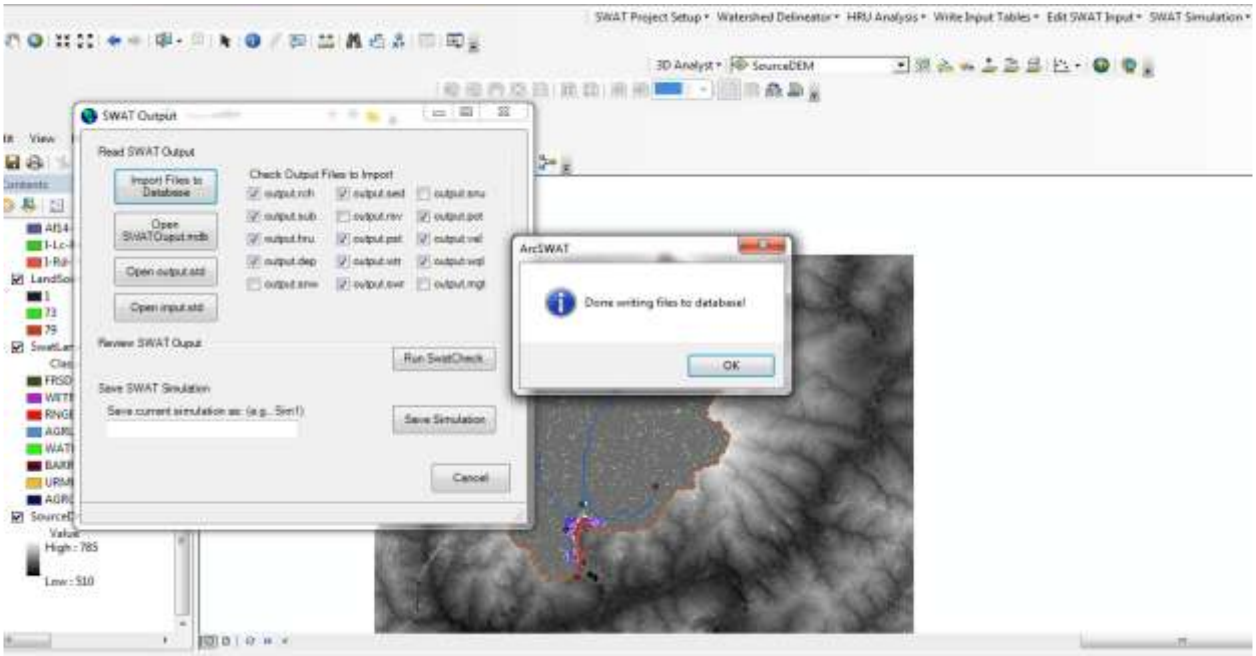
Rainfall Distribution
- ● Skewed normal
- ○ Mixed exponential   1.3

SWAT.exe Version
- ○ 32-bit, debug   ○ 32-bit, release
- ● 64-bit, debug   ○ 64-bit, release
- ○ Custom (swatUser.exe in TxtInOut folder)

☑ Set CPU Affinity   CPU ID: 1

- Log Flow
- Hourly Output
- Headwaters
- Snow Output
- WTR Output
- ☐ Print Pesticide Output
- ☑ Print Soil Storage
- ☑ Print Binary Output
- ☑ Print Vel./Depth Output
- ☐ Print Calendar Dates

Figure A9: SWAT run completed



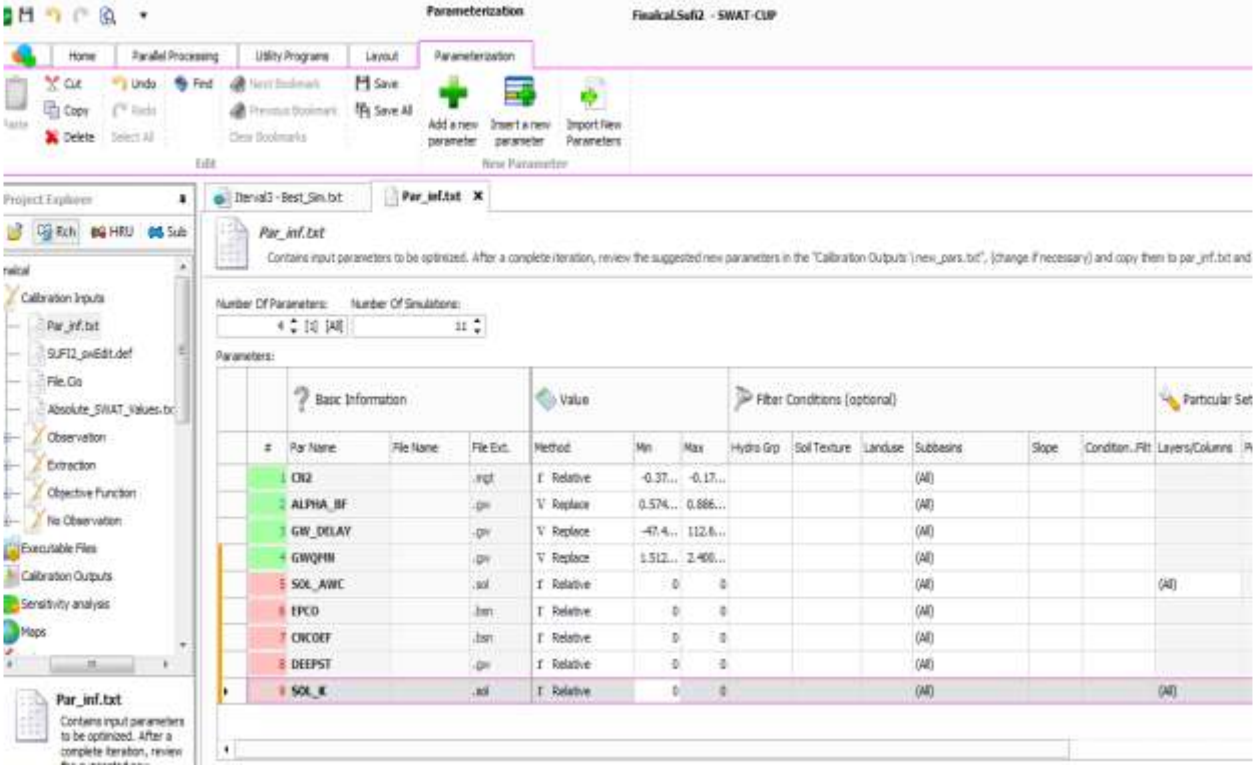
Check Output Files to Import

☑ output.rch ☑ output.sed ☐ output.snu
☑ output.sub ☐ output.rsv ☑ output.pst
☑ output.hru ☑ output.pst ☑ output.vel
☑ output.dep ☑ output.wtr ☑ output.wql
☐ output.snw ☑ output.swr ☐ output.mgt

Save current simulation as: (e.g., Sim1)

Done writing files to database!

Figure A10: Done writing output to database stage



Par_inf.txt

Contains input parameters to be optimized. After a complete iteration, review the suggested new parameters in the "Calibration Outputs \new_pars.txt", (change if necessary) and copy them to par_inf.txt and

Number Of Parameters: 4 [All]

Number Of Simulations: 11

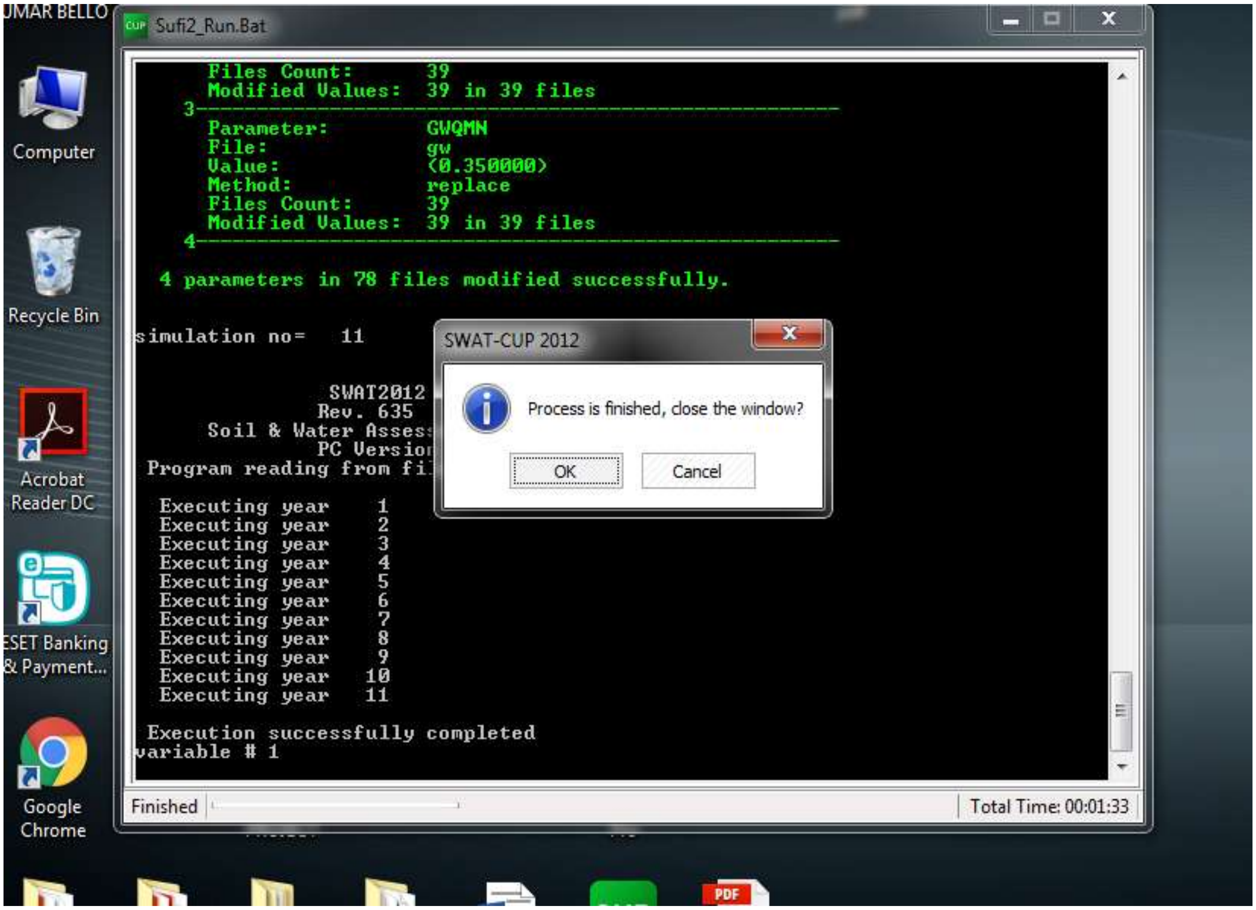
Parameters:

	Basic Information			Value			Filter Conditions (optional)						Particular Set
#	Par Name	File Name	File Ext.	Method	Min	Max	Hydro Grp	Soil Texture	Landuse	Subbasins	Slope	Condition..Fit	Layers/Columns
1	CN2		.mgt	r Relative	-0.37...	-0.17...				(All)			
2	ALPHA_BF		.gw	V Replace	0.574...	0.886...				(All)			
3	GW_DELAY		.gw	V Replace	-47.4...	112.6...				(All)			
4	GWQMN		.gw	V Replace	1.512...	2.400...				(All)			
5	SOL_AWC		.sol	r Relative	0	0				(All)			(All)
6	EPCO		.bsn	r Relative	0	0				(All)			
7	CNCOEF		.bsn	r Relative	0	0				(All)			
8	DEEPST		.gw	r Relative	0	0				(All)			
9	SOL_K		.sol	r Relative	0	0				(All)			(All)

Par_inf.txt

Contains input parameters to be optimized. After a complete iteration, review

Figure A11: SWATCUP Parameterization procedure



```
     Files Count:       39
     Modified Values:   39 in 39 files
   3-----------------------------------------------------------
     Parameter:         GWQMN
     File:              gw
     Value:             <0.350000>
     Method:            replace
     Files Count:       39
     Modified Values:   39 in 39 files
   4-----------------------------------------------------------

  4 parameters in 78 files modified successfully.


simulation no=   11


               SWAT2012
              Rev. 635
     Soil & Water Assess
              PC Versio
 Program reading from fi

  Executing year     1
  Executing year     2
  Executing year     3
  Executing year     4
  Executing year     5
  Executing year     6
  Executing year     7
  Executing year     8
  Executing year     9
  Executing year    10
  Executing year    11

 Execution successfully completed
variable # 1
```

Process is finished, close the window?

Figure A12: SWATCUP Execution Stage for Calibration period

Global sensitivity analysis can be performed after an iteration.

This section of the program performs sensitivity analysis.

Figure A13: Sensitivity Analysis Interface

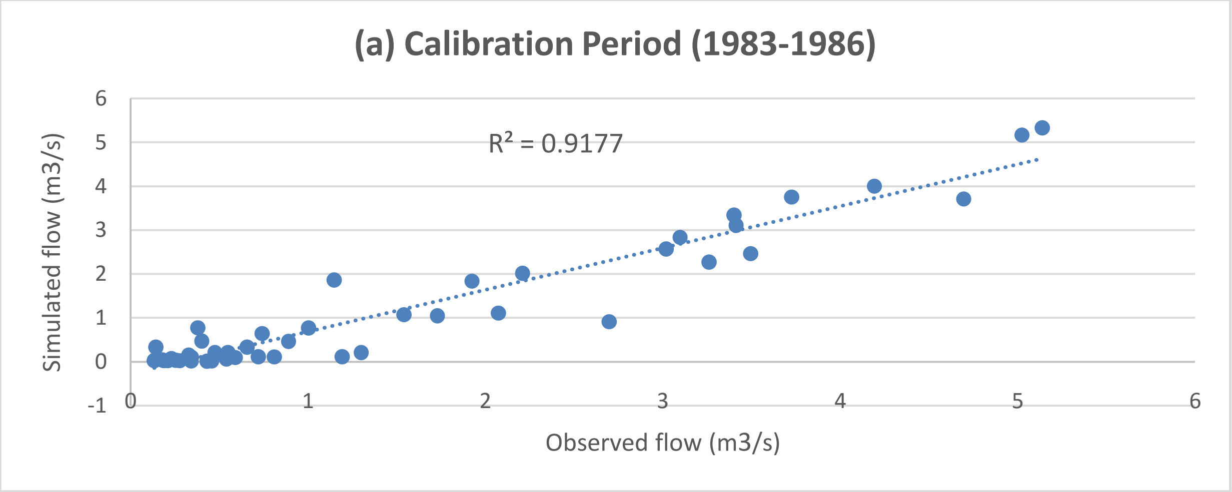


Figure A14: Monthly observed and simulated outflow for the calibration period

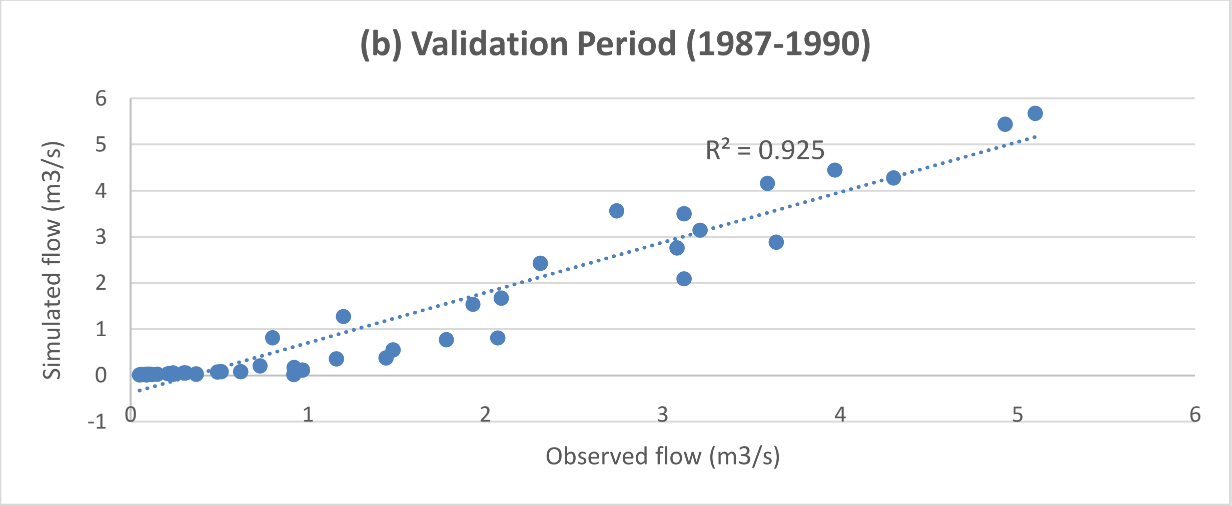


Figure A15: Monthly observed and simulated outflow for the validation period.

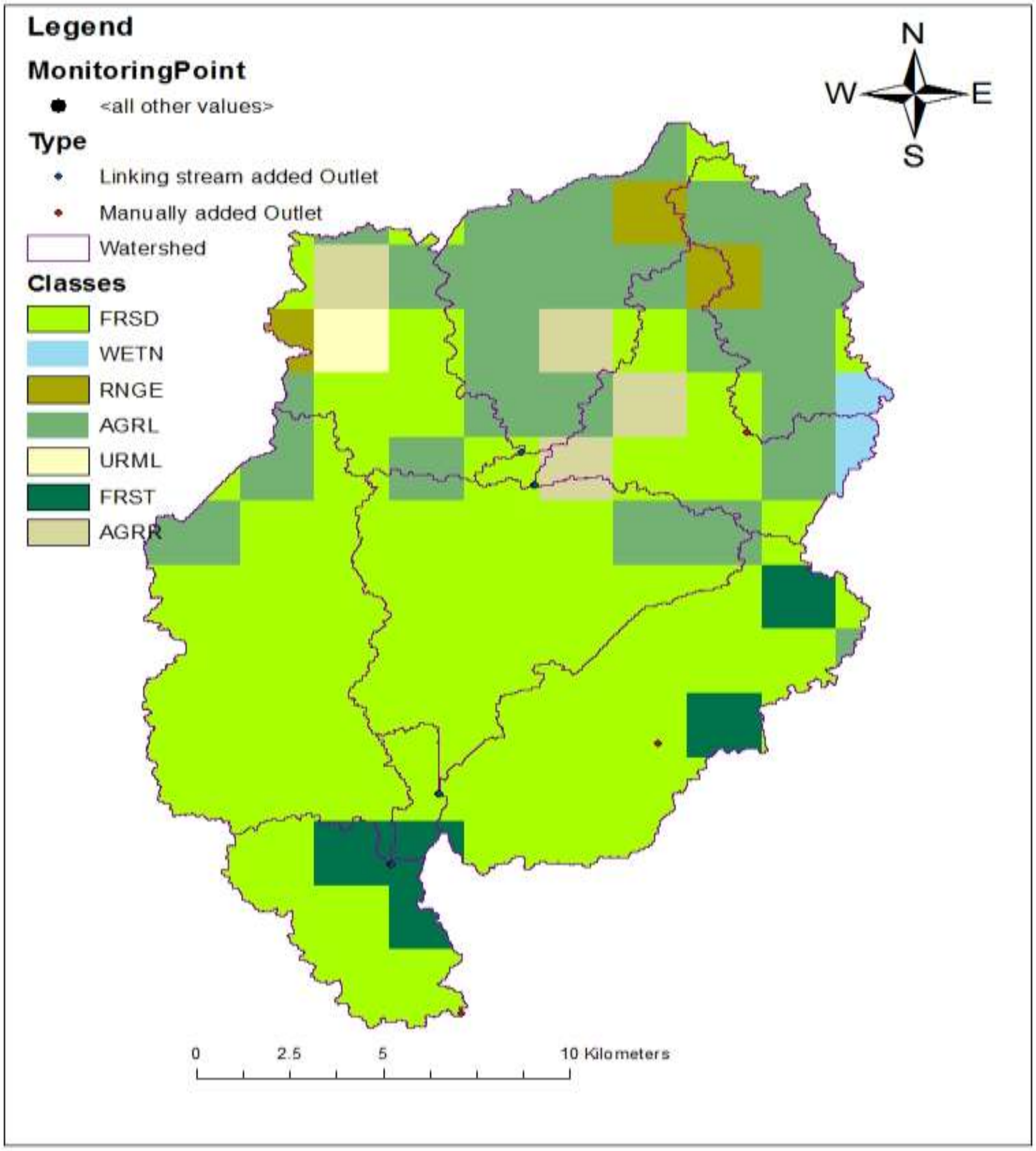


Figure A16: Delineated land use land cover1975

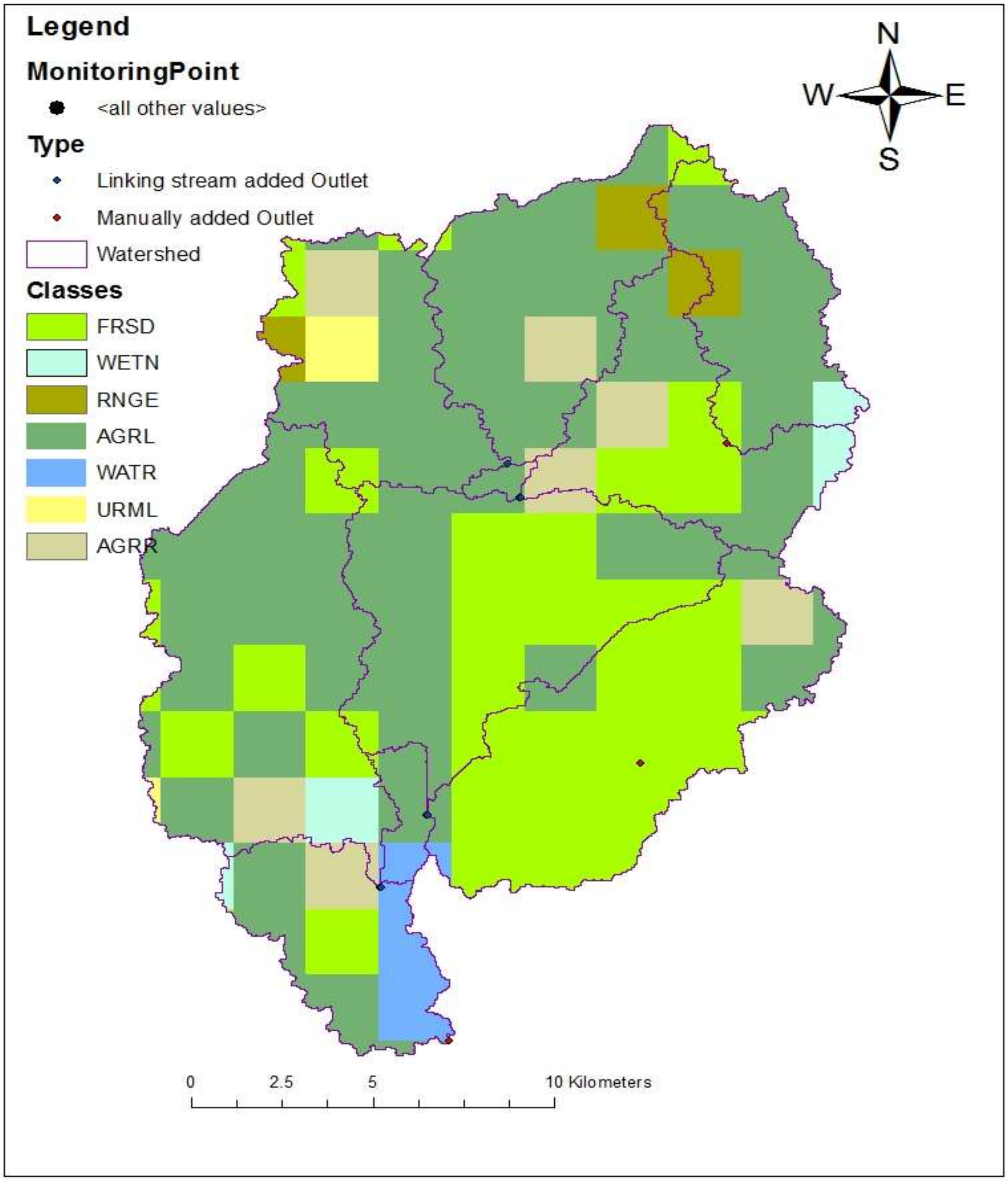


Figure A17: Delineated land use land cover 2000

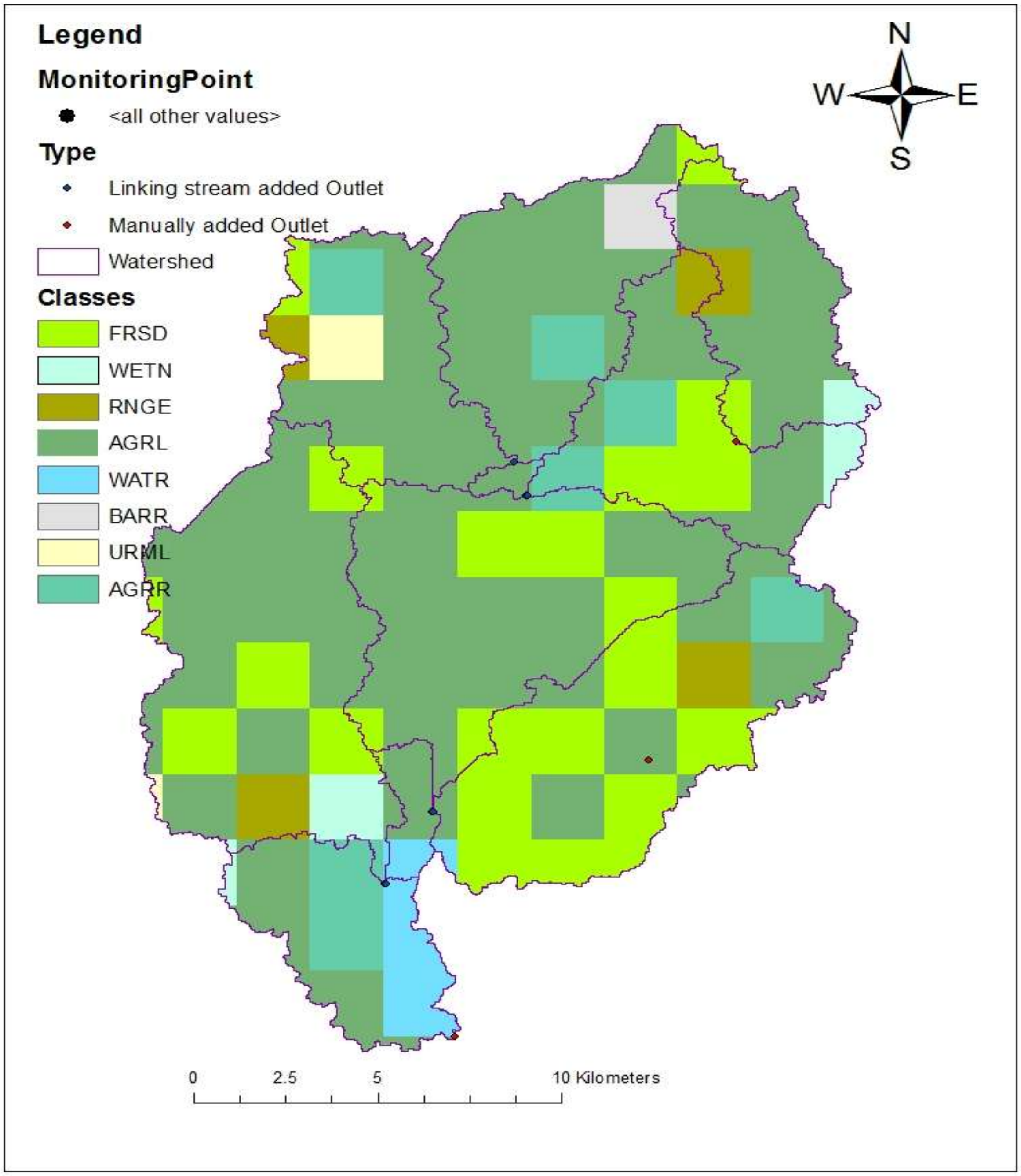


Figure A18: Delineated land use land cover 2013

Best Simulated Values for Calibration period in SWATCUP

FLOW_OUT_1

ID	FLOW OUT SERIES	observed	simulated
1	FLOW_OUT_1_1983	0.548	0.2138
2	FLOW_OUT_2_1983	0.72	0.1131
3	FLOW_OUT_3_1983	0.23	0.0613
4	FLOW_OUT_4_1983	0.254	0.0367
5	FLOW_OUT_5_1983	0.277	0.0244
6	FLOW_OUT_6_1983	0.457	0.0191
7	FLOW_OUT_7_1983	1.729	1.046
8	FLOW_OUT_8_1983	3.495	2.465
9	FLOW_OUT_9_1983	4.696	3.71
10	FLOW_OUT_10_1983	1.147	1.864
11	FLOW_OUT_11_1983	0.379	0.7758
12	FLOW_OUT_12_1983	0.142	0.3345
13	FLOW_OUT_1_1984	0.327	0.1507
14	FLOW_OUT_2_1984	0.23	0.0748
15	FLOW_OUT_3_1984	0.178	0.0408
16	FLOW_OUT_4_1984	0.133	0.0243
17	FLOW_OUT_5_1984	1.192	0.1143
18	FLOW_OUT_6_1984	0.741	0.6439
19	FLOW_OUT_7_1984	3.413	3.109
20	FLOW_OUT_8_1984	3.26	2.274
21	FLOW_OUT_9_1984	2.209	2.015
22	FLOW_OUT_10_1984	2.073	1.11
23	FLOW_OUT_11_1984	0.401	0.474
24	FLOW_OUT_12_1984	1.3	0.2087
25	FLOW_OUT_1_1985	0.59	0.0967
26	FLOW_OUT_2_1985	0.34	0.052
27	FLOW_OUT_3_1985	0.21	0.0286
28	FLOW_OUT_4_1985	0.342	0.0176
29	FLOW_OUT_5_1985	0.43	0.0119
30	FLOW_OUT_6_1985	2.697	0.9135
31	FLOW_OUT_7_1985	3.726	3.755
32	FLOW_OUT_8_1985	5.024	5.168
33	FLOW_OUT_9_1985	5.139	5.333
34	FLOW_OUT_10_1985	3.019	2.571
35	FLOW_OUT_11_1985	1.541	1.074
36	FLOW_OUT_12_1985	0.89	0.4653
37	FLOW_OUT_1_1986	0.475	0.2109
38	FLOW_OUT_2_1986	0.81	0.1109
39	FLOW_OUT_3_1986	0.54	0.0594
40	FLOW_OUT_4_1986	0.135	0.0351
41	FLOW_OUT_5_1986	0.19	0.0236
42	FLOW_OUT_6_1986	0.343	0.1031
43	FLOW_OUT_7_1986	4.192	4.003
44	FLOW_OUT_8_1986	3.097	2.836
45	FLOW_OUT_9_1986	3.401	3.344
46	FLOW_OUT_10_1986	1.924	1.839
47	FLOW_OUT_11_1986	1.003	0.7695
48	FLOW_OUT_12_1986	0.656	0.3353

Best Simulated Values for Validation period in SWATCUP

```
FLOW_OUT_1
ID   FLOW OUT SERIES    observed    simulated
1 FLOW_OUT_1_1987       0.62        0.0821
2 FLOW_OUT_2_1987       0.3         0.0532
3 FLOW_OUT_3_1987       0.21        0.036
4 FLOW_OUT_4_1987       0.1         0.0257
5 FLOW_OUT_5_1987       0.12        0.0194
6 FLOW_OUT_6_1987       0.057       0.0167
7 FLOW_OUT_7_1987       1.2         1.275
8 FLOW_OUT_8_1987       3.08        2.76
9 FLOW_OUT_9_1987       3.59        4.162
10 FLOW_OUT_10_1987     2.09        1.673
11 FLOW_OUT_11_1987     1.44        0.3763
12 FLOW_OUT_12_1987     0.97        0.1159
13 FLOW_OUT_1_1988      0.31        0.0537
14 FLOW_OUT_2_1988      0.37        0.0332
15 FLOW_OUT_3_1988      0.11        0.023
16 FLOW_OUT_4_1988      0.92        0.0167
17 FLOW_OUT_5_1988      0.37        0.0202
18 FLOW_OUT_6_1988      0.8         0.8138
19 FLOW_OUT_7_1988      3.21        3.145
20 FLOW_OUT_8_1988      3.64        2.884
21 FLOW_OUT_9_1988      3.12        2.093
22 FLOW_OUT_10_1988     2.07        0.8111
23 FLOW_OUT_11_1988     0.73        0.2049
24 FLOW_OUT_12_1988     0.49        0.0722
25 FLOW_OUT_1_1989      0.22        0.0373
26 FLOW_OUT_2_1989      0.15        0.0252
27 FLOW_OUT_3_1989      0.07        0.0172
28 FLOW_OUT_4_1989      0.05        0.0126
29 FLOW_OUT_5_1989      0.09        0.0095
30 FLOW_OUT_6_1989      1.78        0.7711
31 FLOW_OUT_7_1989      3.97        4.448
32 FLOW_OUT_8_1989      4.93        5.441
33 FLOW_OUT_9_1989      5.1         5.678
34 FLOW_OUT_10_1989     2.31        2.426
35 FLOW_OUT_11_1989     1.48        0.5514
36 FLOW_OUT_12_1989     0.922       0.172
37 FLOW_OUT_1_1990      0.51        0.0808
38 FLOW_OUT_2_1990      0.24        0.053
39 FLOW_OUT_3_1990      0.24        0.0357
40 FLOW_OUT_4_1990      0.09        0.0254
41 FLOW_OUT_5_1990      0.082       0.0195
42 FLOW_OUT_6_1990      0.24        0.0223
43 FLOW_OUT_7_1990      4.301       4.278
44 FLOW_OUT_8_1990      2.74        3.562
45 FLOW_OUT_9_1990      3.12        3.503
46 FLOW_OUT_10_1990     1.93        1.539
47 FLOW_OUT_11_1990     1.16        0.3579
48 FLOW_OUT_12_1990     0.94        0.1176
```