***MODELLING IMPACTS OF CLIMATE VARIABILITY AND LAND USE CHANGE ON WATER BALANCE IN THE HADEJIA RIVER BASIN, NORTHERN NIGERIA***

**UMAR DA'U ABBA**

**FPAS 2020 2**

# MODELLING IMPACTS OF CLIMATE VARIABILITY AND LAND USE CHANGE ON WATER BALANCE IN THE HADEJIA RIVER BASIN, NORTHERN NIGERIA

By

**UMAR DA'U ABBA**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

**October 2019**

# DEDICATION

This thesis is dedicated to my Parent;

Alh. Abba Umar and Haj. Maryam Sulaiman

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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**Chairman : Associate Professor Mohammad Firuz Ramli, PhD**
**Faculty : Environmental Studies**

Hadejia River Basin (HRB) is located in the semi-arid region of northern Nigeria. The total area of the basin is about 24,896 $km^2$ with about 60% of the population engaged in agricultural activities. Other socioeconomic activities are fishing, grazing, and recreation. Almost all the operational activities are climate dependent and sensitive, therefore any change/variation in climate or factors that may aggravate its impacts such as land use change in the basin might have consequential impacts on the water balance and socioeconomic lives of the people of the area estimated at about 15 million inhabitants. This river basin has attracted several studies, however, none of these studies investigated the impact of climate variability and land use change on the water balance of the basin using any hydrological model such as SWAT. Modelling the impacts of future climate and land use change on water balance in the Hadejia River Basin (HRB) was achieved through the following objectives; (i) examining the trends of precipitation and temperature under the recent climate change (ii) determining the presence of trends and variations in the river discharge (iii) predicting the pattern of land use changes based on the past few decades, and (iv) evaluating current and project the impacts of climate variability and land use change on the water balance of HRB. The methods and techniques used to achieve the stated objectives include multivariate statistical analysis such as ANOVA, cluster analysis, multiple linear regression, Mann-Kendall (MK) and Modified Mann-Kendall (MMK) both of which were used for trend and variations analysis. Others were remote sensing, GIS, CA–Markov model for land use change classification, simulation, and prediction. Furthermore, the future impact of climate and land use/cover changes were evaluated using an integrated approach, combining the climate (GCMs), hydrological (SWAT) and the land use prediction (CA–Markov) models. The results showed increased warming with noticeable moisture improvement that is relatively uniform over the entire landscape (1980-2015). Land use analysis indicates a drastic transformation of forest to non-forest land uses, with the construction land uses being the most expanding land use type with percentage changes of 0.50%, 1.95%, 5.31% in 1990, 2000 and 2016 and 7.8% for the projected period (2032). The calibration and validation of the SWAT result was both acceptable with Nash-Sutcliffe (NS) = 0.72 and 0.63, indicating good performance and robustness of the model. For the future simulations (2020-2040) executed in two different scenarios (1st and 2nd). The results show a decline in average annual precipitation (23.4%), runoff (2.1%), baseflow (3.7%), streamflow (20.4%) and potential evapotranspiration (PET) (0.82%) in the first scenario. While, in the second scenario surface runoff rise by 12.6% but yet water yield declined by 27.2%, suggesting the influence of land use change on surface runoff. On the whole, the basin shows a high sensitivity to climate variations than to the changing land use. Despite this reality, attention should be given to climate and land use issues/problems in the basin, before it gets out of hand. Immediate action should be taken right away on the later the fact that it is logically within human control/ability, unlike climate.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**MODEL KESAN PERUBAHAN IKLIM DAN PENGGUNAAN TANAH TERHADAP PERUBAHAN KESEIMBANGAN AIR DI LEMBAH SUNGAI HADEJIA, UTARA NIGERIA**

Oleh

**UMAR DA'U ABBA**

**Oktober 2019**

**Pengerusi : Profesor Madya Mohammad Firuz Ramli, PhD**
**Fakulti : Pengajian Alam Sekitar**

Lembah Sungai Hadejia (LSH) terletak di dalam daerah separa gersang di utara Nigeria. Jumlah keseluruhan kawasan lembah ini adalah sekitar 24,896 km$^2$ dengan terdapat 60% penduduk yang terlibat di dalam kegiatan pertanian. Aktiviti sosioekonomi lain di lembah ini adalah seperti menangkap ikan, ternakan dan rekreasi. Hampir kesemua aktiviti yang beroperasi ini bergantung dan sensitif terhadap iklim. Oleh yang demikian sebarang perubahan iklim atau faktor-faktor yang boleh memberikan kesan negatif seperti perubahan penggunaan tanah di lembah ini pada akhirnya memberi kesan terhadap kesaimbangan air dan kehidupan sosioekonomi penduduk di lembah ini yang dianggarkan berjumlah sekitar 15 juta orang. Lembah sungai ini telah menarik minat beberapa kajian, namun, tiada di antara kajian ini yang meneroka kesan penggunaan tanah dan perubahan iklim terhadap kesaimbangan air di lembah ini dengan menggunakan model hidrologikal seperti SWAT. Model kesan perubahan penggunaan tanah dan perubahan iklim bagi masa hadapan ke atas kesaimbangan air di Lembah Sungai Hadejia (LSH) diperoleh melalui objektif berikut: (i) memeriksa corak pemendakan dan suhu terhadap perubahan iklim terkini (ii) mendapatkan corak dan kepelbagaian di dalam aliran air sungai (iii) meramalkan corak perubahan penggunaan tanah berdasarkan beberapa dekad yang lalu, dan (iv) menilai arus dan mengunjurkan kesan perubahan iklim dan perubahan penggunaan tanah terhadap kesaimbangan air di LSH. Teknik dan kaedah yang digunakan bagi memperoleh objektif kajian termasuk analisis statistik multivariat seperti ANOVA, analisis cluster, regresi linear pelbagai, Mann-Kendall (MK) dan Modified Mann-Kendall (MMK), dimana kedua-duanya digunakan bagi menganalisasi corak dan perubahan. Selain daripada itu adalah kawalan sensing, GIS, model CA-Markov bagi klasifikasi perubahan penggunaan tanah, simulasi dan ramalan. Selain itu kesan kepada perubahan iklim dan perubahan penggunaan tanah seterusnya dinilai dengan menggunakan pendekatan integrasi, menyatukan iklim (GCMs), hiderologikal (SWAT) dan model ramalan penggunaan tanah (CA-Markov). Hasil kajian menunjukkan terdapat peningkatan pemanasan dengan peningkatan kelembapan yang relatif seragam di keseluruhan landskap (1980-2015). Dapatan kajian juga menunjukkan terdapat penambahan kepanasan dengan penambahbaikan kelembapan yang ketara dan seragam bagi keseluruhan landskap. Analisis penggunaan tanah menunjukkan transformasi drastik hutan kepada penggunaan bukan kehutanan, dengan kegunaan tanah yang berkembang bagi tujuan pembinaan dengan peratus perubahan 0.50%, 1.95%, 5.31% dalam tahun 1990, 2000 dan 2016 dan 7.8% bagi tempoh yang diunjurkan (2032). Penentukuran dan pengesahan dapatan SWAT diterima dengan Nash-Sutcliffe (NS) = 0.72 dan 0.63, menunjukkan prestasi yang baik dan keteguhan model tersebut. Bagi simulasi masa hadapan (2020-2040) dilaksanakan di dalam dua senario yang berbeza (Pertama dan Kedua). Dapatan menunjukkan terdapat penurunan pemendakan tahunan (23.4%), runoff (2.1%), aliran asas (3.7%), aliran sungai (20.4%) dan potensi evapotranspirasi (PET) (0.82%) di dalam senario pertama. Di dalam senario kedua permukaan aliran air meningkat 12.6% tetapi penghasilan air menurun 27.2%, yang mencadangkan pengaruh penggunaan tanah di permukaan runoff. Secara keseluruhan lembah ini menujukkan sensitiviti yang tinggi terhadap perubahan iklim berbanding perubahan penggunaan tanah. Walaupun dengan realiti ini, perhatian patut diberi kepada kedua-dua iklim dan isu/masalah penggunaan tanah di lembah ini. Tindakan segera perlu diambil kepada penggunaan tanah kerana secara logiknya ia adalah di dalam kawalan manusia berbanding iklim.

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This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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This is to confirm that:

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| | |
|---|---|
| AET | Actual Evapotranspiration |
| AGNPS | Agriculture Non-point Source |
| ANOVA | Analysis of Variance |
| AR4 | Fourth Assessment Report |
| BASIN | Better Assessment Science Integrating Point and Nonpoint Sources |
| CA | Cellular Automata |
| CACTCHMOD | Conceptual Water Balance Model |
| CAT | Climate Assessment Tool |
| CCCma | Met Office Hadley Centre, UK |
| CLUE | Conversion of Land Use and its Effects |
| CMIP5 | Coupled Model Intercomparison Project 5 |
| CN | Curve Number |
| CNRM | National Centre for Meteorological Research, France |
| CORDEX | Coordinated Regional Downscaling Experiment |
| ColSim | Columbia Simulation Reserve Model |
| CRU | Climate Research Unit, University of East Anglia, UK |
| CSW | Copper Slough Watershed |
| CV | Coefficient of Variation |
| DEM | Digital Elevation Model |
| DSM | Demand Side Management |
| EDA | Exploratory Data Analysis |
| ET | Evapotranspiration |
| FAO | Food and Agricultural Organization |
| GCM | General Circulation Model |
| GHG | Greenhouse Gases |
| GIS | Geographical Information Systems |

| | |
|---|---|
| GLUE | Generalized Likelihood Uncertainty Estimation |
| GPS | Global Positioning Satellite |
| HBV | Hydrologiska Byrans Vattenavdelning |
| HEC-HMS | Hydrologic Engineering Center-Hydrologic Modelling System |
| HEC-RAS | Hydrologic Engineering Center–River Analysis System |
| HJKYB | Hadejia Jama’are Komadugu Yobe Basin |
| HRB | Hadejia River Basin |
| HRU | Hydrologic Response Unit |
| HSPF | Hydrological Simulation Program-FORTRAN |
| IDW | Inverse Distance Weightage |
| IPCC | Intergovernmental Panel on Climate Change |
| ITCZ | Inter-Tropical Convergence Zone |
| KW | Kinetic Wave |
| LCLC | Land use Land Cover |
| LTM | Land Transformation Model |
| LSR | Least Square Regression |
| MCMC | Markov Chain Monte Carlo |
| MIKE-SHE | Systeme Hydrologique European |
| MMK | Modified Mann-Kendall |
| MK | Mann-Kendall |
| NASA | National Aeronautics and Space Administration, United States |
| NCC | Norwegian Climate Centre, Norway |
| NIMET | Nigerian Meteorological Agency |
| NPC | National Population Commission, Nigeria |
| NRCS | U.S. Natural Resource Conservation Service |
| NRW | Non-Revenue Water |
| PET | Potential Evapotranspiration |
| PCA | Principle Component Analysis |

| | |
|---|---|
| PD | Probability Distribution |
| PRMS | Precipitation Runoff Modelling System |
| RCM | Regional Climate Models |
| RCP | Representative Concentration Pathways |
| RS | Remote Sensing |
| SCS | "Soil Conservation Service" |
| SD | "Statistical Downscaling" |
| SRES | "Special Report on Emission Scenarios" |
| SRTM | "Shuttle Radar Topography Mission" |
| SUFI | "Sequential Uncertainty Fitting" |
| SWAT | "Soil and Water Assessment Tool" |
| TETFUND | Tertiary Education Trust Fund |
| TM | Thematic Mapper |
| TMIN | Minimum Temperature |
| TMAX | Maximum Temperature |
| TMEAN | Mean Temperature |
| TOPMODEL | Topography Based Hydrological Model |
| UBA | University of British Columbia |
| UNFCCC | United Nations Framework Convention on Climate Change |
| UPM | Universiti Putra Malaysia |
| USA | United State of America |
| WA | West Africa |
| WEAP | Water Evaluation and Planning System |
| WMO | World Meteorological Organization |
| WRCP | World Climate Research Program |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Global proliferation in the standard of living, economic and agricultural development has resulted in increasing demand and dependency on water resources (Elsanabary and Gan, 2015; Kusangaya et al., 2014). To this effect, many countries and regions (such as India and Singapore in Asia; Israel, Saudi Arabia and Jordan in the Middle East; Libya in the North Africa and Eritrea in sub-Saharan Africa) have experienced water scarcity and many others are projected to face water stress in the foreseeable future (Faramarzi et al., 2013; Pachauri et al., 2014). This threat is expected to be more devastating in arid and semi-arid regions, where climate variability and changing land use, associated with increased population, desertification, food insecurity and increased irrigation have posed additional challenges (Mwangi et al., 2016; Yang et al., 2019). Consequently, there is an increasing concern from across the world, particularly among researchers on the occurrence and impacts of climate change and the associated anthropogenic causes of the change most of which are attributed to the increased human population (Li et al., 2016). Thus, the recent change in climate is generally being credited to the warming of the earth as a consequence of the increased the concentration of greenhouse gases (GHG) in the atmosphere (Chen et al., 2014) which in one way or the other is linked to anthropogenic sources.

Climate change has been succinctly defined by the Intergovernmental Panel on Climate Change as "any change in the state of the climate that is distinguishable using statistical test(s) such as the mean, standard deviation and coefficient of variation or the unpredictability of its properties which continue for a prolonged period" (Cisneros et al., 2014).

This change in climate can be due to natural variability or as a consequence of anthropogenic activities such as land use changes. The effect of climate change and variability alone has been projected to cause water stress to several billion people by 2030 across the world, especially those relying on various rivers for their water supply (Annex, 2013; Amisigo et al., 2015).

However, besides the effect of climate change and variability, it is recently understood that human activities particularly land use change further worsen the situation (Wuebbles et al., 2014; Zhang et al., 2014). Thus, any intended study aimed at investigating the effect of climate change should also integrate land use change components for better output. Besides climate and land use change, there are other factors that also affect the water balance of a hydrological unit such as a basin e.g. the direct river water abstraction and its regulations via dams and reservoirs construction and management. The water balance of a hydrological domain such as a basin is its recharge and discharge component.

Change and or variability in climate were reported to effects the peak flows, the volume of river water and the flow routing time (Papadaskalopoulou et al., 2015). It also affects the hydrological cycle of a given hydrological unit via the consequence of temperature fluctuations (Herrera-Pantoja and Hiscock, 2015; Zhang et al., 2014). However, land use change mainly altered the flood frequency (López-Moreno et al., 2014), its severity, the base flow, and the annual mean discharge of a river (Pervez and Henebry, 2015).

The combined effects of climate and land use change seriously affects the recharge and discharge component of any hydrological domain and that is what is called the water balance. Thus, climate and land use change impact possesses the potentials to constrains the freshwater resources availability of any hydrological entity and theses impacts has been felt at both global, regional and micro or basins scale (Devkota and Gyawali, 2015; Mwangi et al., 2016). This is even more plausible if Hadejia river basin located in the semi-arid region of Nigeria can be put to focus, an area characterised by increased population (4.5% annually) and a rural economy.

Despite the challenges faced by semi-arid river basins and the increased plethora of climate and land use impact studies around the globe, and in Hadejia River basin (HRB) an integrated study intended at investigating the current and potential impact of climate and land use change using a hydrological model such as SWAT have not been reported even though the the basin is supporting not less than 15 million inhabitants for their livelihoods (Sobowale et al., 2014).

Modelling the impacts of climate variability and land use change on water balance in this study entails the quantification and distinguishing the relative influence of these two factors to the recharge and discharge components of the Hadejia river basin. This was achieved using a semi-distributed hydrological model the Soil and Water Assessment Tool (SWAT) model. The output of the simulation and prediction of this calibrated HRB-SWAT the model will be crucial for planning and management of water-related programs and activities such as water supply and agriculture, and for the preparation against expected extreme weather events such as floods and droughts within the vicinity of the basin (Elias et al., 2015).

Thus, research of this nature stands imperative to provide important information that is currently missing as to the relative sensitivity of basin (HRB) to the effect of climate variability and land use changes. That will enable proper planning and management of the basin's water resources for water supply and agriculture and for mitigation of water related hazards such as floods and droughts. The result of the current study is also hope to guide in policymaking and policy prioritization as it reveals that the basin is more sensitive to climate variability than to land use change. However, the study recommends a holistic approach considering both climate and land use in policy action but in a way given more attention to the effects of land use change which is within human control/capability, unlike climate change. Moreover, regulating land use change may reduce the magnitude of climate change and its consequences as some of its causes are anthropogenic and directly or indirectly linked to the changing land uses.

Thus, from the foregoing it is undisputed that the water balance of the HRB is already being impacted by climate and land use change as portrayed by the alternating floods and droughts in the region (Ogunrinde et al., 2019; Saidu et al., 2019; Umar and Bako, 2019), however, to what extent are the impacts, how would it be in the future and which of the factor impacted the water balance the most. Therefore, the need to distinguish the relative sensitivity of the basin to climate and landuse change has arisen and the anticipated additional water resources management challenges in the future, also call for an investigation.

## 1.2 Research Problem

Climate change and variability are predicted to have serious impacts on the temporal and spatial as well as the duration and amount of rainfall and runoff regimes in WA (Coulibaly et al., 2018), including the fragile arid and semi-arid region of northern Nigeria (Dammo et al., 2015). It is feared that the availability of water resources for agricultural, industrial and domestic uses will likely be threatened in the region (Komi et al., 2016). Moreover, climate variability has been blamed for the increasing frequency of floods and drought in this country. However, it is more devastating in the arid and semi-arid parts of the country been vulnerable and sensitive to even minor climatic changes and has caused a lot of fatalities to human and animal lives, croplands and indeed infrastructures (Sawa and Adebayo, 2011; Sawa et al., 2015). Presently, there is no adequate information with respect to the direction of change in climatic variables and very little is known about the impacts of land use change in the area to allow for water resource planning and management. Moreover, most studies on climate change and variability in Nigeria and particularly in the present study area have been more of qualitative rather than quantitative dimension (Chukwuma, 2014). Thus, it lacks the ability to predict the future impacts of climate change and variability on water resources availability. Similarly, the existing land use change studies in the area concentrate more attention on the impact of urban expansion on agricultural land. Thus, there is no single study known to integrate climate and land use changes via modeling with a view to distinguishing and predicts into the future their relative impact on water balance in HRB.

The marked reduction in river flow in this the region was alarming and is traced to the successive drought experienced throughout Sub-Saharan West Africa in the 70s and 80s (Thompson and Hollis, 1995; Grove and Adams 1988). This has considerably affected the estimated 15 million people which the HRB supported for their livelihoods by diminishing the wet season flood used for flood recession agriculture (Goes, 1999; Sobowale et al., 2010). Thompson and Hollis (1995) have reported a decreasing the trend in flood extent of 962 $km^2$, 525km2 and 413 $km^2$ in 1991, 1992 and 1993 respectively. Moreover, increased population growth (at about 4.3% annually) and urban expansion will raise water demand by 9% in 2010 and is expected to reach 26% in 2020. In the same vein, the water use rate was 75% in 2010 and projected to rise to 100% in 2020 (Sabowale et al., 2010).

Therefore, the present study is conceived to offer solutions to the foregoing by setting up a hydrological model of the study area with a view to distinguish and predict the relative impact of climate variability and land use changes on the water balance of this fragile basin (HRB). This will help to provide an understanding of the direction of change of hydro-climatic and land use parameters. The study will as well provide quantitative information on the future impacts of climate and land use change on water balance in the basin for better water resources planning and management, especially in agriculture and domestic water supply. It is hoped that the success of the present study will inspire other researchers to apply hydrological models in other sub-catchment of the Hadejia Jama'are Komudugu Yobe Basin (HJKYB) in Nigeria. Thus, the study will help environmental managers and policy makers, particularly water resources managers, with the basic information required for appropriate early warning systems against extreme events such as floods and drought, including adaptation and mitigation measures.

## 1.3 Research Questions

a) What has been the direction of change in rainfall and temperature under the recent climate change and variability in the HRB?
b) What is the spatiotemporal variations of river discharge within HRB?
c) What is the rate and pattern of land use/land cover change in the HRB from 1980 to 2016?
d) Can a hydrological model such as SWAT be set up for HRB to simulate and predict the impacts of climate variability and land use change in the basin?

## 1.4 Research Objectives

The general objective of this study is to assess climate variability and land use change and their impact on water balance in Hadejia River Basin (HRB) Nigeria. While the specific objectives are to;

1. examine the trends of precipitation and temperature under the recent climate change in the HRB
2. determine the spatiotemporal variations in the river discharge within HRB
3. examine the rate and pattern of land use/land cover changes in HRB from 1980 to 2016.
4. evaluate the current and project the impacts of climate variability and land use change on water balance using the SWAT model.

## 1.5 Significance of the study

The frequency at which weather-related hazards (floods and droughts) occurs with its untold consequences in Hadejia River Basin (HRB) located in the semi-arid region of Nigeria couples with lack of information crucial for water resource planning and management especially regarding water supply and agriculture was the motivation for this research. Moreover, this river basin was estimated to support not less than 15 million people for their livelihoods (Sobowale et al., 2010; Sobawale et al., 2014). Although several studies related to climate and land use change impact has been conducted at the vicinity of this basin (Ikusemoran and Ezekiel 2011; Ahmed et al., 2017; Abdullahi et al., 2018; Ahmed et al., 2018; Gana et al., 2019; Youdeowei et al., 2019), it is however vital to improve upon these studies using an integrated approach combining hydrological (SWAT), climate (GCMs) and land use simulation and prediction (CA-Markov) models. Thus, this study will contribute to knowledge by providing information regarding the impacts of climate variability and land use changes on water balance in a small tropical river basin (HRB) with limited observed data. The study also opens a new research window, particularly regarding the use of the semi-distributed hydrological model (SWAT) in a data scarce semi-arid region of Nigeria. This will perhaps give researchers an opportunity to relate and understand the interactions between climate and land use change on one hand and the recharge and discharge component of the Hadejia river basin on the other. It is expected in the near future researchers may employ multiple climates, hydrological, and land use change simulation and prediction models for better understanding of the linkages.

The study has also contradicted and washed away the earlier perception that the SWAT model is only applicable in the region with sufficient observe climate and discharge data, as it has proven that this model can as well be used in a data-scarce region with reliable outcomes. Moreover, the sensitivity of the output of the calibrated HRB SWAT model will assist in the basin/water resources management, especially regarding decisions, priorities, and preferences in the side of policymakers as to why climate variability and or land use changes should be given urgent attention.

The study will also enhance and optimize the existing techniques used in climate and land use change impact studies in Nigeria as most of the studies conducted thus far were more inclined to the qualitative approach. Finally, the findings will hopefully serve as a guide for sustainable environmental and water resource management of the entire basin.

## 1.6 Scope and Limitation of the Study

The focus of this study is on the analysis of long-term hydro-climatic and land use data to assess the impacts of climate and land use changes on the water balance of HRB. It is also within the scope of the study to apply various statistical techniques and hydrological model Soil and Water Assessment Tools (SWAT) in particular. To this end, this hydrological model will be to set up for the basin, calibrate and validate it with the aim of using the model to project into the future, and the likely impacts of climate and land use change on the water balance in the basin will be assess. For this purpose, the study will rely on secondary data of climate, discharge/streamflow, slope, soil, and land use satellite imageries that are sourced from various data archiving agencies. In addition, projections of climate change are based on the output of general circulation models (GCMs). Thus, the results of the study were subjected to various limitations such as the uncertainty in the GCMs and the insufficiency and errors in the observed data.

## 1.7 Thesis Outline

Chapter one focuses on the general introduction to the work, gives the statement of the problem, the objectives of the study and the thesis outline. Chapter two focus on the literature review which discusses the earth climate system, climate change, and the Representative Concentration Pathway (RCP) and climate models. It also contains methods of downscaling, hydrological models, previous studies in the HRB, a brief discussion of the Soil and Water Assessment Tool (SWAT) model and the summary of all literature reviewed. Chapter three discusses the location of the study area, its topography, climate, and hydrology. It further describes the data used, some of the statistical tools employed, the theoretical concepts of the hydrological model, SWAT and the general modeling procedure. Chapter four comprises the results obtained and their discussion. Chapter five contains the conclusions drawn from the entire work, the major research findings and the recommendations for further studies. In the end, a short bio-data of the candidate and a list of publications from the study are presented.

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