Wisdom at the source of the Blue Nile

PHYSICALLY BASED RAINFALL- RUNOFF MODELLING IN THE NORTHERN ETHIOPIAN HIGHLANDS:-

THE CASE OF MIZEWA WATERSHED

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Thesis

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The thesis titled “Physically based rainfall runoff modeling in the northern Ethiopian highlands:- the case of Mizewa Watershed” by Mr. Tewodros Taffese is approved for the degree of “Master of Science in Water Resource Engineering”.

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List of Abbreviations

ANRS – Amhara National Regional State

ANRS – BoWRD- Amhara National Regional Water Resource and Development

Arc SWAT- Arc GIS integrated SWAT hydrological Model

CN-Curve Number

DEM-Digital Elevation Model

DEW02-Dew point temperature calculator

Ens-Nash Sutcliff Efficiency

ET-Evapotranspiration

FAO-Food and Agricultural Organization of United Nation

GIS-Geographic Information System

GPS-Geographic Positioning System

HEC-HMS-Hydrologic Engineering Center-Hydrologic Modeling system

HRU-Hydrologic Response Unit

IWRM-Integrated Water Resource Management

NBDC-Nile Basin Development Challenge

NMA-National Meteorological Agency, Ethiopia

NRCS-National Resource Conservation Service

PET-Potential Evapotranspiration

SCS-Soil Conservation System

SRTM-Shuffle Radar Topographic Mission

SWAT-Soil and Water Assessment Tool

SWRRB-Simulator for Ware Resource in Rural Basin

USGS-United States Geographic Survey

UTM-Universal Transverse Mercator

WB-Water Balance

WEAP-Water Evaluation and Assessment planning system

WP-Water Productivity

WXGEN-Weather Generator

Abstract

A study was conducted in Fogera catchment by selecting a smaller watershed of an area 27 km^2. A detailed review of existing rainwater management practices including mapping of locations were performed by surveying using high resolution hand – held Geographic Positioning System (GPS). Some selected practices were proposed corresponding to different landscape of the watershed by consulting what the farmers (and other local stakeholders) think needed and might be needed in the future. The flow was measured at the outlet of the watershed using staff gauge and flow meter to test the efficiency of the model. The hydro-meteorological data were collected from the nearby stations and the quality of those data was checked. The detail land use data was also prepared by surveying and the soil map were used as per FAO classification. Missed hydro-meteorological records were filled depending on their percentage missing; using arithmetic mean for those stations having less than 10 % data missing and neighboring stations for other stations. Weather generator was also created to fill-in missing gaps and generates climate data. Soil and Water Assessment Tool (SWAT 2005) integrated with Arc GIS and Map Window were used to model the watershed which account spatial and temporal variation of inputs at HRUs level. The results were compared and sensitivity analysis has been carried out for SWAT – CN method and resulted in ESCO and CN as the most sensitive parameter. The output were calibrated for the year 1995-2004 using flow data obtained by area proportion from Gumara for Mizewa watershed and Gumara flow for Gumara watershed (to derive parameters for Mizewa watershed) reasonable result were obtained (0.67 E_{ns}, 0.684 R^2). The model was also validated for the year 2005-2009 (0.657 E_{ns}, 0.755 R^2) in both of the cases and compared with the observed value. The study benefits the society by letting to know the available water resource and how to improve and manage the resource.

CHAPTER ONE

1. INTRODUCTION

1.1.Back Ground

Land and rainwater management interventions were not new phenomena in developing countries like Ethiopia. It was practiced continuously in different ways however it has not been done systematically. It is essential to understand the hydrological response of the catchment in order to know water resource potential and suggest better land and water management practices. Therefore, understanding the hydrological processes of different parts of a watershed is crucial to make decisions on water and land resources management. Runoff is one of the major hydrological responses of the catchment which is related with water conservation and soil loss.

The study was intended to investigate the hydrology of the catchment using physically based, conceptual, computationally efficient and semi distributed model SWAT (Soil and Water Assessment Tool) to access the hydrological response from a catchment locally known as 'Mizewa Watershed' located in North Western part of Ethiopia.

1.2.Statement of the Problem

Different land and rainwater management practices have been implemented in the Ethiopian highlands. However the rural poor communities are still remain without sustainable agricultural productivity and livelihood incomes (Lemenih *et al*, 2006). One of the major reasons was land degradation promote losses of soil fertility. This happens in most of the watersheds because of lack of effective land and rainwater management practices. In the previous efforts of rainwater management system (RMS) hydrological response of catchments and the potential water resources were not properly understood. Hence modeling the hydrology of watersheds is required for effective rainwater management strategy. This study is using the Soil and Water Assessment Tool (SWAT) to understand the hydrological process of Mizewa watershed so as to plan, design and manage rainwater properly.

1.3.Objective

The main objective of this study is to investigate the hydrology of Mizewa river catchment using SWAT model.

1.3.1. Specific objectives

a) Detailed review of existing Rainwater management practices (including mapping of locations) and identification of key water resources issues

b) Identification of potential Rainwater management interventions

c) Hydrological modeling to estimate key hydrological fluxes

1.4.Outline of the Research

The thesis was divided in to six chapters. Chapter one provides the brief introduction of the study, statement of the problem and objective of the research. Chapter two deals with data collection, parameter derivation, model input preparation and methodology. Detail descriptions of the study area were included in chapter three. Chapter three presented literature review, previous study in related topics and hydrological data quality test. Chapter four presents model in general, classification of hydrological models, description of SWAT model and SWAT model setup. The fifth chapter presents model output and result discussions. Conclusions and recommendations are included in chapter six.

CHAPTER TWO

2. LITRATURE REVIEW

2.1.General overview

The knowledge and understanding that the scientist has about the world is often represented in the form of models. The goal of the scientific method is to simplify and explain the complexity and confusion of the world. A model is a representation containing the essential structure of some event in the real world. It can be classified as quantitative and qualitative model. In science and engineering, the most essential attribute of model is that of quantitative which yields numerical value. A quantitative model is essential to determine physical variables that cost much to measure in the field. To understand the hydrological process in the system which is essential in decision making, models have been used long in water resources management.

A model used in water resources management should be sufficiently accurate to be used for the intended purpose. The existence of observations determines the validity of the model. Model prediction is compared with field measurement to evaluate its performance without any adjustment to the model parameters (Ward *et al.*, 1999). This process is termed as model validation or verification.

Hydrological models are simplified, conceptual representations of a part of the hydrologic cycle. They are primarily used for hydrological prediction and for understanding hydrological processes. Whenever data is not available, hydrological models are important to establish baseline characteristics and determine long term impacts which are difficult to calculate (Lenhart *et al*. 2002). A modeler should understand the hydrological process and then simulate this process at a desired spatial and temporal resolution (de vos *et al.*, 2006, cited in Musefa, 2007). Two major types of hydrological models can be distinguished: (1) Models based on data; these models are black box systems, using mathematical and statistical concepts to link a certain input (for instance rainfall) to the model output (for instance runoff). The simplest of these models may be linear models, but it is common to deploy non-linear components to represent some general aspects of a catchment's response without going deeply into the real physical processes involved. (2) Models based on process descriptions; these models try to represent the physical processes observed in the real world. Typically, such models contain representations of surface runoff, subsurface flow, evapotranspiration, and channel flow, but they can be far more complicated. These models are known as deterministic hydrology models.

It is essential to determine the amount of water available in the system in order to state the available water potential within the river basin system. Hence, it requires understanding and properly describing water inflow and outflow from the system. In order to describe the movement of water, it would be necessary to have rainfall data and information on runoff, evaporation, infiltration, percolation etc. No hydrological modeling studies were conducted in the study area (i.e. Mizewa watershed) before. The stream flow was also un-gauged and no rain gauge station with in the watershed. However, various studies works have been conducted in Gumara watershed, from which parameters were derived, assessing water availability in terms of surface runoff, ground water and soil moisture and on land degradation (erosion) and management. Therefore, this chapter presents general review of previously works on Gumara watershed.

2.2. Previous studies and approaches

White (2009) assessed the development and application of physically based landscape water balance for Gumara watershed. The main objective of the study was improving SWAT performance in areas dominated by saturation excess runoff process. The principal difference of SWAT-CN and SWAT-WB approach were identified as CN selection based on land use /soil and soil profile water balance simulation respectively. Comparison of model validation resulted in better SWAT-WB performance. The authors concluded that replacing CN with water balance routine in a monsoonal watershed improved SWAT for modeling daily stream flow.

Setegn et al (2008) developed hydrological model for Lake Tana basin. SWAT 2005 model were used to examine the effect of land use, soil, topography and climatic condition on stream flow. Soil evaporation compensation factor ESCO and SCS curve number II were found to be the most sensitive parameters for the sub basins. Calibration resulted with 0.71

and 0.61 coefficient of determination (r^2) and Nash Sutcliff Efficiency (E_{ns}) respectively for Gumara watershed. The model was also validated to give 0.7 r^2 and 0.6 E_{ns}. The authors concluded the successful application of SWAT 2005 model to Lake Tana sub basins for the study of hydrological water balance.

Assefa *et al* (2008) developed flood forecasting and early warning model for Lake Tana sub basin. The study aimed to set up flood forecasting model for Gumara and Rib catchments and verify the accuracy. The rainfall-runoff model was integrated with HEC-HMS for Gumara and Rib using soil moisture accounting model to model soil loss, Clark unit hydrograph for direct runoff, linear reservoir model for base flow and Muskingum–Cunge routing model components. Flows above and below 63 m^3/s were classified as high and low flow ranges respectively for Gumara watershed. Calibration of the model resulted with 0.74 determination coefficient (r^2) and 6.5 root mean standard error (RMSE). Model validation showed good model performance with 0.722 r^2 and 16.3 RMSE. It noted that simulated stream flow were higher than observed value for validation period and seasonality, spatial variability of rainfall soil/land use heterogeneity were identified to be possible source of error in the hydrological modeling. The authors concluded that HEC-HMS continuous hydrologic simulation has good performance for hydrological modeling in Gumara watershed. Further recommendation was provided to use GIS for model parameterization. This was assumed to improve the result since the soil moisture accounting parameters used in HEC-HMS models were derived from general guide lines that refer soil and land use map of the area.

Chebud et al (2009) modeled Lake Stage and water balance of Lake Tana. The study aimed to review water balance parameters and undertake lumped modeling over Lake Tana. Major component of water balance (i.e. surface runoff, rainfall, evapotranspiration (ET) and ground water flow) were estimated separately using different approaches of evapotranspiration estimation. Mean monthly and annual flows of 42 years data (1960 to 2003) was used to analyze the flow. The study indicated there has been high suspended influx (1.937 million tons) from Gumara watershed by citing BCEOM (1999) as a source. The study concluded the assumption of runoff from un-gauged basin would not cause significant uncertainty since close goodness of fit of the model. The flood plain had little effect on the lake water balance

(3%) ET estimation differs seasonally and suggested seasonal application of two methods especially open water surface.

Yibeltal (2008) developed rainfall runoff model for sustainable water resource management as a case study of Gumara watershed. The main objective of the research was developing rainfall runoff model in order to predict and forecast storm events so that water resources are managed properly. HEC-HMS hydrological model was used by integrating GIS and remote sensing techniques for rainfall-runoff estimation from the watershed. Thiessen's Mean Method was used for areal rainfall estimation. World soil and hybrid (supervised and unsupervised) land sat image classification were also used as an input for the model. The runoff volume was determined using SCS-CN (USDA SCS, 1972) method. The model was found to be most sensitive to rainfall input and curve number. However, the result indicated unsatisfactory correlation coefficient between observed and simulated flow (0.498 determination coefficient). The authors finalized the research by concluding data scarcity (2001-2005) made calibration difficult to best fit the model with observed value.

Tadesse (2008) assessed water resource potential of planned development in Lake Tana sub basins using WEAP model. The study aimed to address the effect of planned development activities in Lake Tana sub basins on the water level of the lake. The authors tried to integrate the inflow between Gumara dam and diversion weir with the model as a river system. The inflow, rainfall, evaporation and outflow from the Lake were obtained form study of Tana and Beles sub basins (SMEC, 2007). The author presented average annual unmet demand of Gumara irrigation project (3.7 to 4.2 Mm^3) with and without EFT (Environmental Flows to Tis Issat) and concluded the Lake water level changes with water development activities indicating sector dependent.

Yohannes (2007) assessed water resource potential for Lake Tana basin based on remote sensing data. The research aimed improving hydrological description of Lake Tana basin and thus contributes towards integrated water Resource management (IWRM). The study makes sure the use of remote sensing techniques for hydrologic components of water balance estimation. Satellite derived parameters has been used for evaporation estimation, satellite based rainfall estimate has been validated with recorded data and land cover information has been obtained from moderate resolution optical images. Penman Monteith method for evaporation estimation and HEC-HMS flood hydrograph using SCS and SWAT curve number and soil water balance method for runoff estimation were used in the study. The authors presented the major impact of land use/cover data on runoff estimation in Lake Tana basin so that need to be carefully identified. The authors concluded the goodness fit of soil water balance method for un-gauged catchment runoff estimation in Lake Tana sub basin.

2.3. Gaps

Different studies presented the major impact land use/cover has on runoff estimation and recommended to identify each land use carefully. However, satellite image were used in different studies for land use classification since difficult to conduct field survey in large watersheds. In this study, detail survey of land use/cover was done using hand - held GPS to better estimate water availability on the surface (i.e. surface runoff) by selecting small watershed of 27 km^2 (Mizewa). High runoff generating areas also were identified depending on land use. Potential management interventions were identified by different stakeholders and Agricultural Bureau of the Woreda. Farmers were allowed to choose best and easily adaptable management option based on their capacity for their land at landscape level.

Parameter transferability studies were done in Lake Tana sub basin. The researchers validated their model on gauged catchment and recommended to use it for un-gauged catchments of Tana sub basin based on proxy method principle. However, the model was not checked by measuring un-gauged catchment in Lake Tana sub basin based on regional homogeneity. In this study, manual rain gauges and flow monitoring were installed for Mizewa watershed in order to estimate water potential availability. Rating curve was developed and flow heights were converted in to flow rates and model parameter transferability was checked by using short observed records.

2.4. Hydrological Data Quality Test

The quality of hydro meteorological data is very important for the reliable prediction of the model output The main basic assumption in data analysis are independency, stationarity ,homogeneity and persistence of the data and also the data should be with in upper and lower limit of outlier test.

a) Outlier Test

An outlier is an observation that deviates significantly from the bulk of the data, which may happen due to error in data collection, or recording or due to natural causes. Low and high outliers are both possible and have different effect on the analysis. In this test the quantities X_H and X_L are calculated using equation 8 and 9.

$$X_H = e^{X+K_N s} ----------------------------------(1)$$

$$X_L = e^{X-K_N s} ----------------------------------(2)$$

Where x and s is the mean and standard deviation of the natural logarithms of the sample, respectively and Kn were tabulated for various sample size and significance level (mostly 10% were used for outlier test) were proposed by (Pilon et al., 1985) as:

$$K_N = -3.62201 + 6.28446N^{\frac{1}{4}} - 2.49835N^{\frac{1}{2}} + 0.491436N^{\frac{3}{4}} - 0.037911N ----(3)$$

Sample value greater than X_H are considered as high outliers, while those less than X_L are considered to be low outliers.

Outlier test for 10% significance level from (1992-2009)

Station Name	Rainfall	Max Temp	Min Temp	Humidity	Wind speed	Remark
Alem Ber	Yes	-	-	-	-	Tolerable
Addis Zemen	No	No	No	-	-	Accepted
Bahir Dar	No	No	No	No	No	Accepted
Debre Tabor	No	No	No	Yes	-	Outlier detected
Yifag	No	-	-	-	-	Accepted
Woreta	Yes	No	Yes			Tolerable

Ibnat	No	-	-	-	-	Accepted
Hamusit(Dera)	No	-	-	-	-	Accepted

Table 1: Result of outlier test

No higher as well as lower outlier were detected for Gumara stream flow for the entire simulation period.

b) Test for absence of trend

Testing the time series data for absence of trend is a common practice. There should no correlation between the data collection order and the increase (or decrease) of those data. In this study, Spearman's ranks-correlation method was used to test the absence of trend. This method is based on Spearman-rank correlation coefficient, Rsp, as defined in equation 11.

$$\mathrm{Rsp} = 1 - \frac{6 * \sum_{i=1}^{n}(\mathrm{Di} * \mathrm{Di})}{n * (n * n - 1)} ------------------------------ (4)$$

Where n is the number of data, D is difference, I is the chronological order number. The difference between is computed as in equation 12.

$$\mathrm{Di} = \mathrm{Kxi} - \mathrm{kyi} ---------------------------------(5)$$

Where Kxi is the rank of variable, x, which were the chronological order of observations. The series of observations, yi, were transferred to its rank equivalent, kyi, by assigning the chronological order of an observation in the original time series to the corresponding order number in the ranked series, y, with the same value to take Kx as the average rank. Finally, the null hypotheses (no trend) were tested using Student's t-distribution as defined in equation 13. /Tt/ less than 2.0l indicates the applicability rand of the data at 5 % significance level. The test results were presented in Table 11 below.

$$\mathrm{Tt} = \mathrm{Rsp}[\frac{n-2}{1 - \mathrm{Rsp} * \mathrm{Rsp}}]^{0.5} ----------------------------(6)$$

From the test result, Gumara stream flow data has no trend comparing with its critical value (-2.09 and 2.09).

Stations Name	Statistical Tt value for Rainfall	Remark
Alem Ber	0.078	Accepted
Addis Zemen	-1.27	Accepted
Bahir Dar	-0.42	Accepted
Debre Tabor	-0.34	Accepted
Yifag	0.815	Accepted
Woreta	-1.17	Accepted
Ibnat	0.12	Accepted
Hamusit (Dera)	0.51	Accepted

Table 2: Result of trend test for rainfall

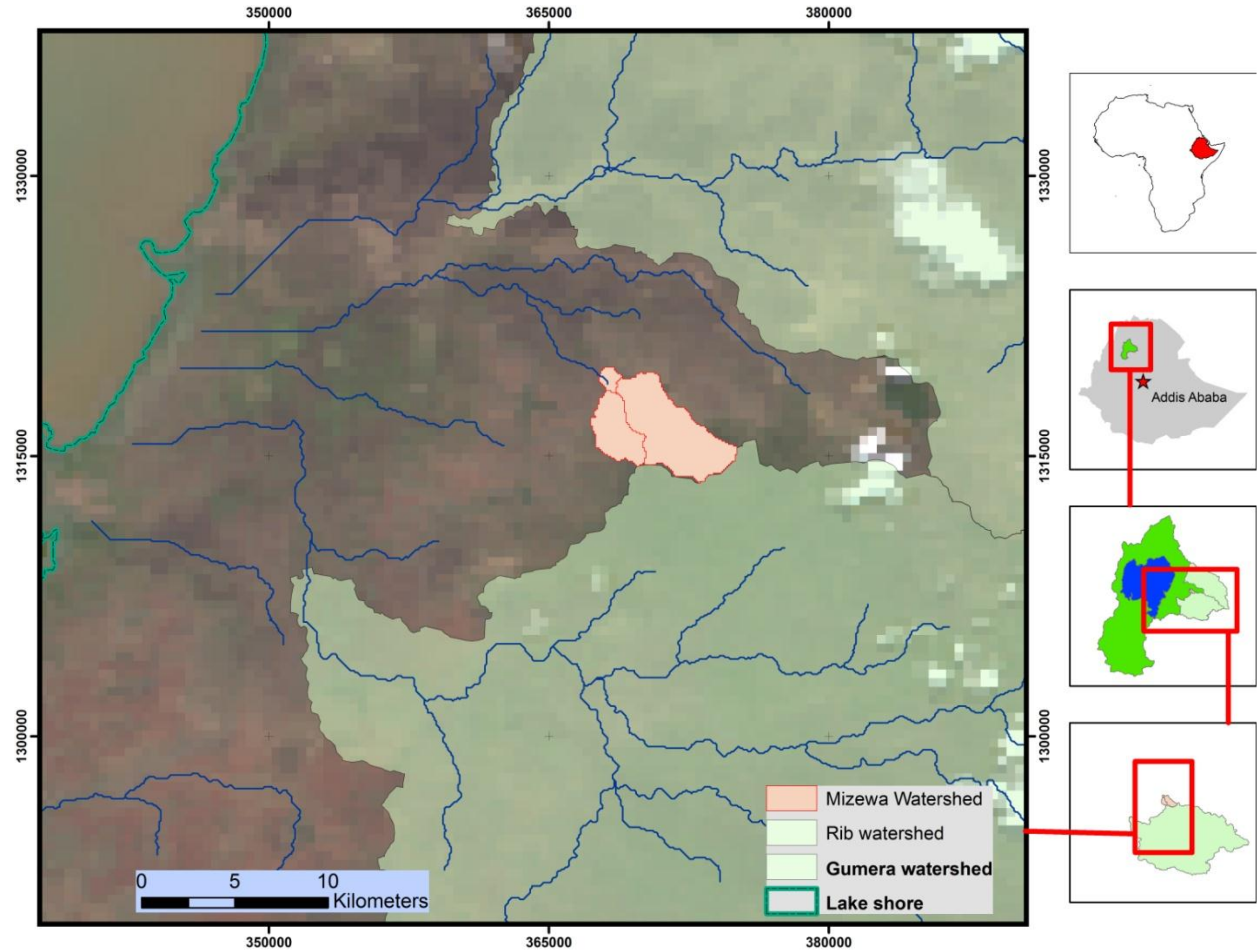
CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of the study Area

3.1.1. Location

Fogera Woreda is situated at $11^{0}58'$ latitude and $37^{0}41'$ longitudes and found in south Gondar zone. Fogera is bordered in the south by Dera, on the west by Lake Tana, on the north by Rib which separates from Kemkem, and on the east by Farta. The elevation ranges from 1774 to 2410 masl which therefore grouped under Woina Dega ecology. Woreta is the capital of the Woreda which is found 625 km from Addis Ababa and 55 km from Bahir Dar (capital of the Amhara National Regional State). Mizewa River was selected as the study catchment. The river flows roughly south-north. A bridge located on the main road from Woreta to Debre Tabor ($11^{o}55.765$'N, $37^{o}47.539$'E, altitude 1,862 masl), just to the west of Woji provides a good point for flow monitoring. The catchment to this point was 27.0 km^2. The river here is perennial. The highest point in the catchment was 2,391 masl. Just upstream of the bridge the river divided into two main tributaries. One the main Mizewa River has a catchment area of 18.80 km^2; the other tributary (Ginde Newr) River has a catchment area of 7.42 km^2. The principal crop grown in the catchment is maize.



Map 1: Location map of Mizewa watershed

3.1.2. Farming System

The farming system in the Woreda is mixed crop-livestock system. The Woreda grows diverse annual and perennial crops. According to the report of agricultural sector (Fogera OoA, 2004) the Woreda is broadly classified in to two farming system. The rice/fish/livestock system is found in north of the main road transecting the Woreda. This area is known as the Fogera plains and is used for livestock grazing. The area gets flooded during the wet season and is not accessible. The cereal/ horticulture /apiculture system is found in the south part of the road transecting the Woreda. The terrain varies from relating flat bottom lands to mid and high altitude areas.

The Woreda is rich with beautiful diverse natural resource and classified as one of the surplus Woreda in the region. It also has the capacity to grow diverse annual and perennial crops. There are two main farming seasons in the Woreda. The main season (kirermt) relies on rainfall, either directly or through its impact on flooding of the plains. The second, dry season runs from September to April, with production relying mainly on irrigation. During the main season, the major crops grown on the upper plain are Finger millet, Teff and Niger seed. In the lower plain, rice, maize and Teff dominate. The total cultivated area was estimated about 45,767 ha where 86% of the area is planted cereals crop (ILRI, 2005).

3.2. Data Collection and Preparation

3.2.1. Identification of key water Resource issues

The key water resource issue of the Woreda was justified from published and unpublished documents while the watershed was field observation through surveying. It is discussed below both on Woreda and watershed level under two main sub topics, water uses and source of water.

Source and use of Water

The area gets much of the flood water that accumulates around Lake Tana and the two big rivers (i.e. Rib and Gumara). According to (Anteneh, 2010) the major water resources of the Woreda are wells (48.8) %, rivers (47.2%), lake (3%) and tap water (0.2 %). It was also mentioned that the rivers bring eroded soil from uphill and deposited on the low land plain and hence river water quality decrease from upstream to downstream. During the dry season there is scarcity of water in the Kebeles that use wells (Anteneh, 2010). The people also supply water to rice plant which is principally provided by rainfall, run-off water and underground water. Stone bunds are usually used for rainfed rice production. The stone bunds also serve to retain flood water, as well as rainwater, which fall during the governing season (tesfaye *et al*, 2004; Abay, 2007).

According to (Bekele *et al,* 2010) the Woreda has a great potential of Irrigation areas using rivers. There are two major rivers that are of great economic importance to the Woreda, the Gumara and Rib. Water is diverted or pumped from these rivers during the dry season to irrigate horticultural crops (namely onion, garlic, tomato, and also potatoes and maize) and grains.

In the lowland areas of the watershed, the farmers use the river for irrigation of Khat plot along its bank which has been a common practice recently. The practice endangered the existence of the already scare water in the area. The river was also used for drinking water, fishing and livestock. Community led traditional water diversion was done along the Mizewa river using stone and mud. However, it created conflict and the structure was demolished by downstream water users leading the water in to its natural water course. The different uses of Mizewa River were presented the figure below.

a) Mizewa River for irrigation b) Mizewa River for drinking water supply

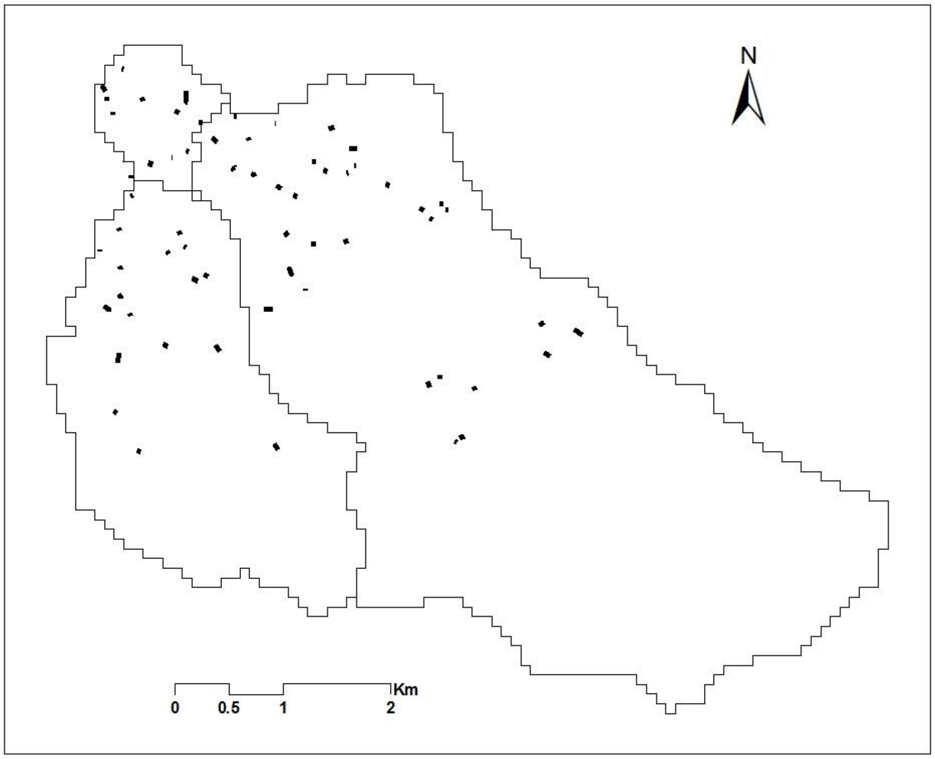
c) Mizewa River for fishing d) Mizewa River for livestock

Figure 1: Multi-use of Mizewa River

The farmers in the middle land area of the watershed, beside to the rain-fed crop; they also used Mizewa River and Ginde Newr (one of the main tributary to Mizewa) to small amount for their production of onion, potato, tomato, Khat and vegetable. Irrigating the fields was accomplished through gravity by diverting water from Mizewa and Gindenewr River. The farmers irrigated their field by rotation and they claimed no conflict in the system. Awramba community is within the Mizewa watershed. The community occupies 17ha of land with 109 households and total population 403 (Source: Ezega.com, 2009). In the community there was one water point sourcing water from a dip well and each house hold fetches 40 litres of water per day from the water point. The average number of each house hold is 4 and 40 litres/day has not been sufficient. Hence the community was obliged to fetch water from Mizewa River for cleaning and other house hold activities. However it was found out that from January to May there were reduction of stream flow due to pumping and diversion of river so that the shortage of water has been immense. The amounts of the river in the highland of the watershed were low and hence could not be used for irrigation and drinking water supply.

3.2.2. Detail Review of Existing RM interventions

The farming practice in the midland and highland watershed is on sloppy and stony ground. The local farmers protected their farmland using stone bunds and contour plowing which probably reduces upland erosion. The bund also acts as farm boundary to protect the entrance of livestock. It seems that in the entire watershed the concept of rainwater harvesting is at an infant stage, though water scarcity and catchment degradation are serious threats. However one settler within the Woreda, small distance far apart from the watershed named, Mohamed Qassim, with the assistance of Woreta Agricultural Bureau developed a trapezoidal pond lined with geo-membrane. The stored water during the rainy season was utilized only up to January, which then after dries-up. The efficiency of the pond was also poor in which water may not be properly stored. There were lack of proper maintenance to the pond which resulted leakage and accumulation of debris at the bottom. The side walls of the pond were also not strong enough to accommodate the heavy storm during rainy seasons. The sidewalls need to be cemented and the geo-m embraces be properly fixed at the mouth of the pond.



Map 2: Location map of stone bunds

a) Stone bunds along farm boundaries b) Trapezoidal pond near to watershed

(Source: IWMI field visit report, 2010)

Figure 2: Existing RM interventions

3.2.3. Identification of Potential RM interventions

The leader of Awramba community, Zumra, indicted that there has been water scarcity and the community recognized water as an asset in their livelihood, 'no difference with oil'. He also mentioned the option for efficient Rainwater Management (RM) strategies in his community were to harvest rainwater from roof tops. As most of the houses in the community have metallic roofs, the rainwater collected needs to be stored in one or more ponds and could possibly be used for planting crops like banana, onion, potato and off farming practices, like dairy farming. The rest of the watershed including the upland areas, which were mostly stony and highly degraded, could possibly be regenerated by planting high yielding crops like citreous fruits and plantation of trees.

The potential land and RM intervention combinations were identified by asking farmers and other stakeholders who might think what is needed and feasible in the future. Various sources were also consulted; this includes Agricultural Bureau of the Woreda and reports of different workshops organized by Nile Basin development Challenge (NBDC) program. As a result, level fanya juu, grass strip along contour, check dam, hand-dug-wells with treadle pump, diesel pump with rivers, roof water harvesting together with ponds, diversification of crops, fallowing, well designed stone bund, planting scattered tree on farm land and soil fertility management (fertilizer, manure) were proposed as potential practice for the low and middle land of the watershed. In addition, hill side terrace (with or without trench), forestation, check dam, well designed stone bunds, fallowing and planting high yielding crops like citreous fruit were also proposed for the highland of the study area. Some practices were suitable for all landscapes and some others were specific. The watershed was divided in to 3 landscapes (i.e. low land, middle land and high land) and 10 farmers were asked to select rainwater management practices for their land.

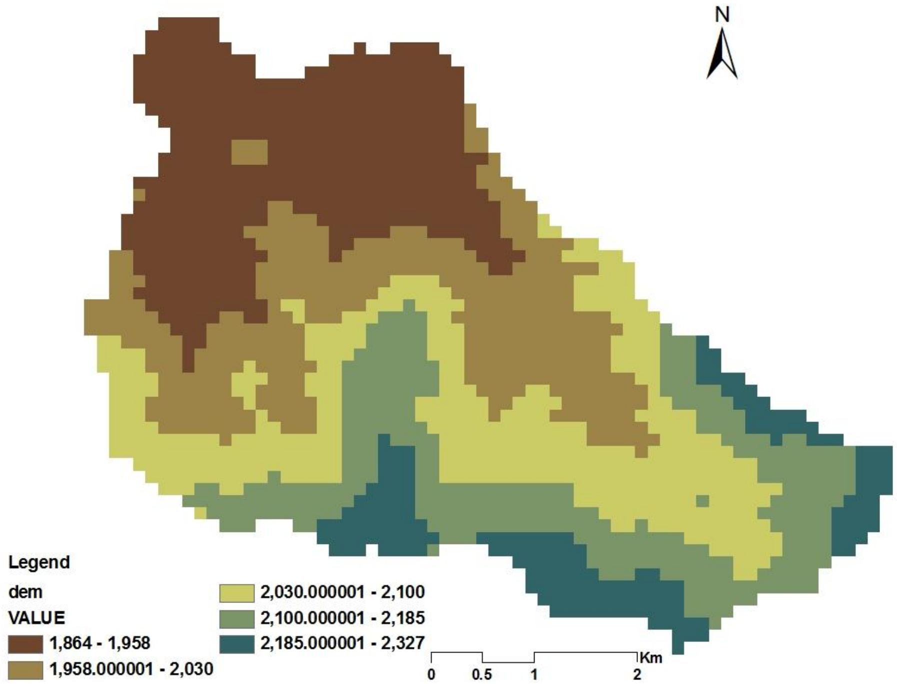
Proposed rainwater management interventions	Choice of farmers at different Landscapes		
	Low land	Middle land	High lands
Level fanya juu	-	-	-
Grass strip along contour	-	-	-
Check dam	1	-	-
Hand-dug-well with treadle pump	-	-	1
Diesel pump with river	5	2	-
Roof water harvesting with ponds	-	6	-
Diversification of crops	-	-	-
Fallowing	-	-	-
Well designed stone bunds	2	1	1
Planting scattered tree on farm land	1	-	-
Fertilizer and Manure	1	-	-
Hill side terrace	-	-	5
Forestation	-	-	3
Planting high yielding crops like citreous fruit	-	1	1

Table 3: Farmers choice of RM strategies

The farmers select what they think might work in the future for their land and the result is discussed in 3 classes based on the landscape. For low land area, 50% of the farmers selected diesel pump with river and 20% of them selected well designed stone bunds. This is due to most of farmers at low land area use the river for irrigation of Khat plots and stones were available intensively within the watershed. For middle land area, 60% of the farmers select roof water harvesting together with ponds while 20% of them select diesel pump with river. This is due to Awramba community with in the middle land areas and has metallic roof houses. Furthermore farmers in the middle land have Khat plots to some extent. At the high land of the watershed, 50% of the framers select hill side terrace and 30% of them selected forestation. This is due to the land is much degraded at this landscape and they think hill side terrace and forestation as feasible interventions to regenerate the land. The farmers also consider their capacity to adopt the interventions on their choice.

3.2.4. Digital elevation Model

Digital Elevation Model (DEM) well define the topography of the area by describing the elevation of any point at a given location and specific spatial resolution as a digital file. It is one of essential spatial input for SWAT to delineate the watershed in to a number of sub watersheds or sub basins based on elevation. Drainage pattern, slope, channel width and stream length with in the watershed were processed using DEM. The raw DEM were obtained from United States Geographic Survey (USGS) with 90x90 resolution and projected using Arc GIS 9.2 software package.



Map 3: Elevation map of Mizewa watershed

Projection	UTM projection
Linear Unit	Meter (1.00)
False- Easting	500000
False- Northing	0
Central Meridian	39
Scale factor	0.9996
Latitude- of –origin	0

Datum	WGS _1984 _UTM _37N

Table 4: Universal Transverse Mercator (UTM) projection

3.2.5. Land use/Land cover

Onion, Potato, tomato, vegetables, finger millet, Niger seeds and maize are common rainfed and irrigation cultivation areas in the middle and highland area of the watershed. Some farmers after getting the seedling from the Woreda Agricultural Bureau plant mango, papaya and coffee. Most upper part of the high land area were covered by bush lands, bush land and maize (mixed), bush land and finger millet (mixed) and forest land. Grazing land in a limited areal extent has been there in the middle and highland of the watershed.

Along the lowlands of Mizewa river bank, nearly 200 meters on both sides, plantation of Khat has been a common practice recently. In these areas Maize, Niger seed and Finger millet have been the main rain-fed crops. Khat in small pockets but intensively is planted and irrigated (wild irrigation) using pumps. Farmers indicated that they have recently discovered good economic income from planting Khat resulting many farm owners along the river banks have converted their plot to Khat plantation.

The spatial components of land use mapping were based on the assessment of current land use. An inventory or map might already available, issued and surveyed by survey department or other institutions, but in these case land uses survey has been performed. In preparing the basic land use map, initially the blocks of land are identified. Using hand - held GPS, the extent (boundaries) of various uses (mixed, predominantly commercial, predominantly residential and so on) were recorded onto the base land use map as polygons for the watershed. Finally, the entire land use was merged together to form the land use of the selected watershed using GIS.

It is essential to prepare land use look up table based on SWAT code by merging together different fields in such a way that the fields as much as possible have similar hydrological response. The land use preparation is presented in Table 2. As a result 16 land use classes was reclassified and reduced to 11 classes in order to correspond with the land use in SWAT interface.

VALUE	LANDUSE	DESCRIPTION	% of Area
1	AGRC	Teff, Niger seed	3.15
2	RNGB	Bush land, Maize-bush, Millet-bush, Millet - Maize - bush and Khat	69.8
3	FRST	Forest-Mixed	13.6
4	CORN	Maize	2.28
5	PNUT	Nut	0.09
6	PMIL	Finger Millet	4.77
7	URLD	Village/ Residential-low-density	0.96
8	BROM	Grazing land	0.3
9	DWHT	Wheat	2.49
10	POTA	Potato- Onion	0.69
11	RNGE	Grazing bush land	1.86

Table 5: Land use lookup table preparation

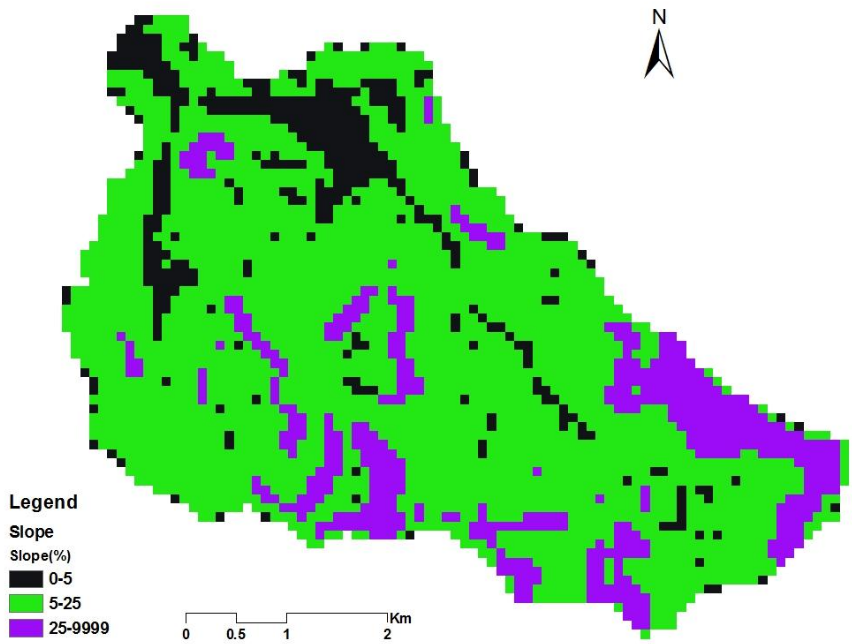
3.2.6. Soil data

World soil classification was developed by the Food and Agricultural organization (FAO) that helped to generalize the soil pedogenesis in relation to the interaction with the main soil forming factors. Most of the names incorporated in the classification were known in many counties. In this particular study, the soil map prepared based on FAO soil classification from Abay basin master plan has been adopted. As a result the entire watershed lies in one soil group called HALUVI for the case of Mizewa watershed. HALUVI soil has 2 soil layers having high percentage of sand and high hydraulic conductivity. The detail land use properties for each crop and soil properties were listed in Appendix 1 and appendix 2 respectively.

3.2.7. Slope

Watershed slope reflects the rate of change of elevation with respect to distance along the principal flow path. After the principal flow paths were delineated, the watershed slope was computed as the difference in elevation between the end points of principal flow path divided by the hydrologic length of flow path. The elevation difference might not be necessarily the maximum elevation within the watershed since the highest elevation may occur along a side boundary of the watershed rather than at the end of principal flow path.

In this particular study, the slope of the watershed was discritized in to 3 as recommended in SWAT manual which corresponds to the landscape. Most part of lowland of the watershed lied between 0-5 %, the middle lies between 5-25 % and the upper land is above 25 % as shown in the map below. The slope of the watershed was necessary spatial data required by SWAT model integrated with Hydrologic Response Unit (HRUs).



Map 4: Slope discretization of Mizewa watershed

3.2.8. Parameter derivation

Regionalization can be described as grouping basins into homogeneous regions. The resulting regions were assumed to be homogeneous in terms of hydrologic responses. In the recent study homogeneity implies that region has similar runoff generating mechanisms. Many regionalization studies concluded that such a region must be geographically continuous. Regionalization can be depending on geographical proximity, climatic and physiographic characteristics of the catchment.

The use of hydrologic models for un-gauged catchments becomes important issues in hydrological study. Regionalization study aimed to estimate parameter values of hydrological models for sub-catchments or large geographic regions. Regionalization methods aim to relate catchment characteristics and geographical location with model parameters. A number of regionalization methods have been listed in different hydrology references. However, generally regionalization method can be categorized in to two: point and interval estimation methods. Point estimation method intends to provide unique parameter values for un-gauged catchment and is adopted in the present study.

In order to derive parameters for un-gauged catchments, first homogenous regions must be identified following regionalization procedures. However, Assefa *et al (*2008) indentified homogeneous regions for the upper Blue Nile basin. Their study resulted in grouping Gumara and Rib on same group as homogenous region. Geographically, Mizewa watershed lied in between Gumara and Rib watersheds resulting regional homogeneity due to geographic continuity. In this particular study, Gumara watershed was selected in order to transfer parameters since geographically near, have similar dominant land use class (i.e. range-brush), better quality data of stream flow and also the dominant soil type in Gumara watershed (HALUVI) were the entire soil type for the case of Mizewa watershed. The parameter transferability of the model was checked by measuring rainfall and stream flow of Mizewa River.

Gumara watershed is highly cultivated region in Ethiopian highlands (White, 2009). It has 1279 km^2 watershed area draining to Lake Tana. Elevation of the watershed determined from 90 m DEM ranges 1797 to 3708 meters above sea level with slope ranging from 0 to 79 %. Arc SWAT delineation resulted in 3 sub basins (by reducing default monitoring points since no gauging stations there) which resulted creating 18 HRUs shown in Appendix 5. Land use map prepared for Tana basin using Land sat images were used for this thesis. Based on this map, the watershed classified in to 6 land use classes: Pine (PINE), Agricultural land-close-grown (AGRC), grazing land (BROM), Water (WATR), Wet land-non-forested (WETN) and Range-brush (RNGB). Range-brush was the dominant land use within Gumara watershed similarly for Mizewa watershed. Soil map were adopted FAO world soil classification and the watershed were classified under 3 soil classes: Chromic Luvisols, Halpic Luvisols, and Eutric Vertisols. Halpic Luvisols has high percentage of sand and Eutric Vertisols has high percentage of clay of all soils within the watershed. As a result, Halpic Luvisols has high hydraulic conductivity while Eutric

Vertisols has low hydraulic conductivity. The detail soil properties used in this study were provided in Appendix 2. Land use and soil map of Gumara watershed were presented in the map below.

3.2.9. Hydro meteorological data

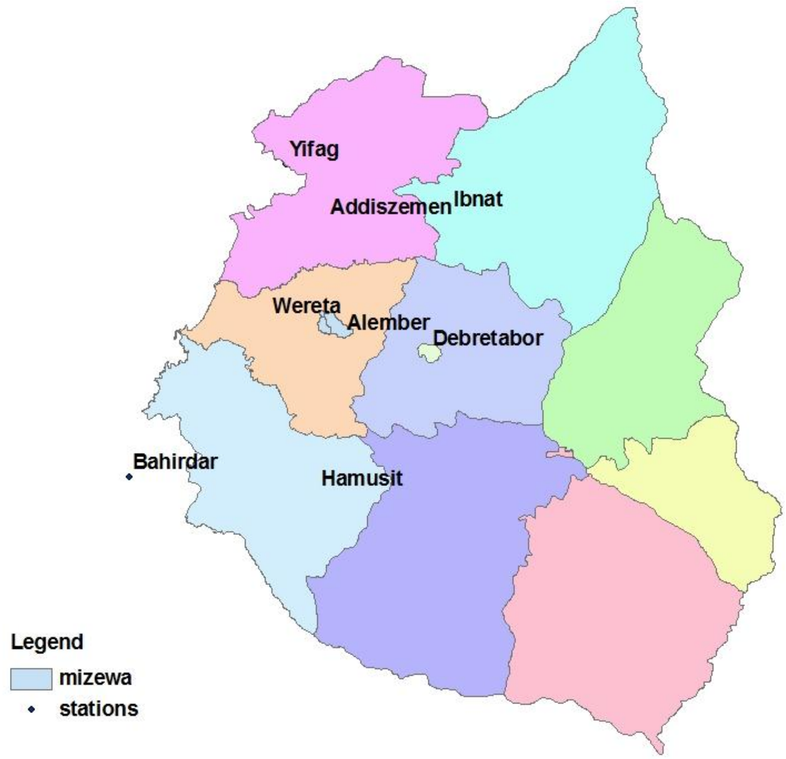
SWAT model largely depends on meteorological data such as daily precipitation, maximum and minimum temperature, wind speed, relative humidity and solar radiation and hydrological data such as river discharge. The hydrological and meteorological data were obtained from Ministry of Water and Energy (MoWE) and National Meteorological Agency (NMA) respectively. The quality of those data is important for reliable prediction of model output.

I. Station location

Different class (class I to class IV) Amhara national meteorological stations were found around the watershed. Maximum and minimum temperature, relative humidity, precipitation and wind speed data from those stations were collected from NMA Bahir Dar branch. The name, classes, zone, location and data records of neighboring stations were presented below.

S.No	Stations Name	Latitude	Longitude	Altitude	Zone	Year
1	Alem Ber	$11^{0}53'$	$37^{0}50'$	2090	South Gondar	1982 - 2009
2	Addis Zemen	$12^{0}07'$	$37^{0}52'$	1850	South Gondar	1992 - 2009
3	Bahir Dar	$11^{0}36'$	$37^{0}24'$	1828	West Gojjam	1992 - 2009
4	Debre Tabor	$11^{0}53'$	$38^{0}02'$	2690	South Gondar	1992 - 2009
5	Yifag	$12^{0}04'$	$37^{0}43'$	1800	South Gondar	1992 - 2009
6	Woreta	$11^{0}55'$	$37^{0}41'$	1980	South Gondar	1992 - 2009
7	Ibnat	$12^{0}08'$	$38^{0}03'$	1800	South Gondar	1992-2009
8	Hamusit (Dera)	$11^{0}46'$	$37^{0}23'$	1900	South Gondar	1992 - 2009

Table 6: Stations location



Map 5: Map of stations location

II. Data Availability

Most of the meteorological stations were grouped under class IV which has only rainfall records and some are class III which has temprature data in addition. Two stations, Debretabor and Bahir Dar belongs to class I which could be weather generator in SWAT data base for this study area to fill the missed records. There have been 8 station around the watershed that has long term records, 18 years of records(1992-2009), used in this study. The data availability informatoion of the station is presented in Table 5.

Stations	Daily meteorological data				Station Classes	Available data Records
	PPT	Temp	RH	Wind Speed		
Alem Ber	x	-	-	-	Class IV	1984 - 2009
Addis Zemen	x	X	-	-	Class III	1997 - 2009
Bahir Dar	x	X	x	x	Class I	1961 - 2009
Debre Tabor	x	X	x	x	Class I	1951 - 2009

Yifag	x	-	-	-	Class IV	1978 - 2009
Woreta	x	-	-	-	Class IV	1969 - 2009
Ibnat	x	X	-	-	Class III	1970 - 2009
Hamusit (Dera)	x	-	-	-	Class IV	1970 - 2009

Table 7: Data availability and station classes

III. Filling Missed Records (include flow information)

In the analysis of hydrological data, the stations were required to have daily records for the required period of simulation (1992-2009) years. It may so happen that a particular rain-gauge was not operative for a part of a month or year (since it was broken or for some other reason) hence it becomes necessary to supplement the missing records. In this research, the mean value of the entire period (arithmetic mean) was used to fill the missed records for the stations with less than 10 percent missed records while for the stations having greater than 10 percent of missed records, neighboring stations were used. The percent of missed records were presented in Table 6 below. As a result, precipitation data of Bahir Dar, Debre Tabor, Yifag and Hamusit (Dera) was filled using arithmetic mean while for Alem Ber, Addis Zemen, Woreta and Ibnat neighboring stations method were used. Those stations filled using arithmetic mean were used to fill the other stations as neighboring station. Using multiple regressions of daily data between neighboring stations, the result obtained in Table 7 having good relation with Debre tabor and Hamusit (Dera).

	Percentage Missing (%)				
Stations Name	Rainfall	Max Temp	Min Temp	Humidity	Wind speed
Alem Ber	56.98	-	-	-	-
Addis Zemen	35.82	10.66	10.77	-	-
Bahir Dar	2.65	11.13	11.37	2.86	
Debre Tabor	1.84	1.02	0.53	11.03	3.24
Yifag	7.76	-	-	-	-
Woreta	39.18	12.8	12.15	-	-
Ibnat	50.6	-	-	-	-
Hamusit (Dera)	21	-	-	-	-

Table 8: Percentage missing of stations

Station Name	Formula	Coefficient of determination
Addis Zemen	0.384debretabor + 1.822	0.50
Alem Ber	0.422debretabor + 2.173	0.53
Ibnat	0.290debretabor + 1.563	0.50
Woreta	0.368hamusit (Dera) +2.02	0.49

Table 9: Data filling formula for missed records

3.2.10. Rating curve development

Rating curve in hydrology is the graph of discharge versus stage (water level above the reference) for a given point on a stream usually at gauging station, where the stream discharge were measured across the stream channel with flow meter. It involves two steps; first the relationship between stage and discharge were established by measuring stage and corresponding discharge in the river and secondly stage of the river were measured and discharge is calculated using the established relationship. The quality of a rating curve often depends on the amount and quality of available measurement. The stage and discharge were needed at low, medium and low flow season for better rating curve development.

In this study, staff gauge were installed at the selected monitoring point. Flow meter measurements were taken only high and medium flow season. To account the lateral variation, the cross-section was divided in to suitable cross-sections. The vertical velocity variations were accounted by taking velocity at different depths (0.6h for water depth less than 50 cm and 0.2h and 0.8h for water depth garter or equal to than 50 cm). No water depths for 3 point measurement were detected at the gauging stations.

Date	Discharge (m3/s)	Staff Reading (m)	Remark
9/01/2011	0.902	0.52	High flow season
9/02/2011	1.311	0.58	
9/03/2011	1.212	0.56	
9/04/2011	1.117	0.55	
9/05/2011	1.066	0.54	
24/11/2011	0.088	0.49	Medium flow season
27/11/2011	0.086	0.47	
28/11/2011	0.086	0.47	
15/01/2012	0.0071	0.4	Medium-low flow season
16/01/2012	0.0071	0.4	
17/01/2012	0.0071	0.4	
18/01/2012	0.0071	0.4	
19/01/2012	0.007	0.4	

Table 10: Stage and discharge measurement

It is convenient to plot using logarithmic scale for the discharge and stage h and often found that subtracting arbitrary value ho so that the plot of the logarithm of the discharge and the logarithm of (h-ho) the points on the rating curve falls approximately on a straight line (Hershey, 1995). The implication can be expressed as in equation 15.

$$Q = C(h - ho)^n \text{-------------------------------} (7)$$

Where c and n are constants. For known zero-stage, the rating curve can be written as Y=b+nx where Y = log(Q), x = log (h-ho), and b = log(C). Using least square solution method, ho are assumed and C and n are estimimated to give best determination coefficient and minimum standared error. The leastsquare equations are given below in equation 16 to 19.

$$n = \frac{N(\sum XY) - (\sum X)(\sum Y)}{N(\sum X^2) - (\sum X)^2} \text{-------------------------------} (8)$$

$$b = \frac{(\sum Y) - n(\sum X}{N} \text{-------------------------------} (9)$$

$$Se = (\frac{1}{N}\sum(Q - Qo)^2)^{\frac{1}{2}} \left(\frac{1}{N}\sum(Q - Qo)^2\right) \text{-------------------------} (10)$$

$$r^2 = (1 - \frac{\sum(Q - Qo)^2}{\sum(Qo - \overline{Qm})^2} ------------------------------ (11)$$

Where Q is simulated value, Qo is observed value and Qm is the observed value and N is the number of data. Finally, the result were presented below in table 13 and figure 12.

Parameters	Value	R2	Se
C	57.96		
N	2.2	0.98	0.019
Ho	0.43		

Table 11: Calibrated parameter values

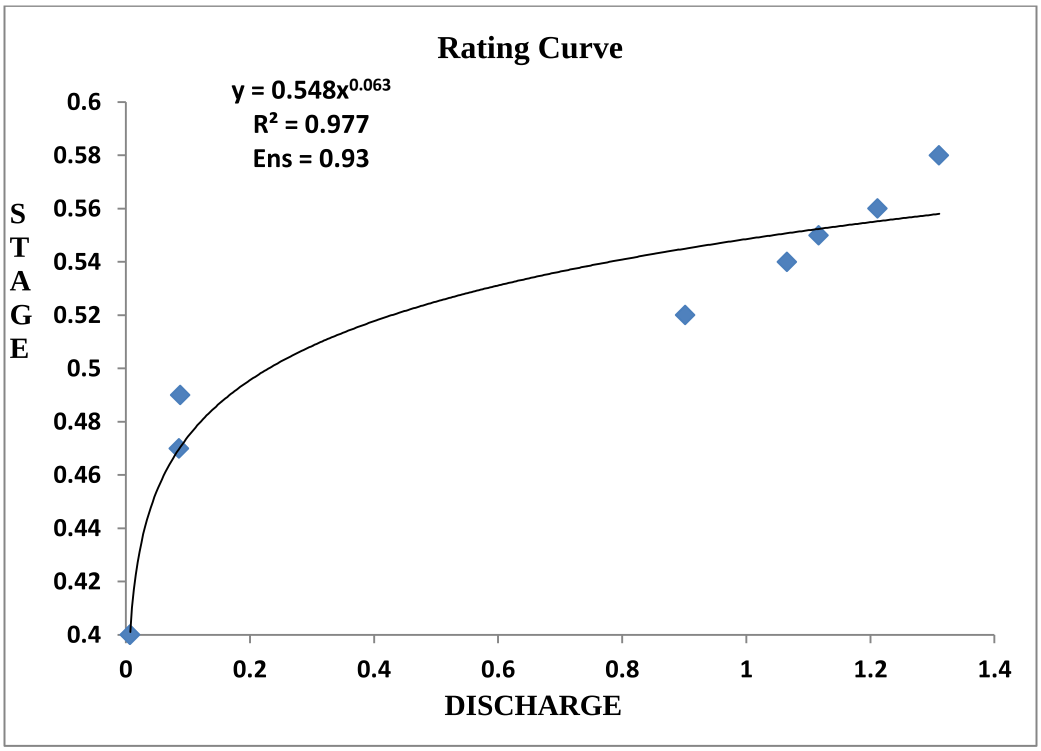


Figure 3: Rating curve (9/01/2011 to 19/01/2012)

The parameter ho (equation 5) is arbitrary and is fixed by trial and error to give minimum standard error, this is considered as the limitation of the formula. The distribution and numbers of measurements from which the rating curve is to be derived are the major factors that affect the determination of discharge from stage-stage discharge relationships (Bosshart, 1995). Uncertainty of applied gauging station, actual measurement of velocity and the corresponding stages are also important factors for accurate discharge determination.

Many contradictory recommendations are published concerning the number of measurements from which stage – discharge relations are determined, however, a stage – discharge relation may be considered sufficiently sustained if at least one measurement per one tenth of the whole range of stage recording has been carried out (Bosshart, 1995). Unique relationship between stage and discharge is not maintained when the control at the gauging station is influenced by other control downstream. In this study, the control point is at the bridge site, the number of measurements is also limited and peak flood events are not captured which have significant impact on rating curve.

CHAPTER FOUR

4. HYDROLOGICAL MODELLING

4.1. SWAT (Soil and Water Assessment Tool)

SWAT is physically based, conceptual and computationally efficient model that operates on a daily time step at basin scale (Arnold *et al*., 1998, 2000; Neitsch *et al*. 2001). It was designed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time (Neitsch, et al., 2005). SWAT uses a two-level disaggregation scheme; a preliminary sub basin identification is carried out based on topographic criteria, followed by further discretization using land use and soil type considerations. Areas with the same soil type and land use form a Hydrologic Response Unit (HRU), a basic computational unit assumed to be homogeneous in hydrologic response to land cover change.

The model was developed by United States department of Agriculture – Agriculture Research Service (USDA – ARS). Simulator for Water Resources in Rural Basins (SWRRB) model were an earlier continuous time step model from which SWAT was developed (Williams et al. 1985; Arnold et al., 1990) that simulate non point source loading from watershed (chemical runoff, erosion) (Knisel, 1980). SWAT model has been applied for various catchments areas ranging from 0.015 km^2 (Chanasyk et al., 2003) to as large as 491,700 km^2 (Arnold et al., 2000) and its accuracy increases as the catchment area is small.

Mostly water enters in the SWAT watershed system in form of precipitation. Flows and water quality parameters are routed in the model on the basis of HRU to each sub basin and subsequently to the watershed outlet. In the present study SWAT 2005 (Soil and Water Assessment Tool) model integrated with Arc GIS techniques was used to simulate runoff yield of the study area.

4.1.1. Hydrologic Water Balance

Water balance is the key for the simulation of hydrology with in a watershed. SWAT uses two phase for the simulation of hydrology, land phase and routing phase. The land phase simulation calculates the amount of sediment, water pesticide and nutrient loading in to the main channel in each basin. The routing phase of define the movement of water, sediment, etc in to the outlet through channel network of the watershed. SWAT uses the following water balance system to simulate the hydrologic cycle with in a watershed.

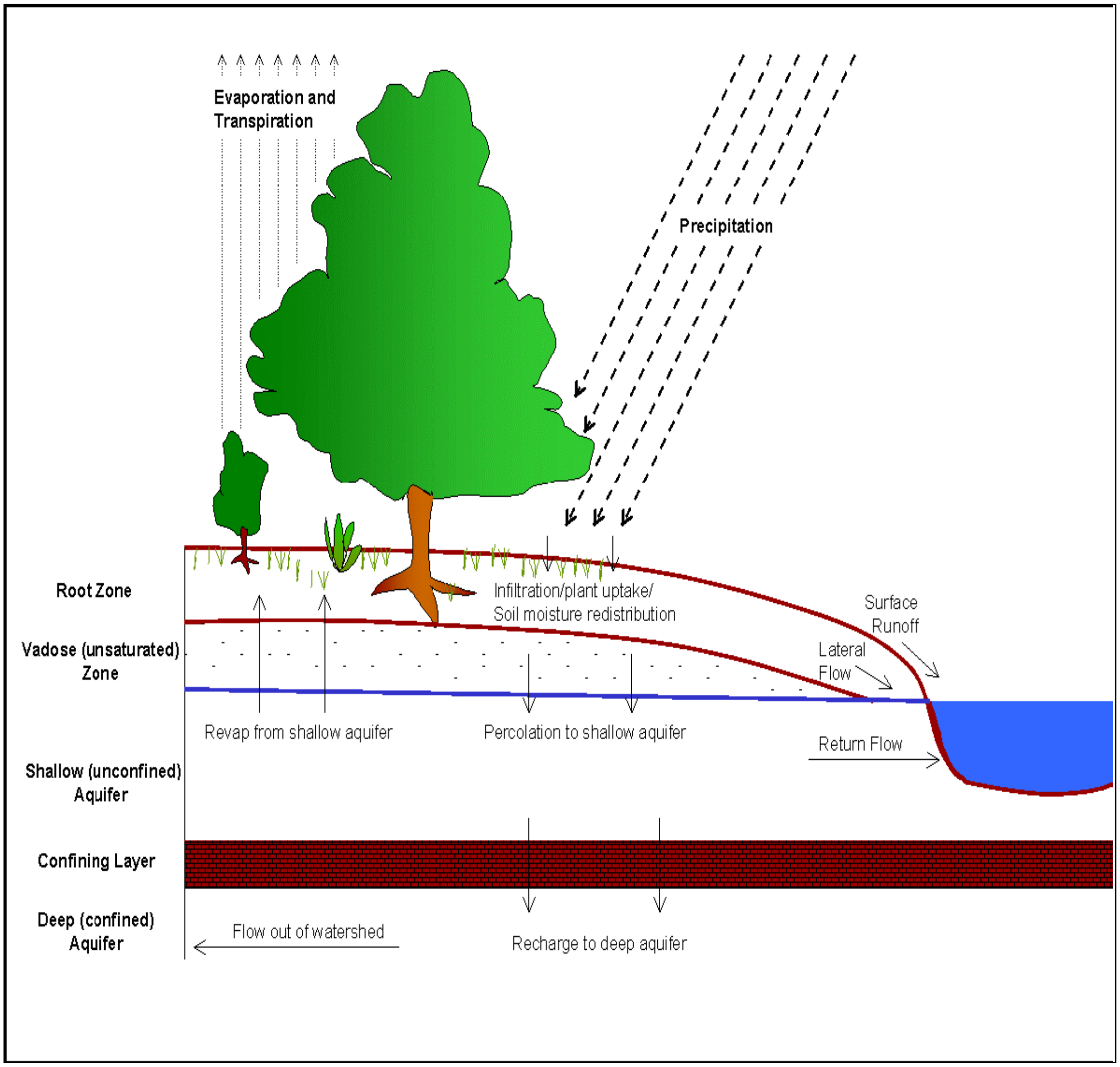


Figure 4: SWAT hydrologic cycle consideration (Source: Neitsch et al., 2001)

The water balance used in SWAT can be expressed as in equation 20.

$$SWt = SWo + \left[\sum_{i}^{t} P_{day} - Q_{Surf} - E_{a} - Q_{Seep} - Q_{gw}\right] - - - - - - - - - - - - - - - 12$$

Where; SWt is the final water content (mm H2O), SWo is the initial soil water content on day i (mm H2O), t is time, days, P_{day} is the amount of precipitation on day i (mm H2O), Q_{surf} is the amount of surface runoff on day i (mm H2O), Ea is the actual evapotranspiration on day i (mm H2O), Q_{seep} is the amount of water entering the vadose (unsaturated) zone from the Soil profile on day i (mm H2O), Q_{gw} is the amount of return flow on day i (mm H2O).

The model reflects difference in evapotranspiration for various land use and soil type in the subdivision of watersheds. The runoff was predicted separated from each HRU and routed to obtain the total yield for the watershed. Hence, increase the accuracy and gives a better physical description of water balance. In this research, both SWAT soil conservation service curve number (SWAT-CN) and water balance (SWAT-WB) method were used.

4.1.2. SWAT-CN Method

I. Surface runoff

SWAT 2005 uses the concept of infiltration excess runoff. It assumes the runoff occurs whenever the rainfall intensity is greater than the rate of infiltration. This process is very important in areas where significant soil crusting and/or surface sealing occurs during storm events, in irrigated fields, in urban areas and more generally during very high rainfall intensity storms. For estimation of surface runoff, SWAT uses two methods based on the above assumption. The soil conservation curve number method (SCS, 1972) and Green and Ampt infiltration method (1911). For this particular research, the soil conservation services (SCS) curve number was used. This is because we do not have hydrological and meteorological data collected at sub-daily scale.

In this method, land use and soil properties are lumped in to a single parameter (White *et al*., 2009). SWAT also uses Natural Resource Conservation Service (NRCS) soil classification based on infiltration properties of the soil (Neitsch et al. 2005) in to four groups (A, B, C, D) having high, moderate, low and very low infiltration rate respectively. In the classification, a soil group has similar runoff potential under similar storm and cover condition. To determine CN, the model then defines antecedent moisture condition based on Curve Number –Antecedent Moisture condition (CN –AMC) (USDA – NRCS, 2004) based on the soil moisture content calculated by the model (Neitsch et al., 2005). The retention parameter (S) then determined using the daily CN value.

$$S = 25.49\left[\frac{1000}{CN} - 10\right] -------------------------------(13)$$

The direct runoff is determined by integrating the above empirical model with SCS runoff equation.

$$Q_{Surf} = \frac{[P_{day} - I_a]^2}{P_{days} - I_a + S} ----------------------------- (14)$$

Where Q_{surf} is the surface runoff or rainfall excess (mm H_2O), P_{day} is precipitation depth for the day (mmH_2O), S is the retention parameter (mm) and I_a is the initial abstraction which usually approximated as 0.2S.

II. Routing

Variable storage routing or Muskingum River routing can be used as routing technique for flow, sediment etc loading. In this research, flow was routed through stream network of the watershed from upland areas to the main channel by variable storage routing which were a process analogous to HYMO (Williams and Hann, 1972). Continuity equation was the concept behind storage routing.

For a given reach,

$$\Delta V_{Stored} = V_{in} - V_{Out} -------------------------------(15)$$

Where; V_{in} is the volume of inflow during the time step (m^3 H_2O), and V_{out} is the volume of outflow during the time step (m^3 H_2O), ΔV_{stored} is the change in volume of storage during the time step (m^3 H_2O). The calculation can be further specified as in equation 24.

$$V_{Stored,2} - V_{Stored,1} = \frac{\Delta t}{2} * \{[q_{in,1} + q_{in,2}] - [q_{out,1} + q_{out,2}]\} ------------ (16)$$

Where; $q_{in,\,1}$ is the inflow rate at the beginning of time step (m^3/s), $q_{in,\,2}$ is inflow rate at the end of time step (m^3/s), $q_{out,1}$ is the outflow rate at the beginning of time step (m^3/s), $q_{out,2}$ is the outflow rate at the end of time step (m^3/s), Δt is the length of the time step (s), $V_{stored,2}$ is the storage volume at the end of time step (m^3 H_2O), $V_{stored,1}$ is the storage volume at the beginning of time step (m^3 H_2O).

The volume of water in the channel was divided by the outflow rate to compute the travel time.

$$TT = \frac{V_{Stored}}{q_{Out}} = \frac{V_{Stored,1}}{q_{Out,1}} = \frac{V_{Stored,2}}{q_{Out,2}} ------------------------- (17)$$

Where; TT is the travel time, V_{stored} is storage volume (m^3 H_2O) and q_{out} is the flow rate.

4.1.3. SWAT–WB method

In this method, CN is replaced by soil profile water balance (WB) calculated for simulation of each day. The runoff is generated based on saturation excess mechanism. In this process, once the soil in the area saturate to the surface, any additional rainfall that falls irrespective of intensity becomes overland flow. For daily model particularly, partly-saturated regions, the approach were shown acceptable (Guswa *et al.*, 2002). SWAT-WB uses the soil moisture routines to determine the degree of saturation - deficit for each day of simulation for soil profile. This saturation – deficit (in mm H_2O) is the available storage, T, and expressed as:

$$T = EDC(\varepsilon - \theta) ------------------------------- 18$$

Where EDC is the effective depth of soil profile (unit less), ε is the total soil porosity (mm), and θ is the volumetric soil moisture for each day (mm). The volumetric soil moisture varies by the day and determined by SWAT's soil moisture routine while the porosity is constant value for each soil type. The effective depth is used to represent the portion soil profile used to calculate saturation deficit and is a calibration parameter (0 to 1). EDC will control the amount of water able to infiltrate each day by including the adjustment to the available storage and also spatially varied in such a way that higher EDC value will be used for areas with low surface runoff generation and low values are assigned to areas with a high likelihood of saturation. The adjusted available storage is then used to determine the portion of rainfall events will infiltrate and will runoff.

$$Q = \begin{cases} 0, \text{if } P < T \\ P - T, \text{if } P \geq T \end{cases} \quad ------------------------------ 19$$

Where Q is surface runoff (mm) and P is precipitation (mm). If the rain event is larger in volume than T, the soil profile will be saturated and surface runoff will occur. However, if the rain event is less than T, the soil will not be saturated and there will not be surface runoff as a result SWAT-WB is no longer reliant upon the CN method (white *et al*., 2009).

Daily and sub-daily meteorological data are essential inputs for SWAT model. The data can be measured previously and prepared in table format or generated by WXGEN weather generator model that also fill missed records if any (Sharpley and Williams, 1990). SWAT uses precipitation, maximum and minimum temperature, solar radiation, wind speed and solar radiation on daily basis.

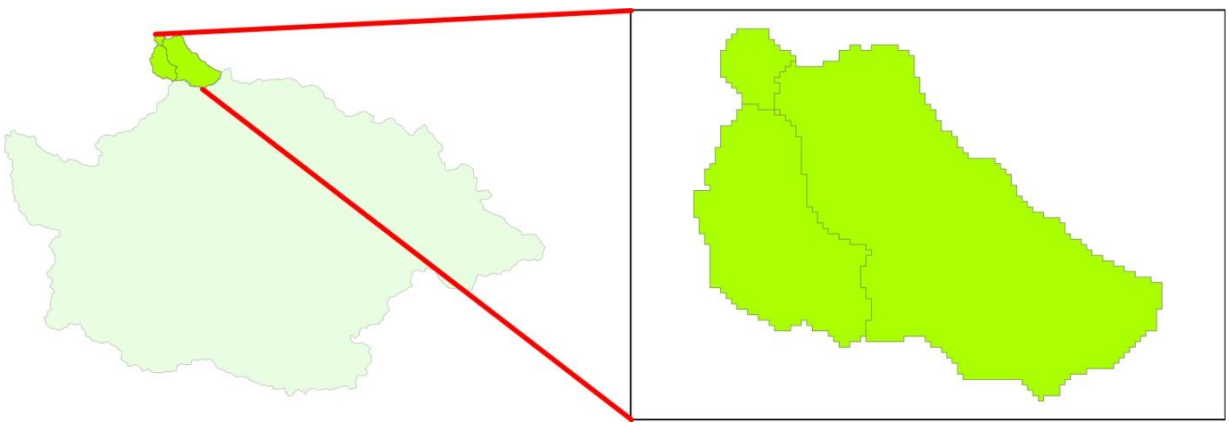
4.1.4. Weather Generator Model

WXGEN model generate precipitation using Markov chain-skewed (Nicks, 1974) or Markov chain-exponential model (Williams, 1995). First order Markov – chain is used to determined whether a day was dry or wet. Exponential or skewed distribution is used to generate precipitation amount whenever a wet day occurs (Neitsch *et al.*, 2005). The WXGEN model was provided using pcpSTAT.exe and dew02.exe (which include humidity data) based on Bahir Dar meteorological data as input information. The inputs for WXGEN model for this research were presented in Appendix 2. SWAT computes potential evapotranspiration (PET) using three methods; the Priestley-Taylor method (Priestley and Taylor, 1972), the Hargreaves method (Hargreaves *et al*., 1985) and the Penman-Monteith method (Monteith, 1965; R.G.Allen, 1986; R.G.Allen *et al*., 1989). In this research, skewed distribution and Penman-Monteith method were used for precipitation distribution and computation of PET.

4.2. Model Setup

4.2.1. Watershed Delineation

Watershed delineator tool in Arc SWAT allows the user to delineate the watershed and sub basins using Digital Elevation Model (DEM). The DEM was loaded from United States Geological Survey (USGS) in to Environmental System Research Institute (ESRI) format. Flow direction and accumulation were the concept behind to define the stream network of the DEM in SWAT. The monitoring points are added manually and the numbers of sub basin were adjusted accordingly. Finally, the watersheds were delineated to be 27 km^2 for Mizewa watershed and 1278 km^2 for Gumara watershed and 3 sub basins are generated for both watersheds.



Map 6: Gumara and Mizewa Watershed

4.2.2. HRU Definition

In SWAT-CN method, HRU definition helps to load land use map, soil map and also incorporate classification of HRU in to different slope classes. The land use map as well as soil map was overlapped 100 % with the delineated watershed and 16 HRUs for Gumara and 18 HRUs for Mizewa watershed were created for the 3 sub basins. The results were presented in Appendix 4 and Appendix 5 for Mizewa and Gumara watershed respectively. For the case of SWAT-WB, 79 and 28 HRU is created for 5 and 3 sub basins of Gumara and Mizewa watershed respectively. The topographic index map is created from DEM and loaded in place of soil map. As a result, 3.862467 and 21.31429 is the minimum and maximum topographic index for Gumara watershed while 4.943861 and 17.46242 is the minimum and maximum topographic index for Mizewa watershed respectively.

4.2.3. Weather Data Definition

Available Meteorological records (i.e. precipitation, relative humidity, minimum and maximum temperature and wind speed) and location of Meteorological station are prepared based on SWAT_CN and SWAT-WB table format and integrated with the model using weather data input wizards. In both methods, Bahir Dar Meteorological station data were used as weather generator.

4.3. Sensitivity Analysis, Calibration and Validation

After the model setup has been completed, the next step is to run the model and analyze the simulation result. The applicability of the model for intended purpose should be evaluated through the process of sensitivity analysis, calibration and validation (White and Chaubey, 2005) for further analysis of the result.

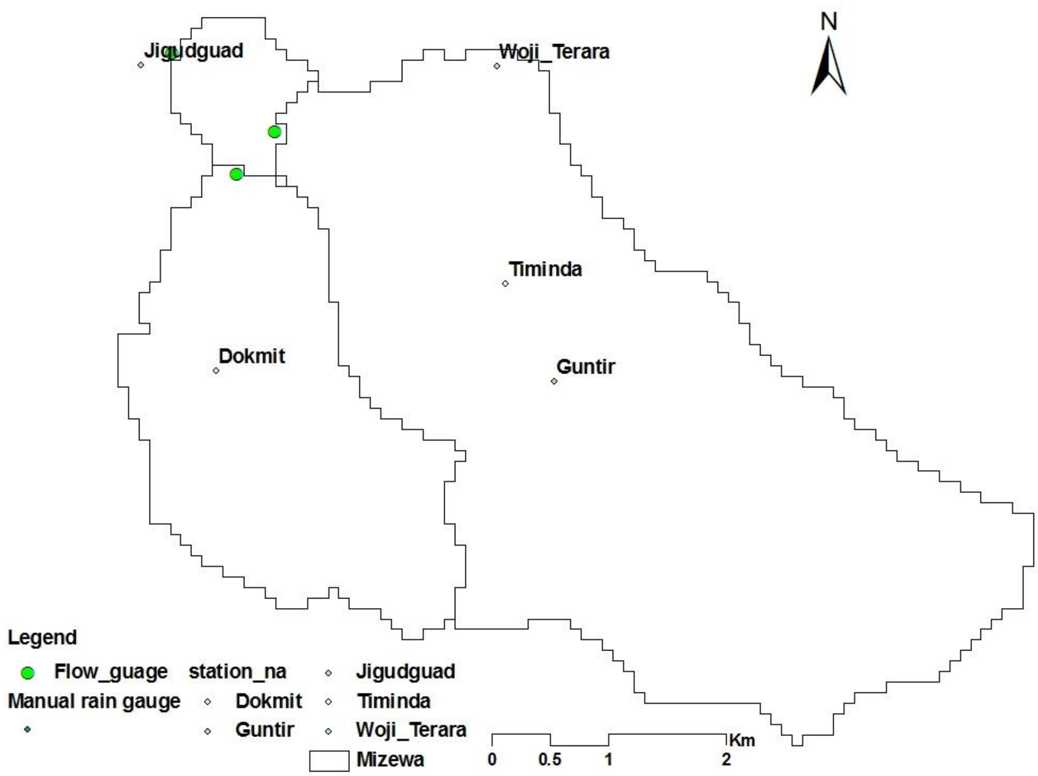
Sensitivity analysis evaluates the influence of different parameters on simulation result, the response of output variable to a change in input parameter (White and Chaubey, 2005). Model users are often faced with the difficult task of determining which parameters to calibrate so that the model response mimics the actual field conditions as closely as possible. In such cases, sensitivity analysis is helpful to identify and rank parameters that have significant impact on specific model outputs of interest (Saltelli *et al*., 2000).The most sensitive parameter corresponds to greater change in output response. To improve simulation result and thus understand the behavior of hydrologic system in Gumara and Mizewa watershed, sensitivity analyses were conducted using the entire flow parameters.

Model calibration involves modification of input parameters and comparison of predicted output with observed values until a defined objective function is achieved (James and Burges, 1982). Parameters identified in sensitivity analysis that influence significantly the simulation result were used to calibrate the model. In this research, model sensitivity and calibration were performed using the output of SWAT-CN method.

Two third of Gumara stream flow data were used for calibration and validated by the rest one third. In order to check the model using measured values, 1 staff gauge and 5 manual rain gauges were installed and stream flow and rainfall data's were collected. Rating curve was developed by collecting flow data for high and medium flow season using current meter. The distribution of monitoring points was presented in the table 13 and map 7 shown below.

Instruments	Sites	Location			Remark
		Lat	Lon	Elevation	
Flow Gauges	Site 1	1319575	367714	1851	Outlet
	Site 1	1316870	368088	1932	Dokmit
	Site 2	1319477	367446	1870	Jigudguad
Rain Gauges	Site 3	1319467	370493	1966	Woji Terara
	Site 4	1317614	370564	1947	Timinda
	Site 5	1316778	370975	1987	Guntr

Table 12: Location of hydro-meteorological stations



Map 7: Location map of hydro-meteorological stations

4.4.Model Performance

The accuracy, consistence and adaptability performance of the model must be evaluated (Go swami *et al*., 2005). Subjective and/or objective estimate of the closeness of simulated behavior of the model to observation is required to assess the performance of the model (P.Krause *et al*., 2005). The performance of the model has been evaluated using efficiency criteria, determination coefficient (r^2) and Nash- Sutcliff Efficiency (E_{ns}), 1970 to measure how well trend in the measure data are reproduced by simulated results over a specified period. Determination coefficient for n time step is calculated as :

$$r^2 = \frac{[\sum_{i=1}^{n}(Qsi - Qsm)(Qoi - Qom)^2}{\sum_{i=1}^{n}(Qsi - Qsm)^2 \sum_{i=1}^{n}(Qoi - Qom)^2} ---------------------- (19)$$

Where Qsi is simulated value, Qoi is measured value, Qom is the average observed value and Qsm is the average simulated value.

Nash- Sutcliff Efficiency (NSE) for n time step is calculated as:

$$NES = 1 - \frac{\sum_{i=1}^{n}(Qoi - Qsi)^2}{\sum_{i=1}^{n}(Qoi - Qom)^2} --------------------------- (20)$$

Where Qoi is observed, Qsi is the simulated and Qom is the observed average values

4.5. General Methodology

The general methodology adopted in this study was presented in figure 5 below.

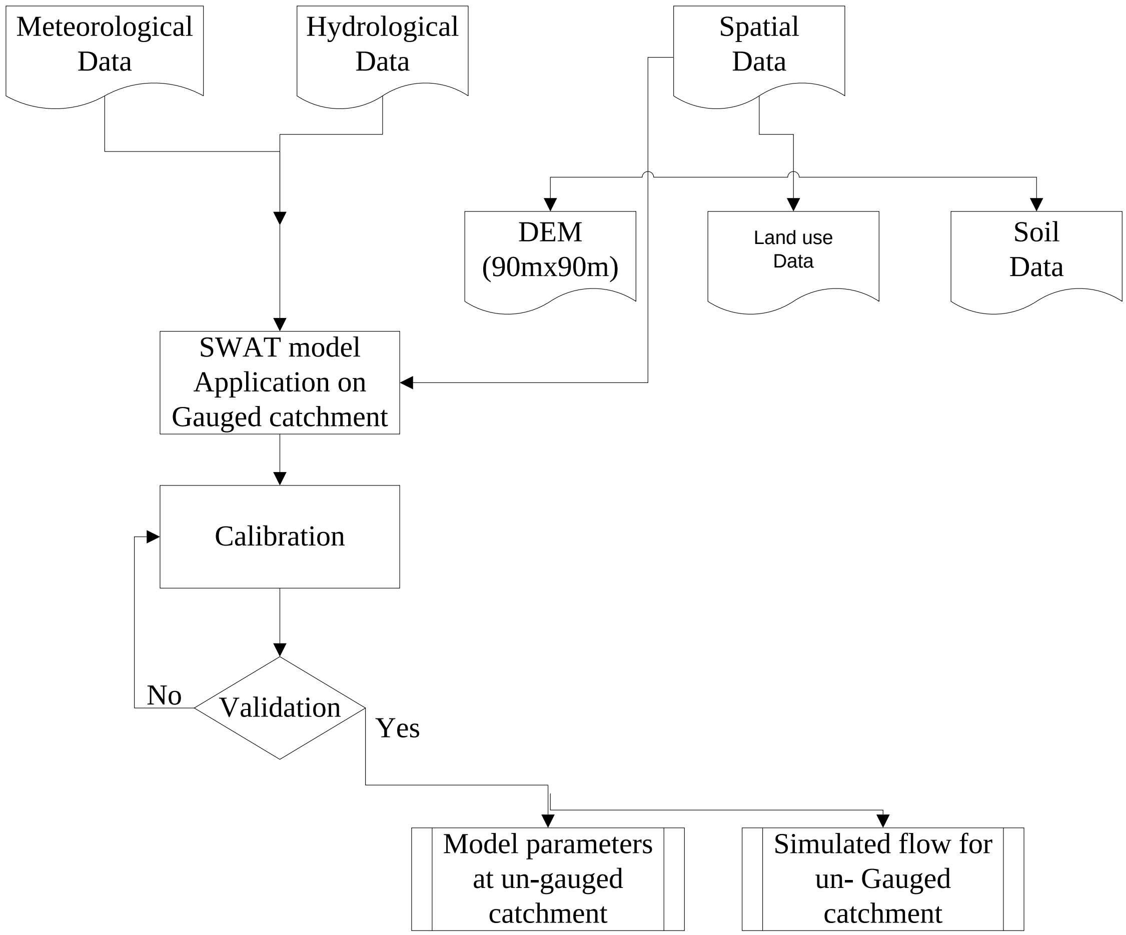


Figure 5: General methodology

CHAPTER FIVE

5. RESULT AND DISCUSSION

The result and discussion section can be classified in to five components: (a) flow parameter sensitivity analysis, (b) analysis of SWAT 2005 model sensitivity to the level of sub basin discretization, (c) Model calibration and validation for flow at Gumara and area proportion from Gumara to Mizewa watersheds (d) comparison of SWAT-CN and SWAT-WB (e) approach impact of land use and soil

5.1. Flow parameters sensitivity analysis

In this study, the entire flow parameters (26 parameters) were used for Gumara and Mizewa (using area proportion from Gumara as an observed flow) watersheds in the sensitivity analysis process and their relative impact was evaluated on the output. Predicted flow was found to be most sensitive for soil, land use properties: soil compensation factor (ESCO), initial SCS curve number II (CN2) and ground water parameters: like threshold depth of water in shallow aquifer for “revap” or percolation to deep aquifer to occur (REVAPmin) and groundwater “revap” coefficient (GW_REVAP). In general, the flow was found to be significantly sensitive to 8 parameters for both Gumara and Mizewa watershed. The level of significance was identified based on the study of Lenhart et al., (2002) that considers their mean index (I). The study classify as very high sensitive for those parameters having /I/ greater or equal to 1, high sensitive for those having 0.2 less or equal to /I/ less than 1, medium sensitive for those having 0.05 less or equal to /I/ less than 0.2 and small to negligible for those having /I/ less than 0.05. Hence, parameters having index value greater or equal to 0.05 are considered as sensitive parameters and used in calibration. Parameters having index value less than 0.05 does not significantly affect the result. The result of sensitivity analysis brought almost similar parameter ranks for the most sensitive parameters in the two watersheds (no significant change) indicating the homogeneity of the watersheds.

Parameters	Description	Rank	Relative sensitivity as per Lenhart et al 2002
ESCO	Soil evaporation compensation factor	1	High
CN2	Initial SCS curve number II value	2	High
REVAPmin	Threshold depth of water in shallow aquifer for “revap” [mm]	3	High
Gw_Revap	Groundwater "revap" coefficient	4	Medium
Gwqmn	Threshold water depth in the shallow aquifer for flow [mm]	5	Medium
Sol_Awc	Available water capacity [mm WATER/mm soil]	6	Medium
Alpha_Bf	Base flow alpha factor [days]	7	Medium
Sol_Z	Soil depth [mm]	8	Medium

Table 13: Most sensitive parameters for flow analysis for the case of Mizewa watershed

Parameters	Description	Rank	Relative sensitivity as per Lenhart et al 2002
ESCO	Soil evaporation compensation factor	1	High
CN2	Initial SCS curve number II value	2	High
REVAPmin	Threshold depth of water in shallow aquifer for “revap” [mm]	3	Medium
Gw_Revap	Groundwater "revap" coefficient	4	Medium
Sol_Awc	Available water capacity [mm WATER/mm soil]	5	Medium
Sol_Z	Soil depth [mm]	6	Medium
Alpha_Bf	Base flow alpha factor [days]	7	Medium
Gwqmn	Threshold water depth in the shallow aquifer for flow [mm]	8	Medium
Ch_K2	Channel hydraulic effective conductivity	9	Medium

Table 14: Most sensitive parameters for flow analysis for the case of Gumara watershed

5.2. Model Calibration and Validation

The comparison of default simulation output with the observed value shows a clear difference between the simulation result and observed stream flow which necessitate model calibration. The manual calibration was time consuming and exhaustive but helped to get better auto calibration result. Soil evaporation compensation factor (ESCO) and initial SCS curve number II value (CN2) were the two most sensitive parameters manually adjusted after auto calibration in order to increase model efficiency. Flow calibration was conducted for Gumara and Mizewa watersheds using observed stream flow for Gumara and area proportion from Gumara stream flow for Mizewa watershed for the year 1995 to 2004 (two third of the entire flow data used to calibrate the model). Three years, 1992, 1993 and 1994 were used for model initialization as recommended by SWAT user manual. Calibrated model efficiency was validated for the year 2004 to 2009 (one third of the entire flow data used for validation).

Parameters that affect the model result were adjusted in order for simulated output to meet the actual values as a result the objective functions (E_{ns} and R^2) are improved. The final adjusted parameter values for Gumara and Mizewa watershed are presented in table 17.

No.	Sensitive Parameters	Lower and upper bound	Final fitted value	
			Gumara	Mizewa
1	ESCO	0-1	0.3982	0.95936
2	CN2	±25	-23.242	-6.1768
3	REVAPmin	0-500	85.414	77.071
4	Gw_Revap	±0.036	-0.01602	0.010414
5	Gwqmn	0-5000	999.22	-19.762
6	Sol_Awc	±25	-3.7461	-23.020
7	Alpha_Bf	0-1	0.083495	0.030422
8	Sol_Z	±25	-1.6576	4.1428

Table 15: Flow sensitive parameters fitted after calibration

The comparison of observed and calibrated flow for 10 years of simulation indicated that there were a good agreement between observed and calibrated flow yielding higher value of coefficient of determination (r^2) and Nash-Sutcliffe efficiency (E_{ns}). The model performance can be judged as satisfactory if r^2 is greater than 0.6 and E_{ns} is greater than 0.5 (Setegn et al., 2008). The model goodness – of – fit was evaluated on daily basis for the two watersheds shown in table 18. Finally fitted parameter values were introduced in SWAT 2005 model for validation and then transferred to Mizewa watershed for further applications.

Rivers	Calibration		Validation	
	R2	NSE	R2	NSE
Mizewa	0.535	0.50	0.656	0.615
Gumara	0.684	0.658	0.755	0.696

Table 16: Calibrated Model Efficiency

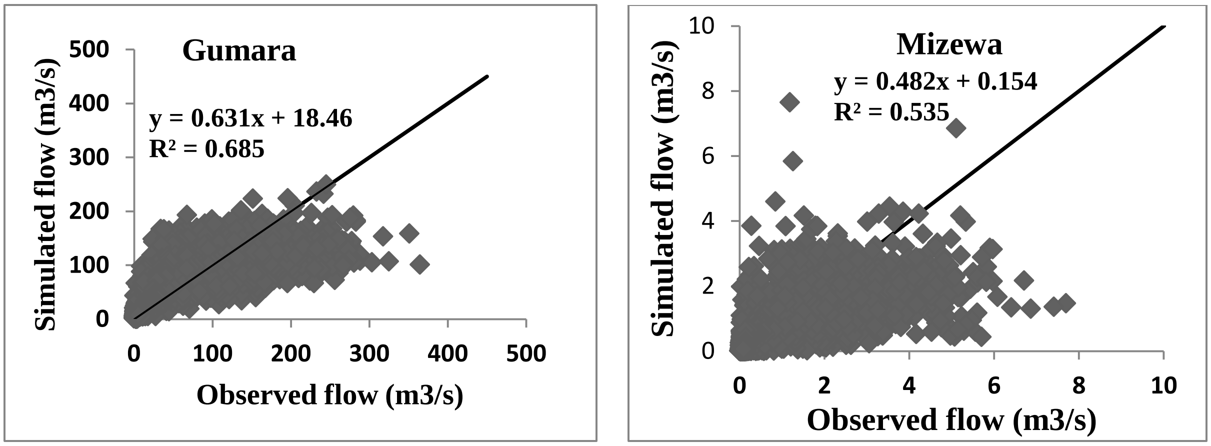


Figure 6: Scatter plot of simulated flow for Mizewa and Gumara watersheds (1995 to 2004)

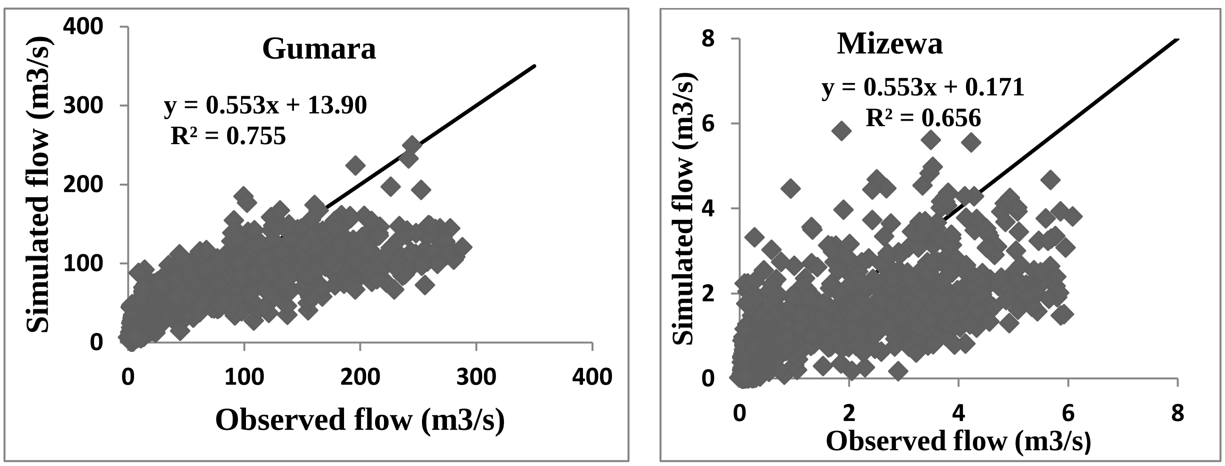


Figure 7: Scatter plot of simulated daily flow for Mizewa and Gumara watersheds (1995 to 2004)

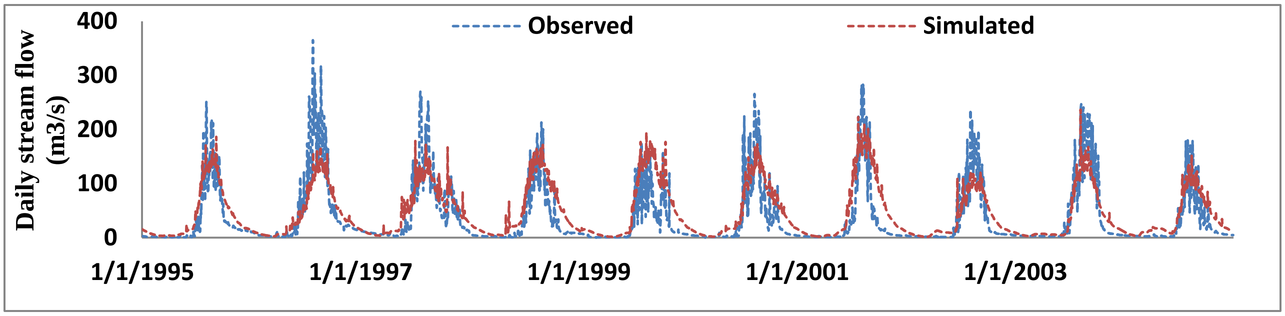


Figure 8: Simulated daily flow for Gumara watershed (1995 to 2004)

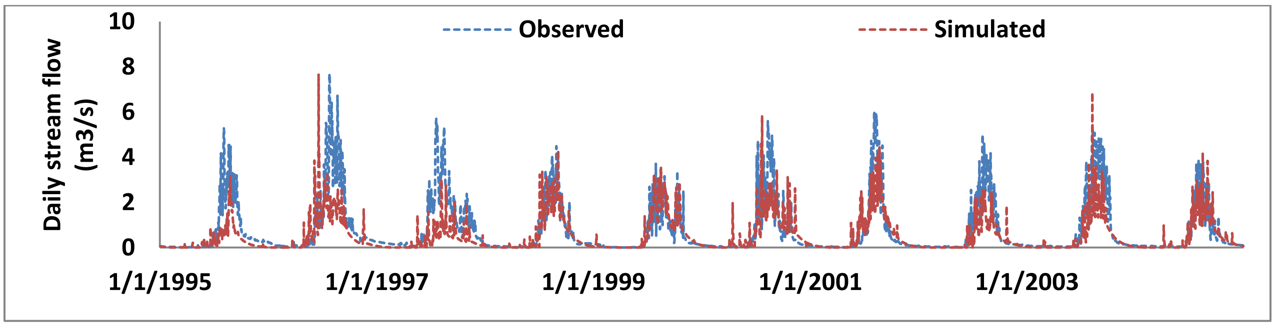


Figure 9: Simulated daily flow for Mizewa watershed (1995 to 2004)

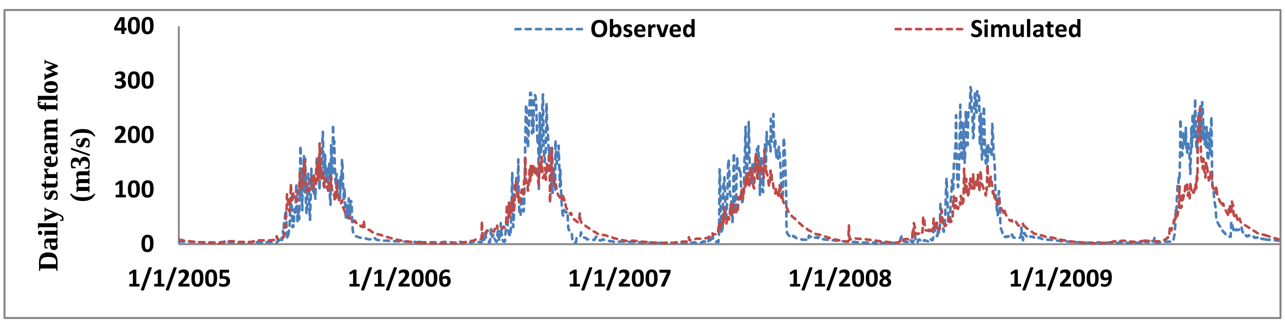


Figure 10: Simulated daily flow for Gumara watershed (2005 to 2009)

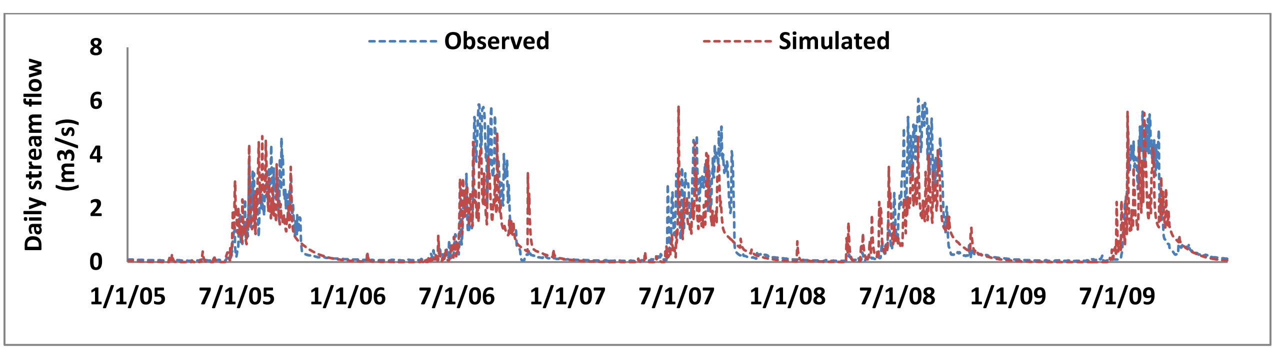


Figure 11: Simulated daily flow for Mizewa watershed (2005 to 2009)

The model underestimated the peak flow from the watershed in most of the year and overestimated for other year while the flow in the dry season was over estimated. At the beginning of rainy season, the simulated flow was greater than observed flow even high rainfall produce small amount of flow indicating that runoff generation was dependent on the wetness of the soil. This idea was supported by the farmers asked for the case of Mizewa River. Mainly, ground water was the source of runoff in the dry season as a result the contribution of lateral flow was negligible in this season.

As the rainy season proceeds, the daily runoff production increases. However, the rate of increase was higher for simulated flow than actually observed which were influenced by initial soil moisture within the watershed. Hence, the soil moisture within the watershed was overestimated by the model. At the end of the rainy season, the actual flow comes to recession faster than the simulated flow.

The performance of the model for validation period is better than that of calibration period. This is due to combined effect of different factors. One is the recent hydro-meteorological data has better quality. Secondly, recent land use and soil map was used to predict the stream flow which can improve the efficiency of the model.

The model was checked using short term observed flow and rainfall (30/8/2011 to 10/31/2011) and the result was presented in table 17 and figure 15 below.

Methods	Model performance	
	r^2	E_{ns}
Area proportion from Gumara	0.562	0.27
Parameters using from Gumara	0.52	0.20

Table17: Model efficiency using short term records of Mizewa River

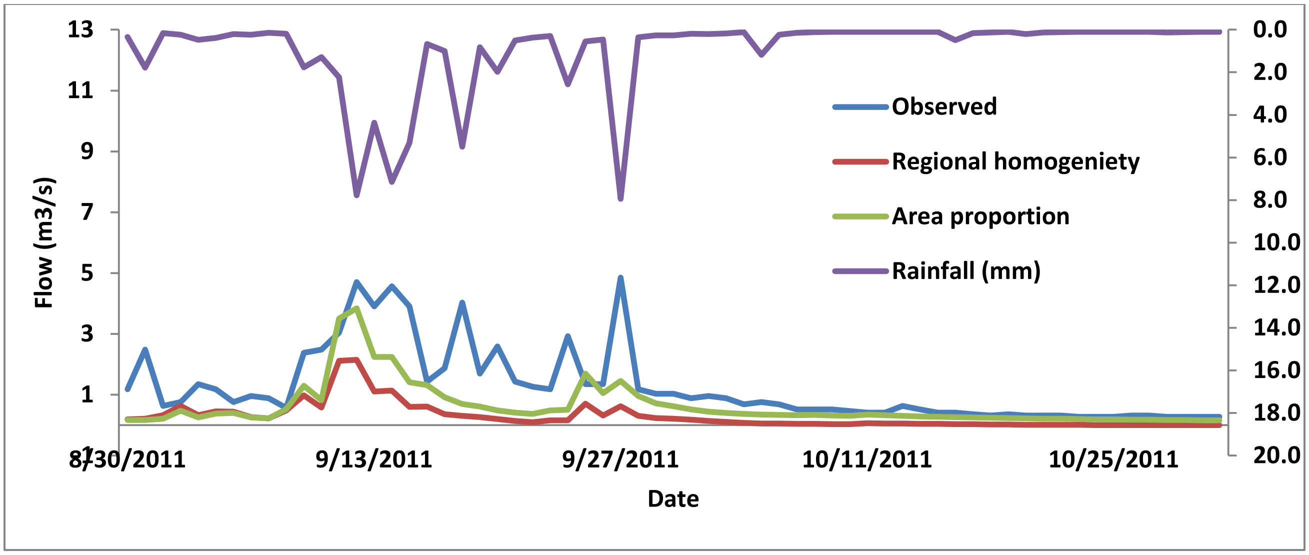


Figure 12: Daily time series of observed and simulated flow for 2 month duration (September – October)

The "Regional homogeneity" in the above simulation indicates the flow obtained by transferring parameters from Gumara watershed while Area proportion" indicates flow obtained by taking area proportional flow from Gumara watershed and calibrating parameters. The model resulted unsatisfactory efficiencies and also under estimate stream flow due to various reasons. One could be short term data were used (2 month) and it was the time that data collection were started and training the observers. So, the observers were not expected to collect quality data during this period. The channel (flow monitoring point) were not found to be stable through the time and only two flow seasons (high and medium) were used for rating curve development which has a great impact in better rating curve estimation. There is also abstraction from the river for irrigation of crop fields. However, the performance of the model was validated using long term flow data (Gumara flow) and resulted good model efficiency. The available water resource of the catchment for the duration is presented as:

Type	Available water resource
Total flow(mm)	34294.7
Surface flow(mm)	22102.5
Base flow (mm)	12192.2

Table18: Available water resource (8/30/23011 to 12/31/2011)

5.3.Comparison of SWAT-CN and SWAT-WB approach

The result of the two models was compared in 3 ways: using long term records for Gumara watershed (from which parameters were derived) and using long term records for Mizewa watershed (taking area proportion form Gumara River) and using available short term records for Mizewa watershed (Mizewa_S). In all cases, the result shows fair prediction for SWAT-CN approach than SWAT-WB. The main reason could be the soil properties. Soil classes in the two watersheds entirely lies on group C and D having low infiltration potential from A to D. Based on Food and Agricultural organization (FAO); group C soils have small infiltration rate even when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine textures while group D soils have high runoff potential and low infiltration rate even when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. This low infiltration capacity of the soils leads infiltration excess runoff generating approach to predict better than that of saturation excess approach in the case of the Gumara and Mizewa watersheds. The soil properties have a great impact in generating runoff.

	SWAT_CN			SWAT_WB		
Objective Function	Gumara	Mizewa	Mizewa_S	Gumara	Mizewa	Mizewa_S
Nash-Sutcliffe efficiency (E_{ns})	0.295	0.458	-0.50	0.294	0.45	-0.51
Coefficient of Determination (r^2)	0.427	0.485	0.110	0.409	0.34	0.13

Table 19: Model Efficiency before calibration (1995 to 2009)

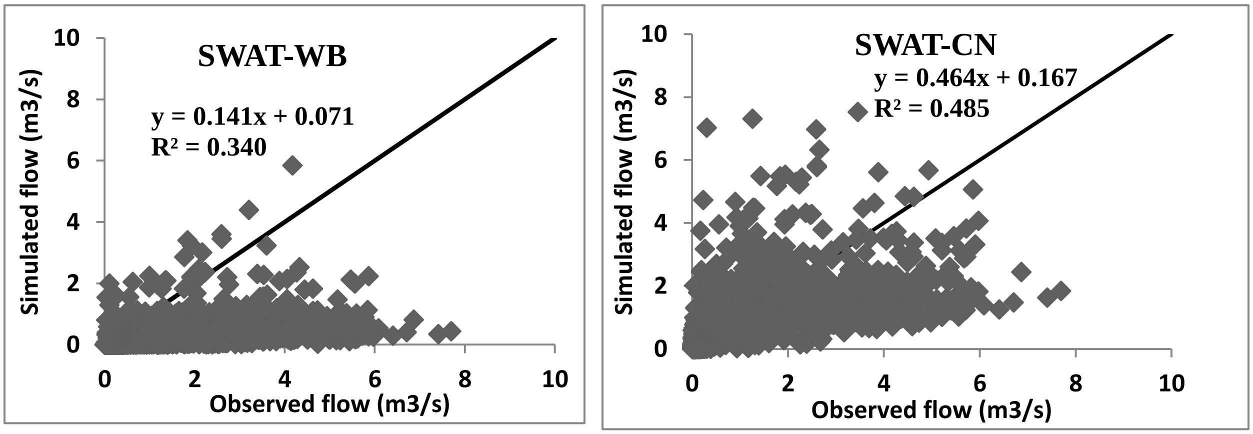


Figure 16: Scatter plot of SWAT-WB and-CN approach for Mizewa watershed (1995 to 2009)

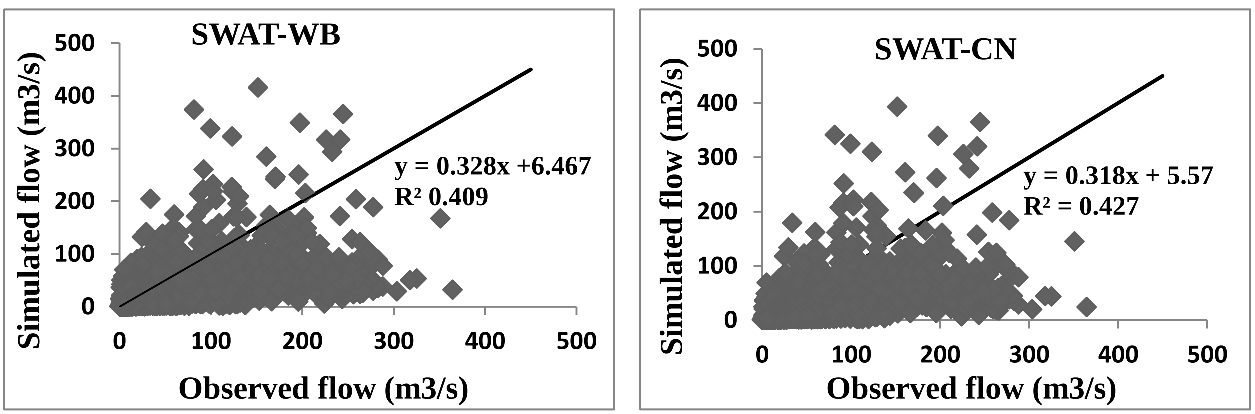


Figure 14: Scatter plot of SWAT-WB and -CN approach for Gumara watershed (1995 to 2009)

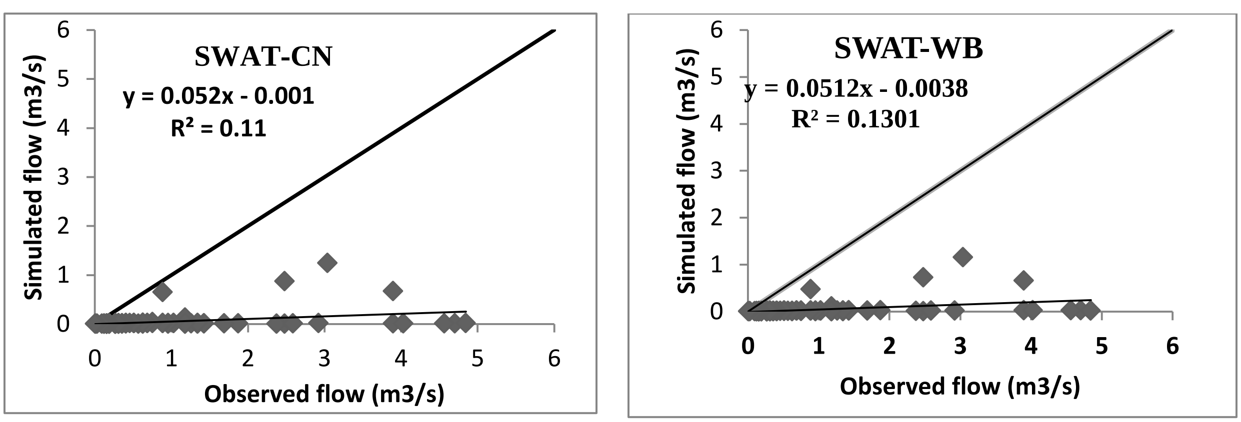


Figure 17: Scatter plot of SWAT-WB and -CN approach for Mizewa watershed (30/8/2011 to 31/12/2011)

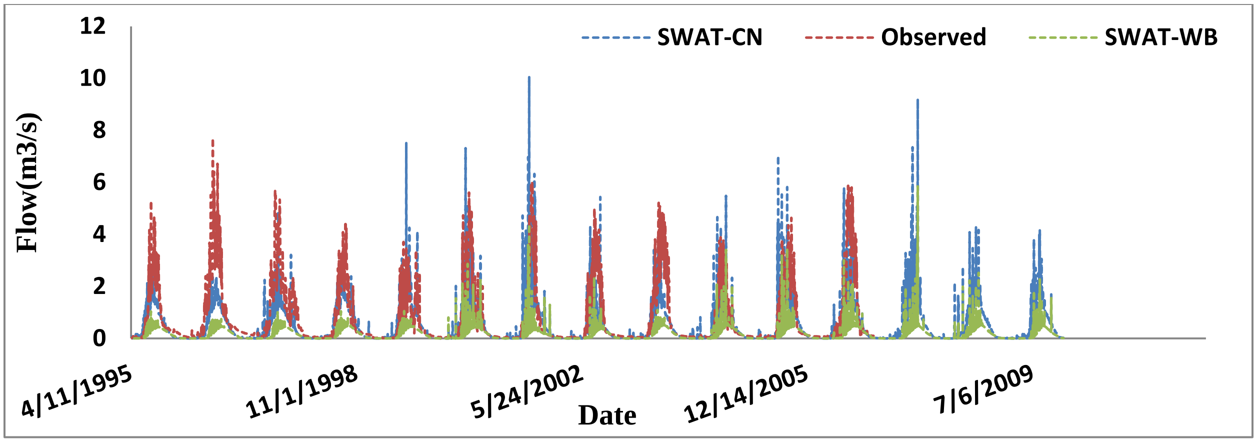


Figure 17: Daily flow simulation using SWAT-WB and SWAT-CN for Mizewa River (1995 to 2009)

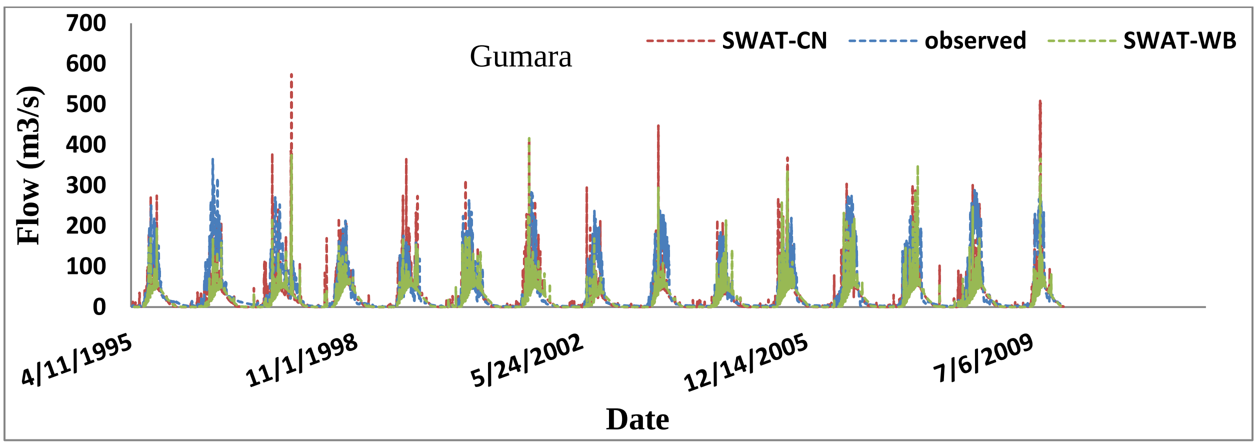


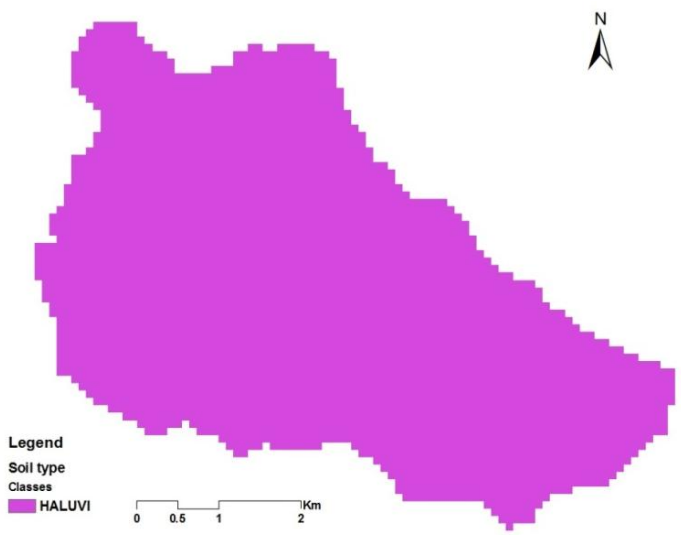
Figure 18: Daily flow simulation using SWAT-WB and SWAT-CN for Mizewa River (1995 to 2009)

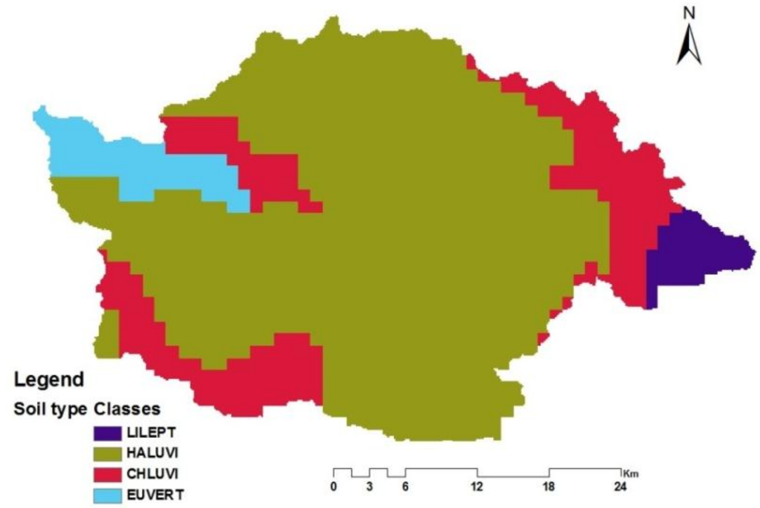
5.4.Impact of land use and soil

The hydrologic response unit (HRU) was defined using multiple scenarios which accounts 5% land use, 20% soil and 20 % slope. More detail (i.e. small percentage) creates more HRUs. Small land use percentage was used to analyze the impact of different land use on runoff generation. Soil can also be influential but soils are not absolute classifications so that only major soil groups are exclusively modeled.

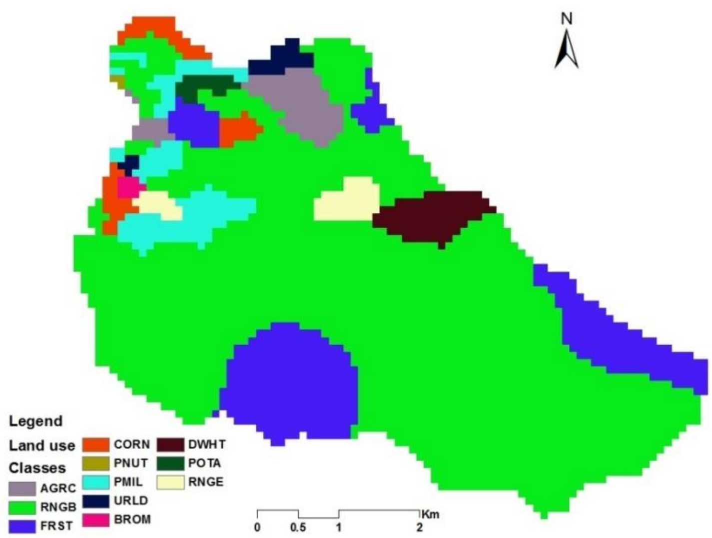
The surface runoff prediction for each HRU was analyzed for Gumara watershed. Areas with Halpic Luvisols contributed the least surface runoff to the reach. Halpic Luvisols has the highest sand content, the lowest clay content and high hydraulic conductivity (125 mm/hr) of all soil in Gumara watershed. Areas with Chromic Luvisols contributed large amount of surface runoff. Chromic Luvisols has low hydraulic conductivity and high clay content on the top of all soil with in the watershed. Halpic Luvisols was the only soil group in the case of Mizewa watershed.

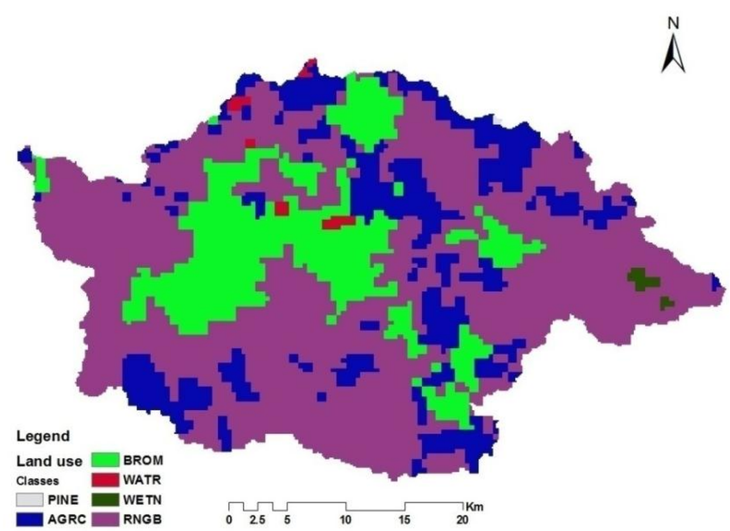
Different land use produces different surface runoff. Areas covered with agricultural land produced large amount of surface runoff of all land uses within the watershed while areas covered with Meadow Brome grass (BROM) and rang-brush (RNGB) contributed small amount of runoff with in the watershed. Most area of Mizewa watershed was covered with range-brush which have similar runoff generating characteristics in case of land use.





Map 8: Soil class of Mizewa and Gumara watersheds





Map 8: Land use map of Mizewa and Gumara watersheds

5.5.Impact of sub watershed discretization

This section can be seen separately for the two watersheds. (I) Mizewa watershed, sub basin discretization was performed based on installed monitoring points resulting in 3 sub basin that accounts for the main drainage line with in the watershed. The number of sub basins matches with the default watershed delineation which indicate increasing number of sub basin above this threshold has no significant change in stream flow simulation. (II) Gumara watershed, in this case, sub basin discretization was performed using the default monitoring points since no monitoring points exist within the watershed except at the outlet. Finally, Gumara watershed was subdivided in to 3 sub basins.

Surface runoff prediction was highly influenced by soil parameter (ESCO) and curve number (CN) which were not significantly affected by the size of sub basin. Due to this reason, sub watershed discretization on SWAT 2005 model has limited impact on simulation of stream flow in Mizewa watershed. In general, there are a number of factors affecting runoff; like watershed, climate. SCS curve number method was used to calculate surface runoff in SWAT model that accounts precipitation and retention. Curve number depends primarily on soil type, land use and to less extent on slope thus making runoff less dependent on sub basin discretization which could be considered as limitation of SWAT-CN.

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATION

In this research, emphasis has been given to runoff estimation from un- gauged catchment using semi distributed model SWAT. Gumara River, which were regionally homogenous with Mizewa River, has been modeled and parameters were derived by calibrating the simulated model with historical records and finally transferred to the un-gauged catchment (Mizewa). The model performance criteria showed the model were good and have acceptable performance. Parameters transferability of the model were checked by monitoring stream and recording rainfall and resulted with good performance (i.e. good parameter transferability). Hence, the model can be applied to watersheds within the same region.

The result of sensitivity analysis showed soil parameter ESCO was the most sensitive parameter. The second sensitive parameter identified is curve number (CN2). Thus, further detail study on soil and crop could possibly improve model performance and accuracy. Different rainwater and land management interventions were selected, which could minimize runoff and increase infiltration capacity, by farmers at landscape level. The selected interventions were among those identified by stakeholders, Agricultural Bureau and scholars at different workshops as potential interventions for the study area. Hydrologic response unit (HRU) analysis result showed agricultural land is the most runoff generating areas. Hence, training some farmers through innovation platform in order to adopt those interventions will result in better watershed management and increased water availability.

The model was calibrated and validated using long term records and resulted good model efficiency. However, the short term records for Mizewa watershed (i.e. 4 months) resulted with unsatisfactory model efficiency. Therefore, further study using long term records for the un-gauged small watersheds is required in order check the transferability of the model and the performance of SWAT-WB and SWAT-CN for Ethiopian highlands. It is also recommended to include low flow season measurements for rating curve development so that model efficiency is improved.

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Appendix

Appendix 1: Parameters for SWAT database for each crops within the watersheds.

CPNM	CROPNAME	BIO_E	HVSTI	BLAI	FRGRW1	LAIMX1	FRGRW2	LAIMX2	DLAI
AGRC	Agricultural Land-Close-grown	30	0.4	4	0.05	0.05	0.45	0.95	0.5
FRST	Forest-Mixed	15	0.76	5	0.05	0.05	0.4	0.95	0.99
WETN	Wetlands-Non-Forested	47	0.9	6	0.1	0.2	0.2	0.95	0.7
RNGE	Range-Grasses	34	0.9	2.5	0.05	0.1	0.25	0.7	0.35
RNGB	Range-Brush	34	0.9	2	0.05	0.1	0.25	0.7	0.35
WATR	Water	0	0	0	0	0	0	0	0
CORN	Corn	39	0.5	3	0.15	0.05	0.5	0.95	0.7
DWHT	Durum Wheat	30	0.4	4	0.15	0.01	0.5	0.95	0.8
PMIL	Pearl Millet	35	0.25	2.5	0.15	0.01	0.5	0.95	0.85
BROM	Meadow Brome grass	35	0.9	3	0.45	0.02	0.8	0.95	0.85
PNUT	Peanut	20	0.4	4	0.15	0.01	0.5	0.95	0.75
POTA	Potato	25	0.95	4	0.15	0.01	0.5	0.95	0.6

Appendix 2: Parameters in SWAT data base for each soil layer in the watersheds

SNAM	OBJECTID	NLAYERS	HYDGRP	SOL_ZMX	ANION_EXCL	SOL_CRK	SOL_Z1	SOL_BD1	SOL_AWC1
HALUVI	205	2	C	1060	0.5	0.5	300	1.42	0.11
CHLUVI	206	2	D	1080	0.5	0.5	300	1.38	0.11
EUVERT	208	2	C	1780	0.5	0.5	300	1.22	0.14

SNAM	SOL_K1	SOL_CBN1	CLAY1	SILT1	SAND1	ROCK1	SOL_ALB1	USLE_K1	SOL_EC1
HALUVI	125.8	0.6	21	25	54	1	0.06	0.39	0
CHLUVI	65.7	0.63	27	22	51	1	0.06	0.37	0
EUVERT	10.1	1.07	54	25	21	1	0.06	0.35	0

SNAM	SOL_Z2	SOL_BD2	SOL_AWC2	SOL_K2	SOL_CBN2	CLAY2	SILT2	SAND2	ROCK2
HALUVI	560	1.38	0.11	58.4	0.26	27	24	49	1
CHLUVI	580	1.33	0.11	26.6	0.35	34	21	45	1
EUVERT	1280	1.21	0.14	10.1	0.56	56	24	20	1

SNAM	SOL_ALB2	USLE_K2	SOL_EC2
HALUVI	0.06	0.38	0
CHLUVI	0.06	0.35	0
EUVERT	0.06	0.34	0

Appendix 3: Parameters for SWAT data base used for WXGEN model

Month	tmp_max	tmp_min	hmd	dewpt	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD	SOLARAV	WNDAV
Jan	27.51	7.73	6.94	9.41	38.3	42.31	0.52	0.01	0	0.2	53.47	0.82
Feb	29.37	9.61	0.04	8.34	0.51	0.51	2.27	0.02	0	0.5	52.74	1.13
Mar	30.53	11.75	0.35	8.82	6.63	6.61	0.91	0.1	0	2	53.84	1.27
Apr	30.67	14.11	0.75	10.46	21.64	21.32	0.94	0.16	0	3.4	51.22	1.38
May	29.89	14.78	2.23	13.11	74.5	73.14	1.5	0.39	0.03	7.4	46.5	1.27
Jun	27.29	14.21	1.23	14.8	124.76	122.18	2.78	0.95	0.04	13.8	45.77	1.22
Jul	24.29	13.99	2.38	15.09	296.34	291.72	0.94	0.95	0.05	20.3	40.26	0.93
Aug	24.34	13.75	1.21	15.37	257.78	252.71	1.44	0.95	0.03	20.2	38.11	0.78
Sep	25.63	12.9	2.75	14.96	135.48	133.31	2.27	0.95	0.06	14.5	45.47	0.85
Oct	26.66	13	18.75	13.29	155.04	160.41	1.93	0.35	0.07	7.2	48.02	0.93
Nov	27.05	10.5	0.4	11.58	7.9	7.88	2.41	0.08	0	1.8	49.2	0.95
Dec	27.36	7.93	0.08	9.74	1.12	1.12	3	0.03	0	0.7	51.67	0.85

Appendix 4: Final HRU Distribution for Mizewa watershed

Watershed	Mizewa (27 km^2)	%Watershed Area
LANDUSE:	Range-Brush --> RNGB	79.17
	Forest-Mixed --> FRST	15.33
	Corn --> CORN	1.08
	Pearl Millet --> PMIL	4.42
SOILS:	HALUVI	100
SLOPE:	0-5	2.49
	5--25	89.21
	25-9999	8.29

		Sub basins information		%Watershed Area	%Sub basin Area
SUBBASIN #			1	4.11	
LANDUSE:		Range-Brush --> RNGB		1.76	42.86
		Forest-Mixed --> FRST		0.23	5.56
		Corn --> CORN		1.08	26.19
		Pearl Millet --> PMIL		1.04	25.4
SOILS:		HALUVI		4.11	100
SLOPE:		0-5		1.53	37.3
		5--25		2.51	61.11
		25-9999		0.07	1.59
HRUs	1	Range-Brush --> RNGB/HALUVI/0-5		0.65	15.87
	2	Range-Brush --> RNGB/HALUVI/5-25		1.11	26.98
	3	Forest-Mixed --> FRST/HALUVI/5-25		0.16	3.97
	4	Forest-Mixed --> FRST/HALUVI/25-9999		0.07	1.59

	5	Corn --> CORN/HALUVI/0-5	0.42	10.32
	6	Corn --> CORN/HALUVI/5-25	0.65	15.87
	7	Pearl Millet --> PMIL/HALUVI/0-5	0.46	11.11
	8	Pearl Millet --> PMIL/HALUVI/5-25	0.59	14.29
SUBBASIN #		2	69.56	
LANDUSE:		Range-Brush --> RNGB	59.76	85.92
		Forest-Mixed --> FRST	9.79	14.08
SOILS:		HALUVI	69.56	100
SLOPE:		5--25	63.17	90.81
		25-9999	6.39	9.19
HRUs	9	Range-Brush --> RNGB/HALUVI/5-25	59.76	85.92
	10	Forest-Mixed --> FRST/HALUVI/5-25	3.4	4.89
	11	Forest-Mixed --> FRST/HALUVI/25-9999	6.39	9.19
SUBBASIN #		3	26.33	
LANDUSE:		Range-Brush --> RNGB	17.64	67
		Forest-Mixed --> FRST	5.31	20.17
		Pearl Millet --> PMIL	3.38	12.83
SOILS:		HALUVI	26.33	100
SLOPE:		5--25	23.53	89.37
		25-9999	1.84	6.98
		0-5	0.96	3.65
HRUs	12	Range-Brush --> RNGB/HALUVI/5-25	17.64	67
	13	Forest-Mixed --> FRST/HALUVI/25-9999	1.84	6.98
	14	Forest-Mixed --> FRST/HALUVI/5-25	3.47	13.2
	15	Pearl Millet --> PMIL/HALUVI/5-25	2.42	9.18
	16	Pearl Millet --> PMIL/HALUVI/0-5	0.96	3.65

Appendix 5: Final HRU distribution for Gumara watershed

Watershed	Gumara (1278 km^2)	% watershed Area
LANDUSE:	Agricultural Land-Close-grown --> AGRC	18.27
	Meadow Brome grass --> BROM	19.71
	Range-Brush --> RNGB	62.02
SOILS:	CHLUVI	10.98
	HALUVI	83.35
	EUVERT	5.66
SLOPE:	5--25	82.91
	25-9999	9.29
	0-5	7.8

Sub basins information		%Watershed Area	%Sub basin Area
SUBBASIN #	1	46.48	
LANDUSE:	Agricultural Land-Close-grown --> AGRC	9.66	20.79
	Meadow Brome grass --> BROM	10.72	23.06
	Range-Brush --> RNGB	26.1	56.14
SOILS:	HALUVI	4.11	100
SLOPE:	5--25	37.19	80.01
	25-9999	9.29	19.99
HRUs 1	Agricultural Land-Close-grown --> AGRC/CHLUVI/5-25	2.22	4.77
2	Agricultural Land-Close-grown --> AGRC/HALUVI/5-25	5.55	11.94
3	Agricultural Land-Close-grown --> AGRC/HALUVI/25-9999	1.9	4.08
4	Meadow Brome grass --> BROM/HALUVI/5-25	8	17.22
5	Meadow Brome grass --> BROM/HALUVI/25-9999	2.72	5.84
6	Range-Brush --> RNGB/CHLUVI/5-25	7.11	15.31
7	Range-Brush --> RNGB/HALUVI/5-25	14.31	30.78
8	Range-Brush --> RNGB/HALUVI/25-9999	4.68	10.06
SUBBASIN #	2	19.29	
LANDUSE:	Agricultural Land-Close-grown --> AGRC	2.28	11.81
	Meadow Brome grass --> BROM	2.29	11.87
	Range-Brush --> RNGB	14.72	76.32
SOILS:	HALUVI	13.62	70.63
	EUVERT	5.66	29.37
SLOPE:	5--25	11.49	59.58
	0-5	7.8	40.42

Sub basins information		%Watershed Area	%Sub basin Area
HRUs 9	Agricultural Land-Close-grown --> AGRC/HALUVI/5-25	2.28	11.81
10	Meadow Brome grass --> BROM/EUVERT/0-5	0.74	3.86
11	Meadow Brome grass --> BROM/HALUVI/5-25	1.54	8.01
12	Range-Brush --> RNGB/EUVERT/0-5	4.92	25.51
13	Range-Brush --> RNGB/HALUVI/5-25	7.67	39.76
14	Range-Brush --> RNGB/HALUVI/0-5	2.13	11.05
SUBBASIN #	3	34.23	
LANDUSE:	Agricultural Land-Close-grown --> AGRC	6.33	18.48
	Meadow Brome grass --> BROM	6.7	19.59
	Range-Brush --> RNGB	21.2	61.93
SOILS:	CHLUVI	1.65	4.82
	HALUVI	32.58	95.18
SLOPE:	5--25	11.49	59.58
	0-5	7.8	40.42
HRUs 15	Agricultural Land-Close-grown --> AGRC/CHLUVI/5-25	1.65	4.82
16	Agricultural Land-Close-grown --> AGRC/HALUVI/5-25	4.68	13.66
17	Meadow Brome grass --> BROM/HALUVI/5-25	6.7	19.59
18	Range-Brush --> RNGB/HALUVI/5-25	21.2	61.93

Declaration

I, the under designed, declare that the thesis comprises my own work. In compliance with internationally accepted practices, I have duly acknowledged and referenced all materials used in this work. I understand that non-adherence to the principle of academic honesty and integrity, misrepresentation/fabrication of any idea/data/fact/source will constitute sufficient ground for disciplinary action by the university and can also evoke penal action from the sources which have not been properly cited or acknowledged.

Signature

Name of Student

University Id. number

Date