Addis Ababa University

School of Graduate Studies

Addis Ababa Institute of Technology

Hydraulic Engineering Stream

Assessment of Land Use/Land Cover Change Impact on Stream Flow Using SWAT Model (The Case Study of Katar Catchment)

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University

In Partial Fulfillment of the Requirements for the Degree of

Master of Science in Civil Engineering

(Hydraulic Engineering Stream)

Tolera Kabeto Dode   ID: GSR/1294/08

Adviser: Dr. Eng. Dereje Hailu

Addis Ababa, Ethiopia

March 2018

Approval

As members of the Examining Board of the Final MSc. Open Defense, we certify that we have read and evaluated the thesis prepared by: Tolera Kabeto Dode. ID No GSR/1294/08

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I certify that I have read and recommend for acceptance by Addis Ababa University a thesis entitled**:** **"***Analysis of Land Use/Land Cover Change Impact on Hydrological Regime Using SWAT Model (The Case Study of Katar Catchment)*" for the partial fulfillment of the requirements of the degree of Masters of Science in Civil Engineering (Major Hydraulic Engineering).

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Dr. Eng. Dereje Hailu (Advisor)

Date ……………….

STATEMENT OF THE AUTHOR

The author declares that this thesis is not submitted to any other institution for the award of any academic degree or diploma. The source of all materials used in this work has been acknowledged. This thesis has been submitted in partial fulfillment of the requirements for MSc. degree in Hydraulic Engineering at Addis Ababa University and deposited at the University Library to be made available to borrowers - under rules of the Library.

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Place: Addis Ababa Institute of Technology, Addis Ababa, Ethiopia

March 2018

BIOGRAPHICAL SKETCH

The author was born in June1989 in East Shoa Zone/Dugda District. He attended his elementary and secondary school education at Meki Junior School and Meki Catholic School respectively. He completed his high school in 2007 and joined Haramaya University Institute of Technology in 2008 and graduated with BSc. Degree in Department of Soil and Water Engineering in June 2013.

After graduation, he was employed as Assistant lecturer by Adama Science and Technology University from July 2013 until he joined Addis Ababa University in October 2015 for MSc. in Hydraulic Engineering.

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LIST OF ABBREVIATIONS

AOI	Area of Interest
CRV	Central Rift Valley
DEM	Digital Elevation Model
FAO/UNESCO	Food and Agicultural Organization/United Nations Educational,Scientific and Cultural Organization
GIS	Geographic Information System
GUI	Graphical User Interface
GW_Q	Ground Water Flow
HEC-HMS	Hydraulic Engineering Centre-Hydrologic Modeling System
HRU	Hydrologic Response Unit
LU/LC	Land Use/Land Cover
MoWIE	Minstry of Water Irrigation and Electricity
NSE	Nash and Sutcliffe simulation efficiency
PBIS	Percent bias
R^2	Coefficient of Determination
SUFI 2	Sequential Uncertainty Fitting
SURQ	Surface Runoff
SWAT	Soil and Water Assessment Tool
WGEN	Weather Generator

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ABSTRACT

Water is a precious and finite resource and must be managed in sustainable way to meet human as well as environmental needs. Land use land cover change has an impact for alteration of watershed hydrology. In the last 24 years Katar catchment experienced land use/land cover change. The Katar watershed, which is the major contributor of runoff for Lake Ziway is very sensitive to land use and land cover change. The basin is undergoing land use change due to intensive cultivation and urbanization as a result of population growth which has an impact on hydrologic response of the basin. This study quantified basin runoff volume using SWAT model and assessed the effect of land use/land cover change on the stream flow. Geographic Information system (GIS) was integrated with SWAT model to carry out the study. Arc GIS10.4.1 and Erdas IMAGINE2014 were used to process soil raster data set and prepare land use/cover map from Land sat image acquired in 1995 and 2015 respectively. Land use classification was performed using supervised classification system and accuracy assessment was done using confusion matrix. Classification result indicated expansion of agricultural and settlement lands. Using the two land use/cover map SWAT model was set up and run and the default simulation was compared with the observed data. Then sensitivity analysis was made on monthly basis using 20 flow parameters where only six parameters were identified as influencing the flow. The model calibration was done from 1991 to 1999 and validation period from 2000 to 2004. The calibration and validation results showed good match of simulation with observation with Nash-Sutcliff efficiency 0.84 and 0.6 coefficient of determination (R^2) 0.87 and 0.62 for calibration and validation respectively. The result showed that the mean wet monthly flow increased by 17.21% (from 50.38m^3/s in1995 to 59.05m^3/s in 2015) and the mean dry monthly flow decreased by 41.69% (from 22.43m^3/s in 1995 to 13.08m^3/s in 2015). Generally the study result indicated flow during wet season increased whereas during dry season decreased. The SURQ contribution increased whereas GWQ decreased from 1995 to 2015 as a result of expansion of agricultural and settlement area. The study results showed change in flow with change in land use/cover.

1. INTRODUCTION

1.1 Background of the Study

Water is a precious substance and necessary for all living things. It is a finite resource and must be managed in sustainable way to meet human as well as environmental needs. Land use/ land cover change has an impact for alteration of watershed hydrology. The land use planning and management are highly related to the sustainability of water resources as changes of land use are linked with amount of water through relevant hydrological processes (Guo, 2008). Effective methods and mechanism should be used to maintain water sustainability. Nowadays, the hydrological models are good to represent the hydrological characteristics (Surur, 2010)

Hydrological modeling and water resource management are highly related to the processes of the hydrologic cycle. This cycle can be affected by land use and land cover change. Land use land cover is in a dynamic condition especially in developing countries like Ethiopia. The land use and land cover changes can be caused by human and natural factors (Meyer, W.B. and Turner, B. L., 1994). The understanding of the influence of land use land cover change on hydrology enables water resource planners to formulate policies to minimize the effects of future land cover changes on hydrology.

The sustainable use of water is becoming increasingly important in legislative agenda of Ethiopia. The overall goal of the Ethiopian Water Resource Policy is to enhance and promote all national efforts toward the efficient, equitable and optimum utilization of the available water resources of the country for significant socio-economic development on sustainable basis.

Over the past years, increasing extents of land were converted into agricultural lands (Ambachew Getnet and Fungai Svondo, 2010) because of population growth and increase in foreign direct investment which change the use and distribution of water. The removal of surface water and ground water for irrigation changes the water's natural distribution and impacts the sustainability of ecosystem that depends on it.

The increase in population number put pressure on water resource. The land use changes due to population increment that impact water resources are expansion of agricultural activities and urbanization. Tillage of the land and clearing of forests can change infiltration and runoff characteristics, which affect ground water recharge, water yield and Evapotranspiration.

Changes in land use have potential impacts on water resources, yet quantifying these impacts remain among the more challenging problems in hydrology.

Land and water resources degradation are the major problems in the Ethiopian Central Rift Valley Basin. The area is one of the most important from its water resources development point of view. The CRV basin lakes are undergoing degradation due to upstream land use land cover change impacts like agricultural expansion which affects streams feeding the lakes. The lakes surface water level have dropped across the Central Rift Valley because of water extraction for irrigation (Legesse, D. and Ayenew, T., 2006). Agricultural expansion (irrigation system), urbanization, poor land use practices and improper management systems have a significant impact on basin hydrology. Farm lands and settlements expanded which is mostly associated with the decrease in forest land (Kassa, 2007). The Katar River catchment, a sub catchment of CRV basin is experienced land use and land cover change which impacts basin hydrology. The Katar River which feed Lake Ziway showed flow variation over the past years due to catchment exposure to LU/LC change. The Katar Catchment flow variation has an impact on Lake Ziway. Therefore, to propose type of management it requires, the identification of the LU/LC change impact on the Katar basin hydrology is very important. The understanding of the impacts of LULC change on hydrologic processes and combining this understanding into the emerging focus on LULC change are major needs for future. So far, limited studies have been conducted to identify the impact of LU/LC on basin hydrology to combat the problems in Rift Valley Basin Katar Sub watershed. In this study a physically based watershed model, SWAT model was applied to the Central Rift Valley Ketar Sub watershed for assessing impact of land use change on basin hydrology and the findings of this study will also enable planners to formulate policies to minimize the undesirable effects of future land use/land cover changes in the catchment.

1.2 Problem Statement

The Katar watershed, which is the major contributor of runoff for Lake Ziway is a very important area in connection with its water resources. The contribution of Katar River to Lake Ziway is 36.62% out of overland flow from un gauged catchment and Meki River contribution to the Lake (Abu, 2010). The basin experienced land use and land cover change over the past decades. The basin is intensively cultivated and there is high expansion of settlement in the basin. The hydrological processes are highly related to land use and land cover change. The Katar River showed flow variation since the hydrological processes are sensitive to land use and land cover change. The basin is undergoing land use change due to intensive cultivation and urbanization as a result of population growth which has an impact on hydrologic response of the basin. The conversion of forested land into irrigation agricultural activities and urbanization has a great influence on the land use and land cover of the basin as well as on basin hydrology. Therefore, there is the need for the basin to formulate strategies to manage water resources in the basin. This can be done after quantification of the basin runoff. Therefore, this study quantifies basin runoff volume using SWAT model and assess the effect of land use change on the stream flow.

1.3 Objectives

Main Objective

To assess basin hydrologic (surface runoff, ground water flow & stream flow) response under land use and land cover changes in Katar watershed using SWAT model

Specific Objective

- ✓ To determine the land use changes over the last 21 years in Katar Basin
- ✓ To Evaluate the Effects of Land Use/Land Cover Change on Stream Flow

1.4 Research' Questions

- ✓ How the land use/land cover changed over the past 21 years
- ✓ How stream flow changed with change in land use/land cover?

2. LITERATURE REVIEW

In this section, literatures were cited on relevant topics such as land use and land cover change, land use and land cover change studies in Ethiopia, land use/land cover change impacts on hydrology, hydrological models, and hydrological model selection criteria, application of hydrological model (SWAT), SWAT development and interface, SWAT-CUP and model performance evaluation criteria.

2.1 Land Use and land cover change

Land use and land cover can be defined as how land is utilized. For example, residential and industrial land use would be considered one type of developed land use. Land cover is slightly different. A park could be forest, in this land use is a park and land cover is a forest.

Land use and land cover change are significant in catchment studies. Some work by (Golosov, V. and Panin A., 2006) showed that hydrological regime and sediment flux change drastically following the farming activities within a basin. Cultivation of land exerts a major influence on the relationship between surface and subsurface flow. According to data from long term observations done in paired catchments, in the forest zone of Central Russia (Golosov, V. and Panin A., 2006). Surface runoff is extremely limited under grass or forest vegetation compared with agricultural land.

Hydrological effects of land use/land cover change manifested in many ways and at different spatial and temporal scales. Most obvious is the immediate and direct effects on the quantity and quality of catchment's runoff. For example, land cover change is the most significant factor driving hydrologic changes such as runoff volume, timing and variability (Fohrer, 2001). The simplest method to assess these effects on hydrologic response of catchment is by comparing stream flow and runoff generated from the catchment areas with the contrasting land use types (Barkhordari, 2003). The main causes for land use change are due to manmade and natural causes, where the man made causes are mainly attributed to the reach for resources to meet human needs. For instance, deforestation is a result of the need for timber for construction, fuel wood and clearing for agricultural development and for settling the ever increasing population (Chemelil, 1995) and increase in foreign direct investments or land grabbing (Ambachew Getnet and Fungai Svondo, 2010), increased deforestation in the investment area (Gobena, 2010).

2.2 Land Use and Land Cover Change Studies in Ethiopia

In Ethiopia, land is used for agricultural purposes, for construction of buildings and roads and extra purposes. In the country most of the land is used for subsistence farming. With the population growth and slow technological adoption which can increase production, there is deforestation for more production which means conversion of forest to agricultural land and expansion of urban settlements.

The researches conducted by different researchers in different parts of the country indicate that there were LU/LC changes in the country. For instance (Hadgu, 2008) identified that decrease of natural vegetation and expansion of agricultural land cover over a period of 41 years in Tigray, northern part of Ethiopia. The other research indicated that the expansion and intensification of agricultural land is due to population growth (Efrem, 2010) in the semiarid of Central Rift Valley of Ethiopia and (Molla, 2014) Concluded that LU/LC dynamics in the Central Rift Valley Region of Ethiopia was due to population pressure which caused agricultural expansion in to marginal land and more sever land degradation. (Kassa, 2007) indicated that farm lands and settlements has expanded which was mostly associated with the decrease in forest in Hare watershed Southern Rift Valley Lakes Basin and deforestation was due to rapid population growth.

2.3 Land Use and Land Cover Change Impacts on Hydrology

Water on earth exists in a space called the hydrosphere and lithosphere, circulates and forming hydrologic cycle. The cycle has no beginning and no ending and can be affected by different factors. Among those factors, manmade activities, land use and land cover change can affect hydrological processes such as infiltration, runoff and groundwater recharge. Different studies indicate that land use and land cover change have an impact on hydrologic components. For instance, (Adamu, 2013) concluded that land use and land cover changes have major impacts on hydrological processes, such as runoff and ground water flow, (Melesse, 2012) concluded that the decrease of forest land and grass land was accompanied by the increase in agricultural and built up areas and this change in land use and land cover increased surface run off during wet seasons and reduced base flow during the dry seasons. (Gebrie, 2016) Concluded that the land use and land cover change have a great influence on stream flow especially during wet season than dry season. Cultivation of land exerts a major influence on the relationship between surface and subsurface flow. According to data from long term observations done in paired catchments, in the forest zone of Central Russia (Golosov, V. and Panin A., 2006). Surface runoff is extremely limited under grass or forest vegetation compared with agricultural land.

2.4 Hydrologic Models

Hydrologic modeling has proved to be very important tool that can be applied to understand and explain the effects of LU/LC change on hydrologic response of a catchment (Baldyga, J. T., 2005). Hydrological models are mathematical descriptions of components of the hydrologic cycle. They have been developed for many different reasons and therefore have many different forms. However, hydrological models are in general designed to get a better understanding of the hydrologic processes in a watershed and of how changes in the watershed may these phenomena and for hydrologic prediction (Kassa Tedele, 2007). They are also providing valuable information for studying potential impacts of changes in land use and land cover or climate change.

There are many classification of hydrologic models, deterministic versus stochastic, lumped versus distributed and etc. On the basis of process description, the hydrological models can be classified in to three main categories (Cunderlik, 2003).

Lumped models

Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub basins. The parameters often do not represent physical features of hydrologic processes and usually involve certain degree of empiricism. These models are not usually applicable to event scale processes. If the interest is primary in the discharge prediction only, then these models can provide just as good simulations as complex physically based models (Beven, K.J.;, 2000).

Distributed models

Parameters of distributed models are fully allowed to vary in space at resolution chosen by the user. Distributed modeling approach attempts to incorporate data concerning the spatial distribution of parameters together with computational algorithms to evaluate the influence of this distribution on simulated precipitation runoff behavior. Distributed models generally require large amount of data.

Semi distributed models

Parameters of semi distributed models are partially allowed to vary in space by dividing the basin in to a number of smaller sub basins. The main advantage of these models is that their structure is more physically based than the structure of lumped models and need less input data than fully distributed models. SWAT, HEC-HMS and HBV are Considered as semi distributed models.

2.5 Hydrological Model Selection Criteria

There are many criteria which can be used for choosing the right hydrologic model. These criteria always project dependent, since every project has its own specific requirements and needs. Further, some criteria are user dependent, such as the personal preference for graphical user interface (GUI), computer operating system, input out management system and structure. The four fundamental criteria that must be considered for model selections are:

- ✓ Predict the impact of land management practices on water, sediment, and agricultural yields in large complex watersheds with varying soils, land use and management conditions over long periods of time

- ✓ Requires specific information about weather, soil properties, topography, vegetation, and land management practices in watershed. SWAT models water movement, sediment movement, crop growth, and nutrient cycling with this information. Therefore, watersheds with no monitoring data can be modeled, and the effect of changes in input data can be quantified
- ✓ Hydrological processes that need to be modeled to estimate the desired outputs adequately (Is the model capable of simulating single event or continuous processes?)
- ✓ Available of input data (Can all the inputs required by the model be provided within the time and cost constraints of the project?

In addition, the model must be readily and freely available within available documentation and should be applied over a range of catchment sizes from large to global.

For this study SWAT (semi distributed model) is selected because its structure is more physically based than the structure of the lumped model, freely available and meets the objective of this study.

2.6 SWAT Development and Interface

SWAT model is a semi distributed; time continuous watershed simulator operating on daily time step (Arnold, J. G., srinivasan, R., Muttiah, R. S and Williams, J. R., 1998). It is developed for assessing the impact of management and climate on water supplies, sediment and agricultural chemical yields in watersheds and larger river basins. The model is physically based and allows simulation of a high level of spatial detail by dividing the watershed into a large number of sub watersheds. The major components of SWAT include hydrology, weather, erosion, plant growth, nutrients, pesticides, land management and stream routing. The program is provided with an interface in Arc GIS (Arnold J. G., 2012) for the definition of watershed hydrologic features and storage as well as the organization and manipulation of the related spatial and tabular data.

2.7 Application of Hydrological Model (SWAT)

SWAT model has been applied in agricultural watersheds and have been successfully calibrated and validated in many areas of the world. The studies indicated that the

SWAT model is capable of simulating hydrologic process from complex and data poor watershed with reasonable model performance statistical values. (Ndomba, 2002), was applied the SWAT model in modeling of Pangari River (Tanzania) to evaluate the applicability of the model in complex and data poor watershed. (Adeogun G. Adeniyi, 2014), was used SWAT models to predict water balance and water yield of a catchment area in Nigeria. It was suggested that, SWAT model could be a promising tool to predict water balance and water yield in sustainable management of water resource. (Getachew Tegegne, 2013), was applied SWAT model on Lake Tana Reservoir Water Balance and reported that, the overall model performance was satisfactory. Similarly, (Tibebe D. and Bewket W., 2010) also applied SWAT model to evaluate surface runoff generation and soil erosion rates for a small watershed (Keleta Watershed) in the Awash River basin, Ethiopia, and recommended that, the SWAT model provides a useful tool for soil erosion assessment from watersheds and facilitates planning for a sustainable land management. (Damtew Fufa, 2015), was applied SWAT model for hydrological modeling of Katar watershed, Lake Ziway catchment and recommended the use of SWAT model for further future research.

The above literature review indicated that the SWAT model is capable of simulating hydrological process with reasonable accuracy and can be applied to large and complex watersheds.

2.8 SWAT Calibration and Uncertainty Procedures (SWAT-CUP)

Distributed watershed models are increasingly being used to support decision making in land use change. These models should pass through a careful calibration and uncertainty analysis. Large scale distributed models are difficult to calibrate and to interpreter the calibration because of large model uncertainty, input uncertainty and parameter non uniqueness. To perform parameter calibration and uncertainty analysis different programs are introduced. SWAT-CUP is one of the program which is currently used by different researchers.

SWAT-CUP is a public domain and any calibration, uncertainty or sensitivity can be linked to SWAT. The program links Generalized Likelihood Uncertainty Estimation (GLUE), Parameter Solution (ParaSol), Sequential Uncertainty Fitting (SUFI2) and Markov Chain Monte Carlo (MCMC) procedures to SWAT (Abbaspour, 2015). It enables sensitivity analysis, calibration, validation and uncertainty analysis of SWAT models. SUFI method determines uncertainty through the sequential and fitting process in which iteration and unknown parameter estimates are achieved before the final estimates.

2.9 Model Performance Evaluation

For evaluation of model performance, (Da Silva, 2015) describes model evaluation guidelines for quantification of accuracy in watershed modeling. The evaluation was performed by visual and statistical comparison of the measured and simulated data. The graphical method provided an initial overview. The statistical criteria used to evaluate the performance of the model.

The Nash and Sutcliffe simulation efficiency (NSE) describes the deviation from the unit of the ratio of the square of the difference between the observed and simulated values and the variance of the observations. The value of the coefficients varies from minus infinity to one with the latter value indicating perfect agreement between the simulated and observed data. A smaller NSE value indicates poorer fit between the simulated and observed data. It is possible to obtain negative value of the NSE indicating that the average of the observational data provides a better fit to the data compared to the simulated data.

The percent bias (PBIS) describes the tendency of the simulated data to be greater or smaller than the observed data, expressed as percentage. The optimum PBIAS value is zero and low values indicate that the model simulation is satisfactory. Positive values indicate a tendency of the model to underestimate while negative values are indicative of overestimation. This test is recommended due to its ability to reveal any poor performance of the model.

There are no existing standards describing the range of the values of the statistical parameters that would indicate acceptable performance of the model (Loague, 1991).

Table 1: Statistical Parameters of Model performance

Statistical Criteria	Value	Performance Classification
$NSE = 1 - [\frac{\sum_i^n Qm - Qs)^2}{\sum_i^n (Qm - \overline{Qm})^2}]$	0.75<NSE<=1	Very good
	0.65<NSE<=0.75	Good
	0.5<NSE<=0.65	Satisfactory
	0.4<NSE<=0.5	Acceptable
	NSE<=0.4	Unsatisfactory

$$R^2 = \frac{[\sum_i (Q_m - \bar{Q}_m)(Q_s - \bar{Q}_s)]^2}{\sum_i (Q_m - \bar{Q}_m)^2 \sum_i (Q_s - \bar{Q}_s)^2}$$	$R^2>0.6$	acceptable
$$\mathrm{PBIAS} = \left[\frac{\sum_i^n (Q_m - Q_s)}{\sum_i^n Q_m}\right] * 100$$	PBIAS<±10 ±10≤PBIAS<±15 ±15≤PBIAS<±25 PBIAS≥±25	Very good Good Satisfactory Unsatisfactory

R^2 is coefficient of determination, Q is discharge, m is measured and s is simulated.

3. MATERIALS AND METHODS

3.1 Descriptions of the Study Area

3.1.1. Location

The study area, Katar River catchment is sub catchment of Ethiopian CRV basin. This watershed is located in the Oromia Regional State of Ethiopia and northern part of CRV catchment in the part of the Ziway Shala basin. In terms of geographic coordinate system, the watershed lies between $7^0$21’34’’ to $8^0$9’55’’ North latitudes and $38^0$53’57’’ to $39^0$24’46’’ East longitudes. The Ketar River and its tributaries start from the eastern parts of mountains Chilalo, Galema and Kakka of Arsi Zone and drains to Lake Ziway. The over flow of Lake Ziway drains to Lake Abiyata. Topographically, the Ketar catchment shows variation with altitude ranging from around 1673m near Abura (at gauging Station) to about 4181m above mean sea level on the high volcanic ridges along the eastern watershed. The total area of the watershed, upstream the gauging station is estimated to be 3132.1km^2.

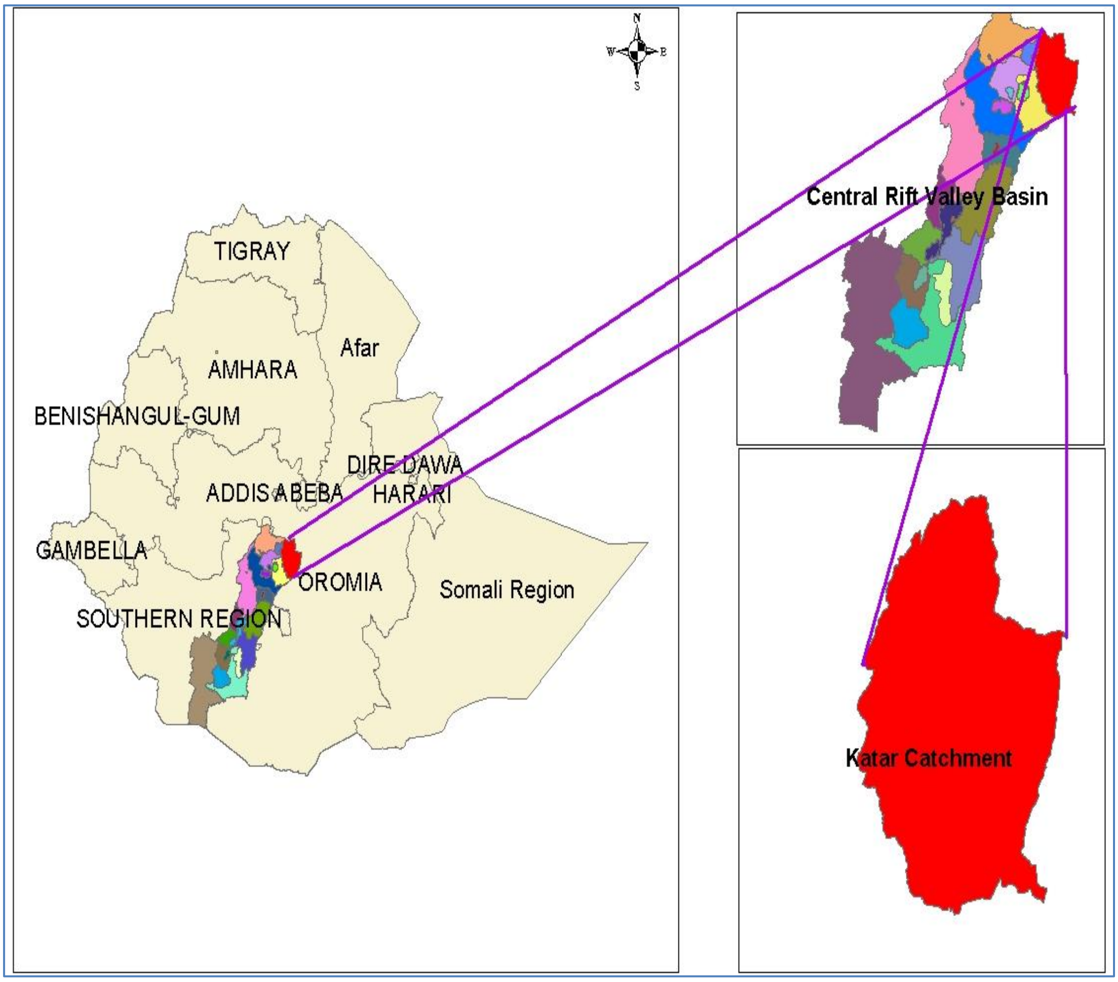


Figure 1: Location Map of the Study Area

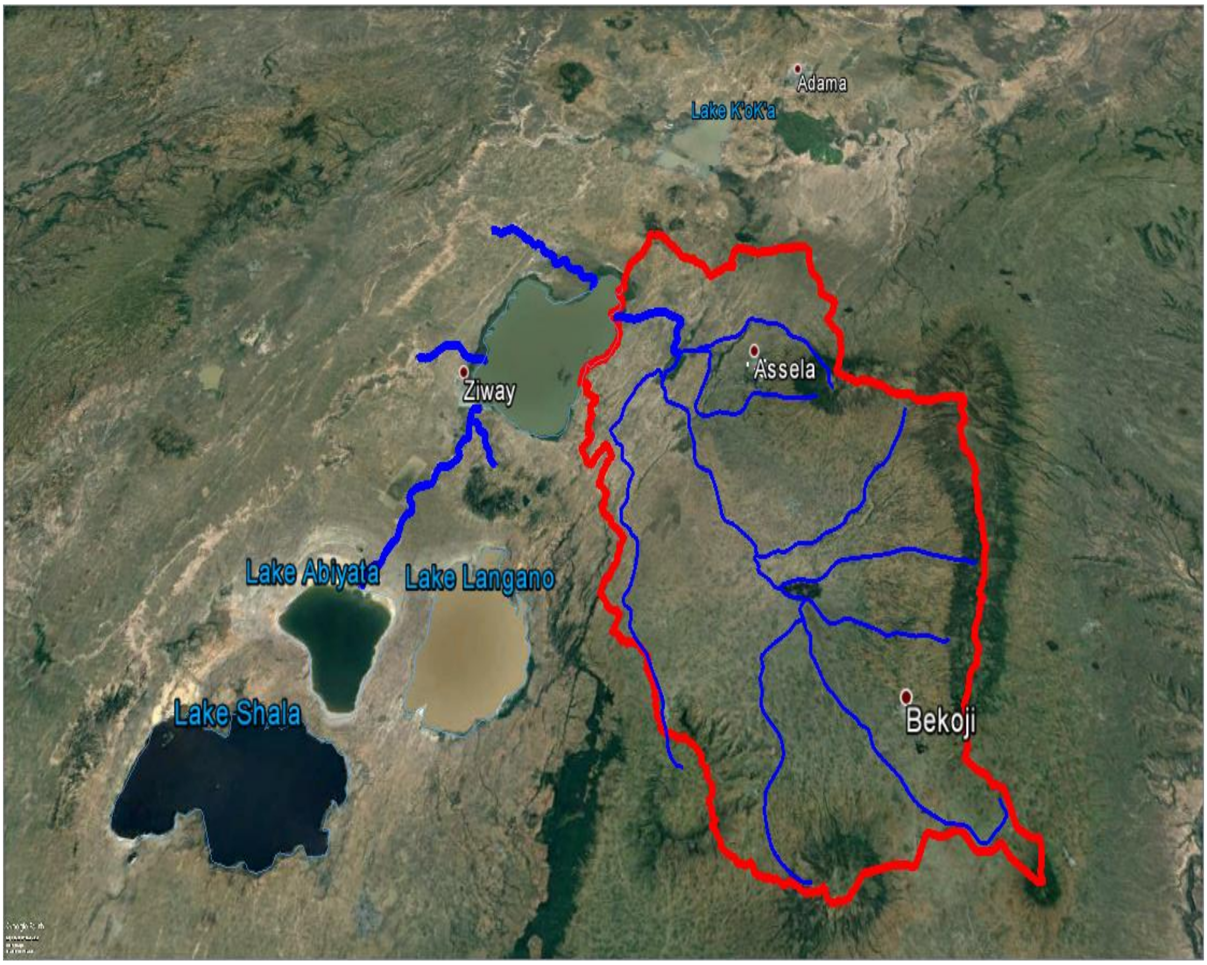


Figure 2: Location Map of Katar River Catchment Relative to Ziway Lake (Source: Google Earth)

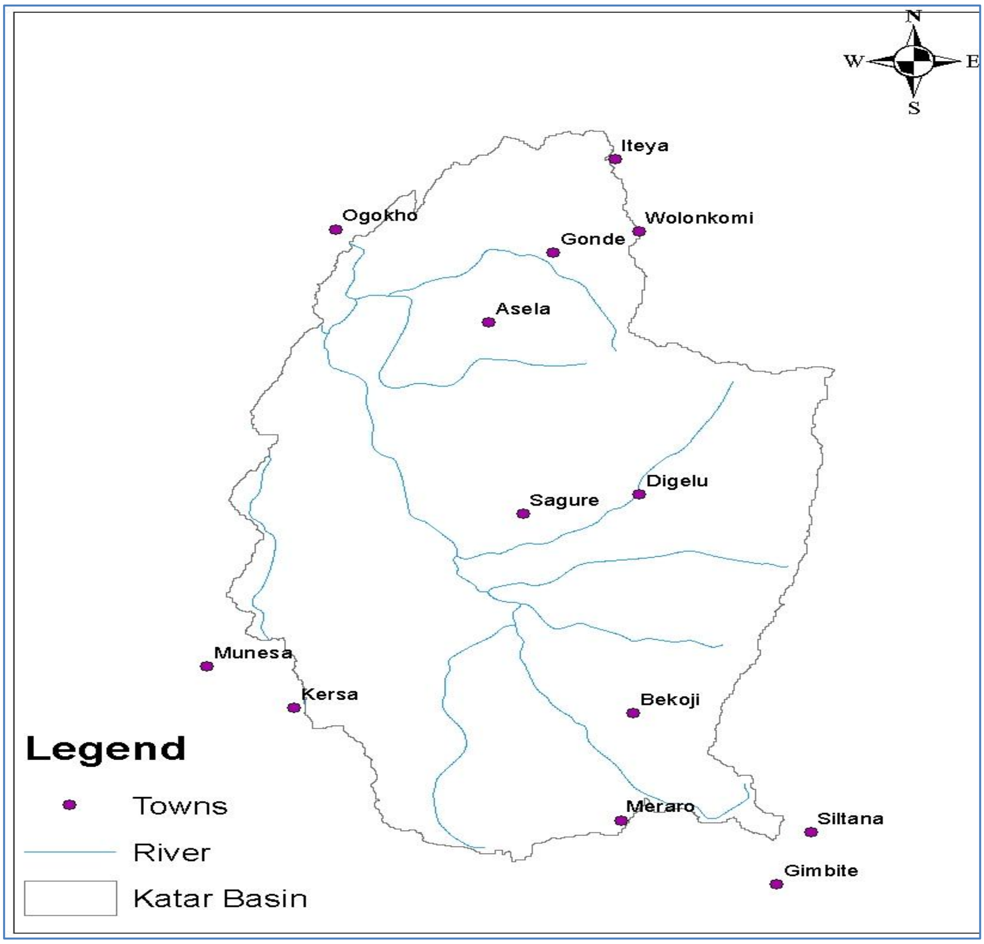


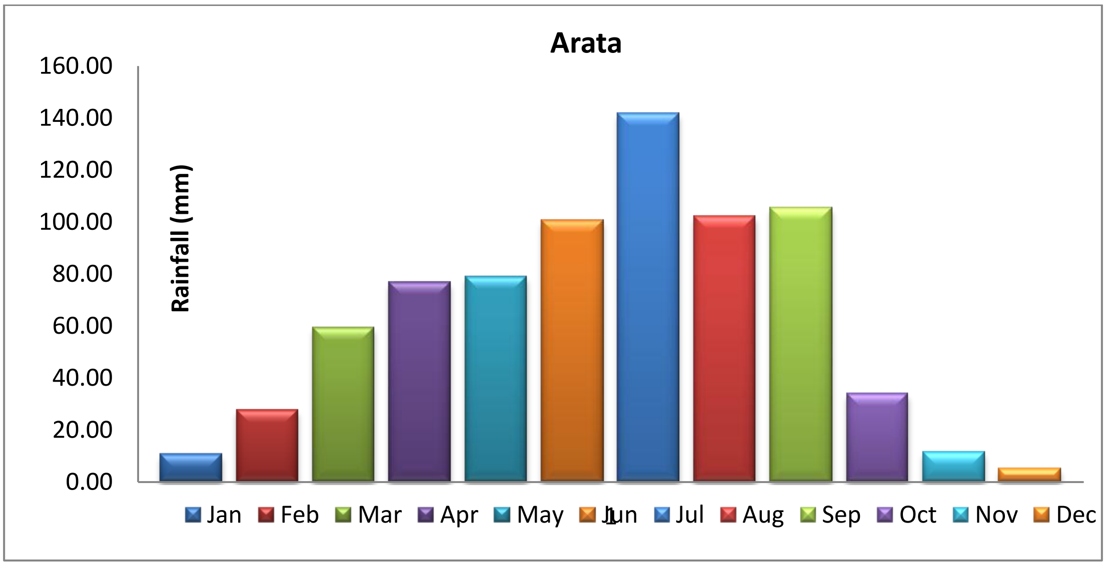
Figure 3: Towns in Katar Catchment

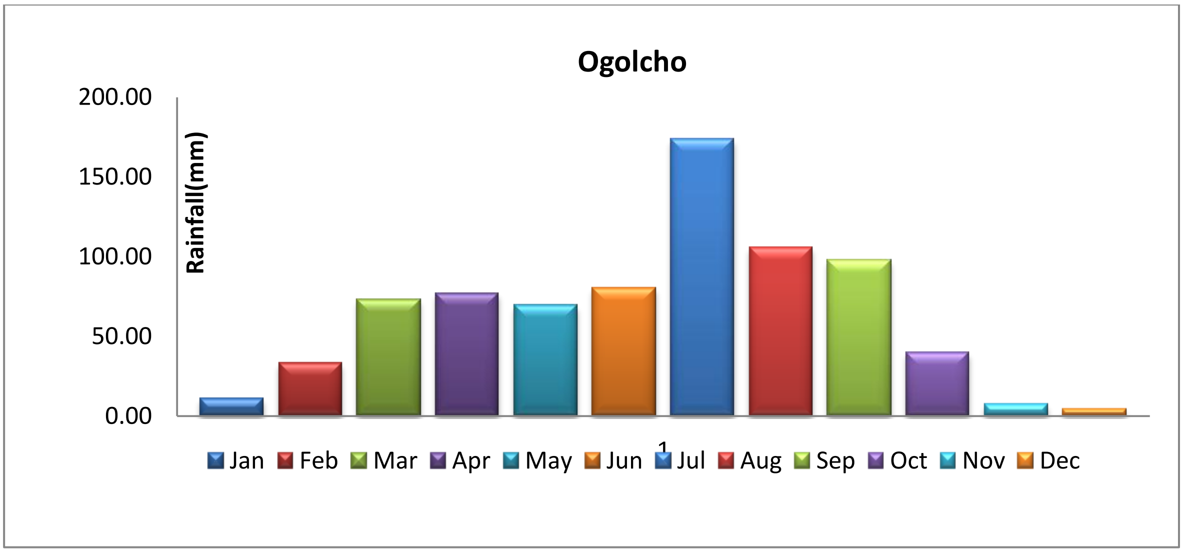
3.1.2 Climate

According to Koppen's climate classification system of Ethiopia, the dominant climatic types are the Hot Arid Climate, the Hot Semiarid Climate, and Tropical Climate with distinct dry winter and Tropical Monsoon Rainy Climate with short dry winter, Warm Temperate Rainy Climate with dry winter and Warm Temperate Rainy Climate without distinct dry season.

. The most common classification system, traditional classification system mainly relies on altitude and temperature shows the presence of five climatic zones. These are, Wurch (cold climate at more than 3000 Mts. altitude), Dega (temperate like climate-highlands with 2500-3000 Mts.altitude), Woina Dega (warm at 1500-2500 Mts. altitude), Kola (hot and arid type, less than 1500m in altitude), and Bereha (hot and hyper-arid types) climates (NMSA., 2001). Classification with respect to rainfall regimes shows the presence of monomial, bi-modal and diffused pattern of rainfall climates. Consideration of moisture index shows that large portion of the country falls under semiarid and arid climates. The high altitude variation (1673 to 4181) in the Ketar catchment falls into Wurch and woina dega (warm) according to traditional classification system.

The rainfall distribution in the Katar River Catchment varies from higher altitudes in the mountainous regions to the low land areas. The monthly rainfall distributions of the study area indicate that July, August and September are the wettest months of the year in all the selected stations except Arata. The mean monthly rainfall of the Arata, Assela, Kulumsa, Bokoji and Ogolcho stations (1985-2015) are shown in Figure 4. The mean annual rainfall (1985-20015) of the study area as shown in Figure 5 varies from around 754mm Arata up to 1076mm for Bekoji and mean annual temperature varying from 14.7C to 21.3 as show in Figure 6 below.




Ogolcho
200.00
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100.00
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Rainfall(mm)
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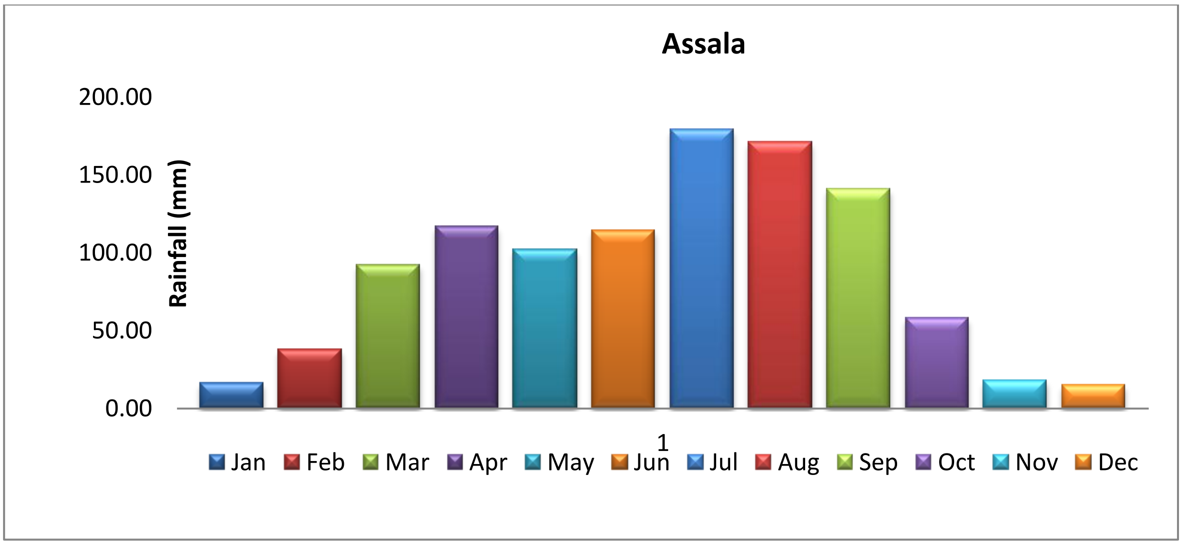
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec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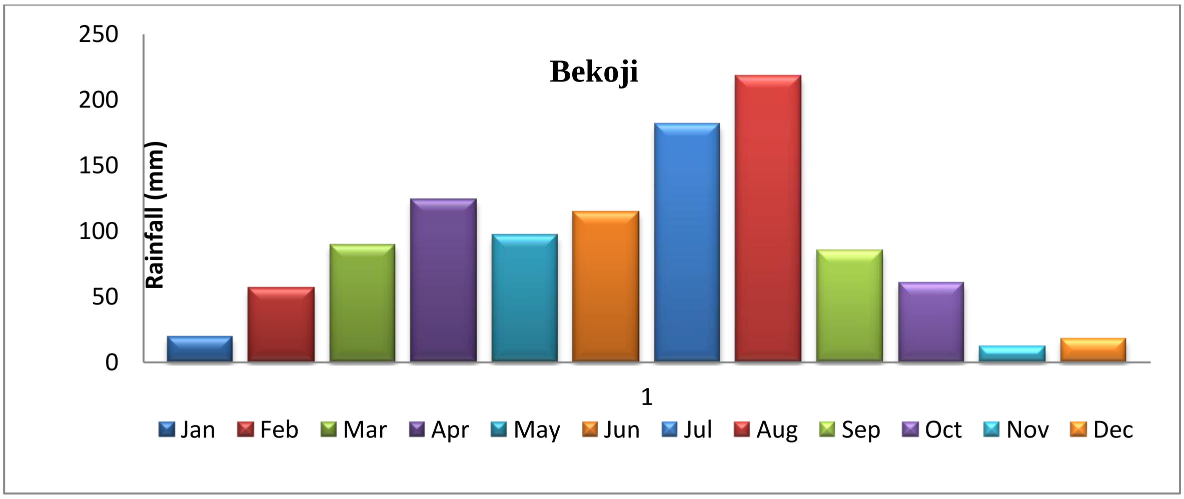
Bekoji
250
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100
50
0
Rainfall (mm)
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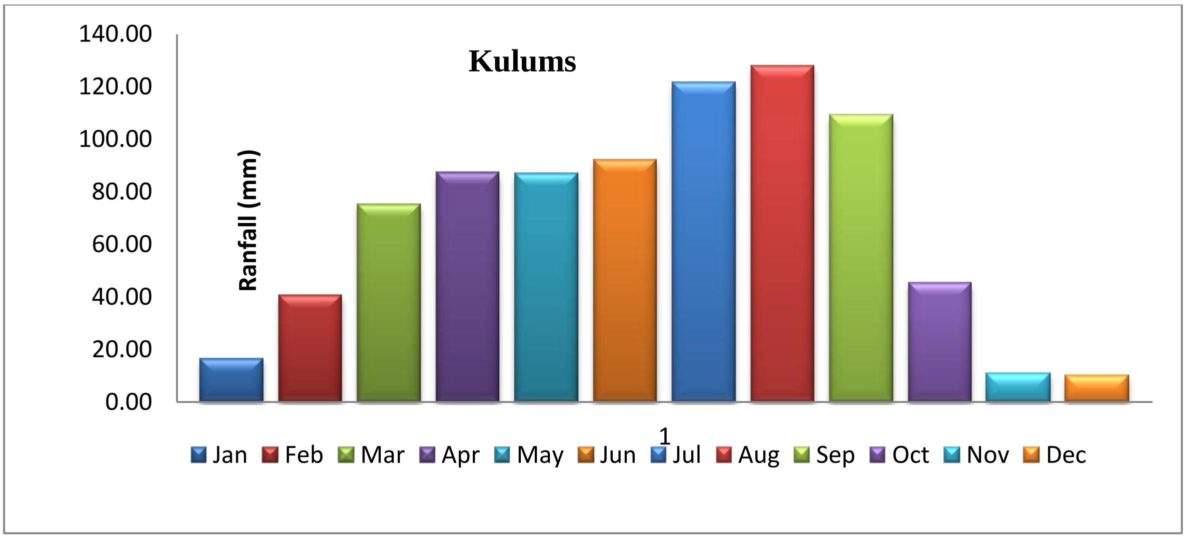

Figure 4: : Mean Monthly Rainfall Distribution for Selected Meteorological Stations (1985-2015)

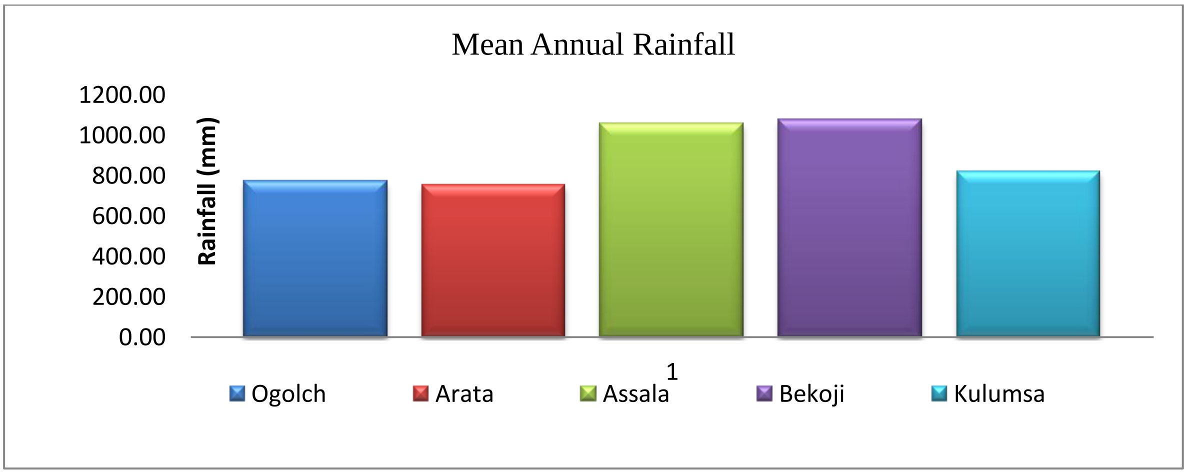

Figure 5: Mean Annual Rainfall of Selected Stations (1985-2015)

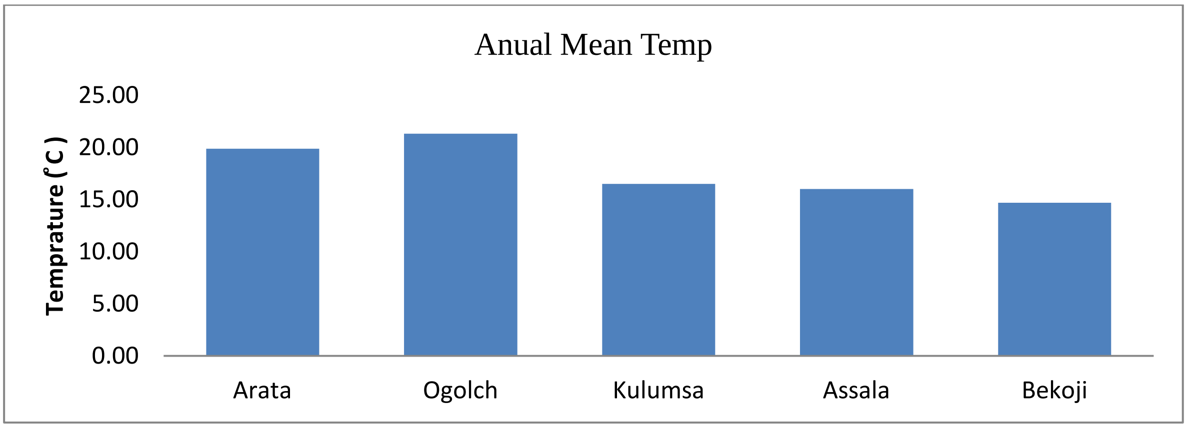

Figure 6: Annual Mean Temperature of All Selected Stations (1985-2015)

3.2 Land Use /Land Cover

The dominant land use in the Kater watershed is agriculture. The basin is as a whole intensively cultivated and different crops are grown in the basin using both rain and irrigation. The Katar irrigation Scheme was established by government in Tiyo Woreda, Oromia Region in 1987. The main crops produced in this scheme are onion, cabbage, potato, sugarcane, carrot etc. Crops like teff, maize and bean are also cultivated during the rainy season. The catchment provides water for domestic (rural and urban water supply) and agriculture sectors. Figure 18 shows the land use/cover classes of 1995 and 2015 over the study area.

3.3 Soil

Soil data is a significant component in the study of land use and land cover change impact on hydrological components of watershed. According to previous study (Makin M. K., 1976) the soil type in the study area is closely related to parent materials, degree of weathering and the relief that has significant influence on the development of soil types. The main parent materials are basalt, ignimbrite, acid lava, volcanic ash and pumice.

According to the FAO/UNESCO soil classification system the study area comprises of five major soil types, such as Chromic Luvisols , Eutric Vertisols, Haplic Luvisols, Mollic Andosols and Vertic Cambisols. The soil raster data set was taken from Ethiopian MoWIE.

3.4 SWAT Model Selection Criteria

The chosen hydrological model in this study was SWAT. It was successfully used for various studies of water resources area (Kassa Tedele, 2007) applied SWAT model in analyzing the impact of land use and land cover change on stream flow in the case of Hare River watershed, Ethiopia and proved the model's acceptance in hydrological performance , (Damtew Fufa, 2015) was applied to Ketar watershed to evaluate its simulating capacity through calibration and validation on monthly basis and recommended to use the model for further simulations and analysis of land use/land cover change on hydrologic regime of Ketar watershed for future research. In addition the model software with some tutorial video is freely available on the SWAT website (Soil and water Assessment Tool http://swat.tamu.edu/) to download.

In addition

- ✓ It has the capability of predicting the effect of soil, land use and land cover change on catchment hydrologic response
- ✓ SWAT is a public domain software
- ✓ Uses readily available inputs
- ✓ The model is capable of simulating major watershed hydrologic processes
- ✓ Computationally efficient to operate on large basins in reasonable time
- ✓ The model has a community of developers and users that help each other for better understanding

An accuracy predictive capacity of SWAT model depends on accuracy of input data which is a major problem in developing countries like Ethiopia.

3.5 Theoretical description of SWAT

The large-scale spatial heterogeneity of the study area is represented by dividing the watershed into sub basins. Each sub basin is further discretised into a series of hydrologic response units (HRUs), which are unique soil-land use combinations. Soil water content, surface runoff, nutrient cycles, sediment yield, crop growth and management practices are simulated for each HRU and then aggregated for the sub basin by a weighted average.

Physical characteristics, such as slope, reach dimensions, and climatic data are considered for each sub basin. For climate, SWAT uses the data from the station nearest to the centric of each sub basin. Calculated flow, sediment yield, and nutrient loading obtained for each sub basins are then routed through the river system. Channel routing is simulated using the variable storage or Muskingum method.

The water in each HRU in SWAT is stored in four storage volumes: snow, soil profile, shallow aquifer and deep aquifer. Surface runoff from daily rainfall is estimated using a modified SCS curve number method, which estimates the amount of runoff based on local land use, soil type, and antecedent moisture condition. Peak runoff predictions are based on a modification of the Rational Formula (Chow, 1988). The watershed concentration time is estimated using Manning’s formula, considering both overland and channel flow.

The soil profile is subdivided into multiple layers that support soil water processes including infiltration, evaporation, plant uptake, lateral flow, and percolation to lower layers. The soil percolation component of SWAT uses a water storage capacity technique to predict flow through each soil layer in the root zone. Downward flow occurs when field capacity of a soil layer is exceeded and the layer below is not saturated. Percolation from the bottom of the soil profile recharges the shallow aquifer.

Daily average soil temperature is simulated as a function of the maximum and minimum air temperature. If the temperature in a particular layer reaches less than or equal to 0^{o}C, no percolation is allowed from that layer. Lateral sub-surface flow in the soil profile is calculated simultaneously with percolation. Groundwater flow contribution to total stream flow is simulated by routing a shallow aquifer storage component to the stream.

The model computes evaporation from soils and plants separately. Potential Evapotranspiration can be modeled with the Penman Monteith, Priestley–Taylor or Hargreaves methods, depending on data availability. Potential soil water evaporation is estimated as a function of potential ET and leaf area index (area of plant leaves relative to the soil surface area). Actual soil evaporation is estimated by using exponential functions of soil depth and water content. Plant water evaporation is simulated as a linear function of potential ET, leaf area index, and root depth, and can be limited by soil water content.

3.6 Hydrological Components of SWAT

Simulation of hydrology of a watershed is done in two separate components. One is the land phase of the hydrologic cycle that controls the water movement in the land and determines the water, sediment, nutrient and pesticide amount that will be loaded into the main stream. Hydrological components simulated in land phase of the Hydrological cycle are canopy storage; infiltration, redistribution, and Evapotranspiration, lateral subsurface flow, surface runoff, ponds and tributary channels return flow. The second component is routing phase of the hydrological cycle in which the water is routed in the channels network of the watershed, carrying the sediment, nutrients and pesticides to the outlet. In the land phase of the hydrologic cycle, SWAT simulates the hydrological cycle based on the water balance equation.

$$SW_t = SW_O + \sum (R_{day} - Q_{surf} - E_a - W_{deep} - Q_{gw}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where, SW_t is the final soil water content (mm), SW_0 is the initial soil water content for day i (mm), t is the days, R_{day} is the day precipitation (mm), Q_{surf} is the surface runoff (mm), Ea is the Evapotranspiration (mm), W_{seep} is the seepage from the bottom soil layer (mm) and Q_{gw} is the groundwater flow on day i (mm).

Brief description of some of the key model components are provided in this study. More detailed descriptions of the different model components are listed in (Arnold, 1998) and (Neitsch, 2010). Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration.

SWAT offers two methods for estimating surface runoff: the SCS curve number procedure (USDA, 1972) and the Green & Ampt infiltration method (Green, W.H. and Ampt, G.A., 1911). Using daily or sub daily rainfall, SWAT simulates surface runoff volumes and peak runoff rates for each HRU. The SCS curve number equation is (SCS, 1972):

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

In which, Q_{surf} is the accumulated runoff or rainfall excess (mm), R_{day} is the rainfall depth for the day (mm), S is the retention parameter (mm). The retention parameter is defined by equation

$$S = 25.4\left(\frac{100}{CN} - 10\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. 3$$

SWAT includes two methods for calculating the retention parameter; the first one is retention parameter varies with soil profile water content and the second method is the retention parameter varies with accumulated plant Evapotranspiration. The soil moisture calculation method over estimate runoff in shallow soil. However, calculating daily CN as a function of plant Evapotranspiration, the value is less dependent on soil storage and more dependent on antecedent climate.

$$S = S_{max} * \left(1 - \frac{SW}{(SW + \exp(w_1 - w_2 * SW))}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. 4$$

Where S is the retention parameter for a given day (mm), S_{max} is the maximum value the retention parameter can achieve on any given day (mm), SW is the soil water content of the entire profile excluding the amount of water held in the profile at wilting point (mm), and w_1 and w_2 are shape coefficients. The maximum retention parameter value, S_{max} is calculated by solving equation 6 using CN1

$$\mathrm{S_{max}} = 25.4(\frac{1000}{\mathrm{CN_1}} - 10 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..5$$

When the retention parameter varies with plant Evapotranspiration, the following equation is used to update the retention parameter at the end of every day.

$$S = S_{prev} + E_o * \exp\left(\frac{-cncoef - S_{prev}}{S_{max}}\right) - R_{day} - Q_{surf} \dots\dots\dots\dots\dots\dots.6$$

Where S is the retention parameter for a given day (mm), S_{prev} is the retention parameter for the previous day (mm) , Eo is potential Evapotranspiration for the day (mm per day), cncoef is the weighting coefficient used to calculate the retention coefficient for daily curve number calculations dependent on plant Evapotranspiration, S_{max} is the maximum value the retention parameter can achieve on any given day (mm), R_{day} is the rainfall depth for the day (mm) and Q_{surf} is the surface runoff (mm). The initial value of the retention parameter is defined as $S=0.9*S_{max}$.

The SCS curve number is a function of the soil permeability, land use and antecedent soil water condition. SCS defines three antecedent moisture conditions: I dry (wilting point), II average moisture and III wet (field Capacity). The moisture condition I curve number is the lowest value the daily curve number can assume in dry conditions. The curve number for moisture conditions III and I are calculated with equations 8 and 7 respectively.

$$CN_1 = CN_2 - \frac{20 * (100 - CN_2)}{(100 - CN_2 + \exp(2.533 - 0.0636 * (100 - CN_2)))} \dots\dots.7$$

$$CN_3 = CN_2 * \exp(0.00673 * (100 - CN_2)) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 8$$

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

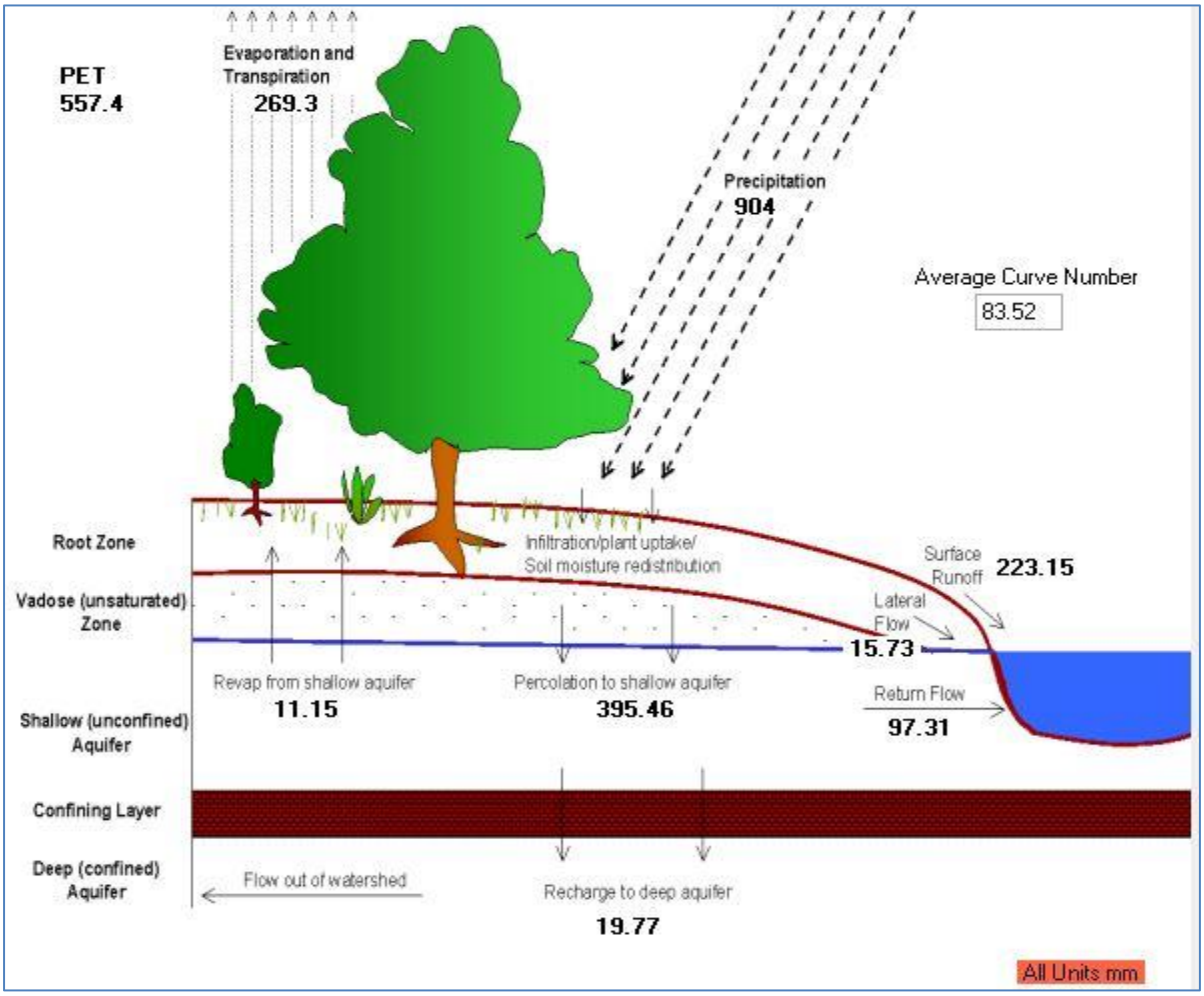

Figure 7: Land Phase of the Hydrologic Cycle

3.7 Methodology

The following figure indicates the general workflow of Katar Catchment study.

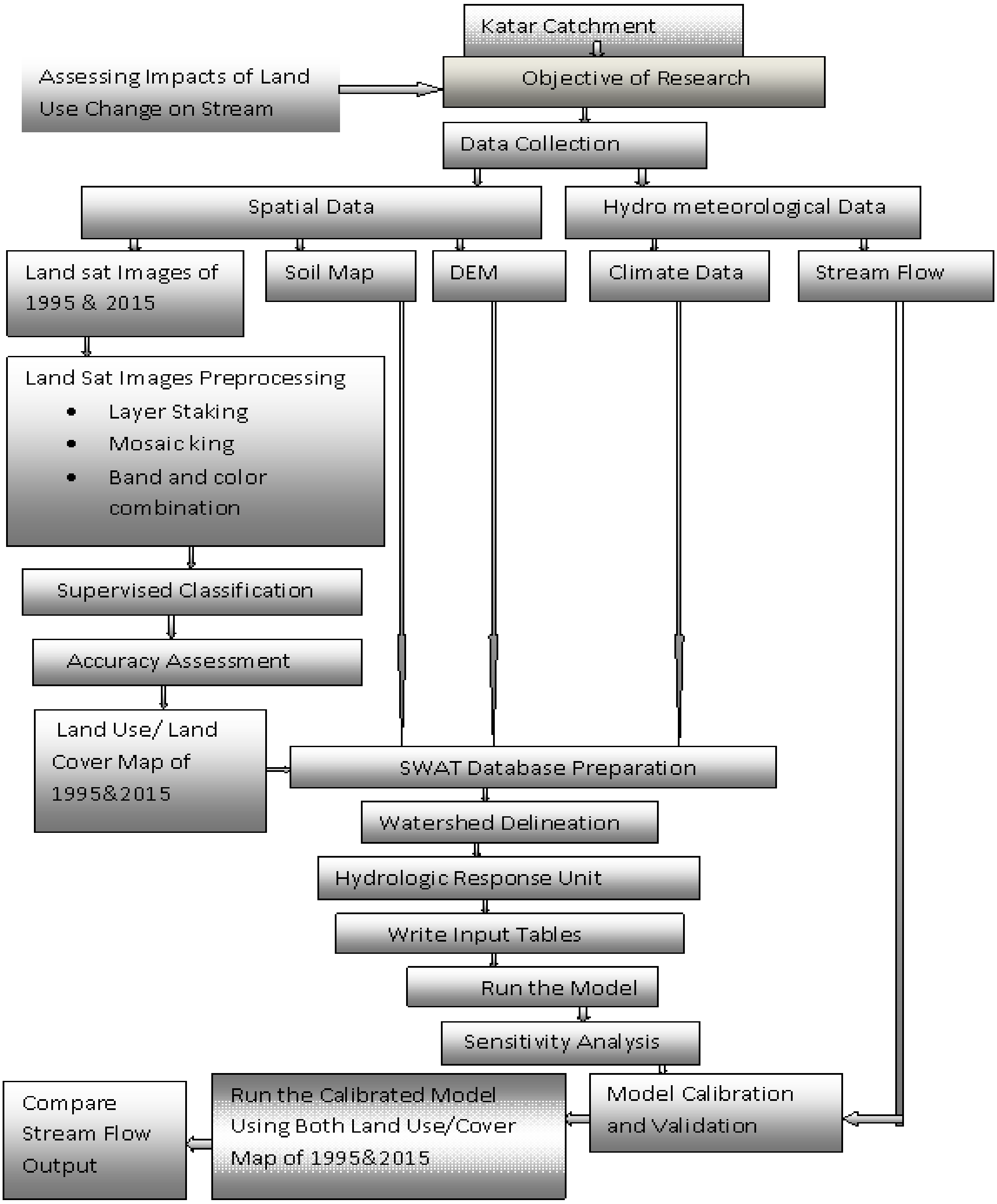

Figure 8: Framework of the Study

The above figure indicates the general work flow of the Katar Catchment. After identifying the problem of the catchment, the objective of the research was set. Then various data such as spatial (Land sat images of 1995 &2015, soil map and DEM) and hydro meteorological (Climate and stream flow) data were collected. Preprocessing of land sat images such as layer stacking, mosaic king and band and color combination were done to make ready for supervised image classification. The supervised classification and classification accuracy assessment were done using

ERDASIMAGINE2014 and finally the land use map of 1995 and 2015 of Katar Catchment was prepared. After preparing SWAT data base, watershed delineation, Hydrologic Response Unit Analysis, Write Input Tables for weather stations activities were performed. Then the SWAT model was run with default values and the simulation was compared with observation data. Then the manual calibration was done to adjust prior to automatic calibration. Sensitivity analysis was done using SWAT CUP (SUFI2). After sensitivity analysis model calibration and validation was done and finally the calibrated model was run using both land uses (1995 &2015) and the result was compared to assess the impact of land use and land cover change on stream flow.

3.7.1 Data Collection

The data required for this study included spatial (Digital Elevation Model, land use/ land cover and soil) data which were used to derive raster layers, daily data of climatic variables (daily data of precipitation, maximum and minimum temperature, relative humidity, wind speed and solar radiation) and stream flow data. Rainfall was used to simulate basin hydrological response whereas stream flow data was used for calibration and validation of the model.

3.7.1.1 Spatial Data

DEM data

The topography of any point in the watershed can be described by Digital Elevation Model (DEM). The DEM used to delineate the watershed boundary, stream network and create sub basins.

For this study the DEM of Ethiopia 90m by 90m resolution was obtained from Ministry of Water, Irrigation and Electricity of Ethiopia, department of GIS. Katar Watershed DEM clipped from Ethio DEM and used in SWAT watershed delineation. It was projected to Adindand UTM Zone 37 to create overlay with soil and land use raster data set using GIS 10.4.1 and used to generate watershed boundary using SWAT.

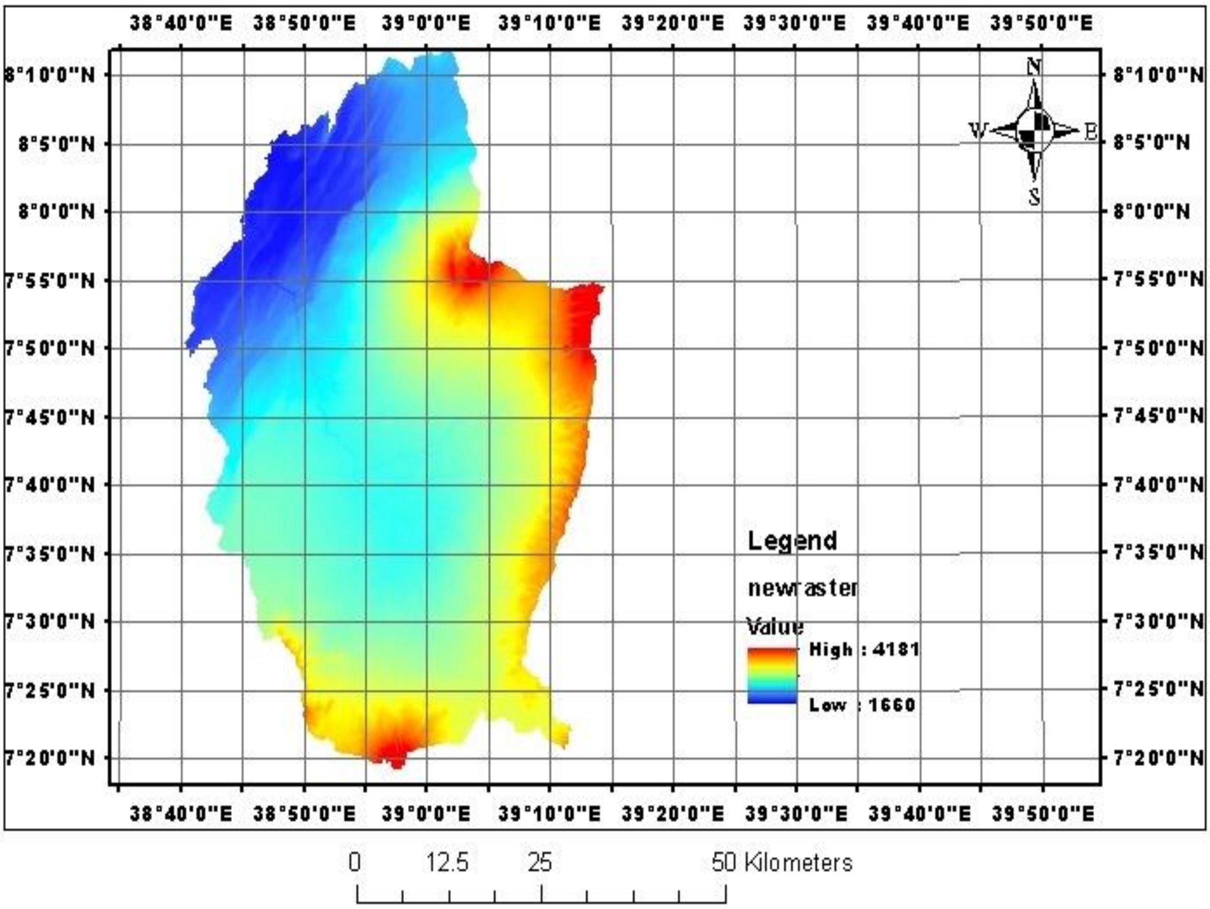

Figure 9: Digital Elevation Model of Katar Watershed

Soil Map

Soil properties are one of the major factors affecting catchment response to stream flow. Therefore, SWAT requires soil with its physical and chemical properties as input file. The soil map of the study area was obtained from Ministry of Water, Irrigation and Electricity of Ethiopia. Five major soil groups were identified as FAO/UNESCO soil classification system in the study area. The soil map of the study area is shown in Figure 10

The soil physical and chemical properties such as soil texture, available water content, bulk density, hydraulic conductivity and organic carbon content for different layers of each soil type of the study basin were used from the raster soil map obtained from Ministry of Water, Irrigation and Electricity of Ethiopia. To integrate the soil map with SWAT model, a user soil data base was prepared and added to the SWAT user soil data bases using Arc GIS10.4.1. The soil textural distribution in Katar Catchment is shown as below in Table 2.

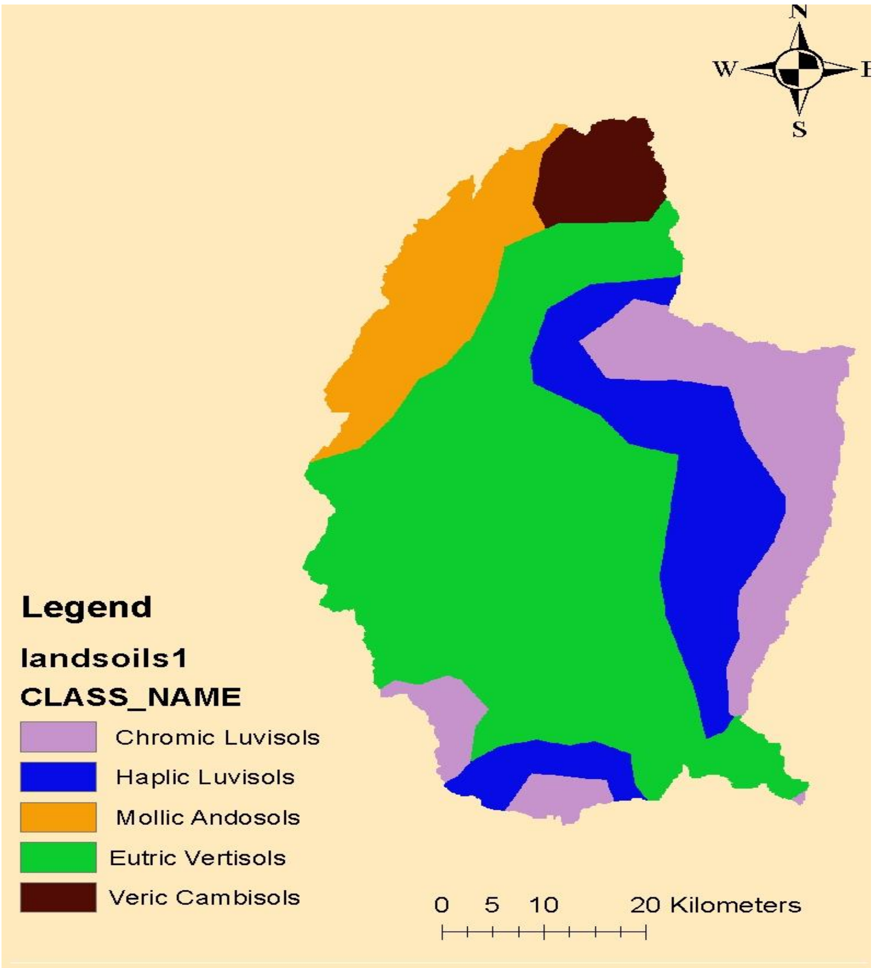

Figure 10: Major Soil Map of Katar Catchment

Table 2: Soil Textural Distribution in Katar Watershed

Soil Textural Classification					
Soil Types	Clay%	Silt%	Sand%	Area_ha	Area (%)
Chromic Luvisols	24	28	48	50425.47	16.1
Eutric Vertisols	56	25	19	159965.1	51.07
Haplic Luvisols	22	37	41	55715.17	17.79
Mollic Andosols	22	39	39	33203.58	10.6
Vertic Cambisols	51	29	20	13899.83	4.44
Total				**313209.18**	**100**

Land Sat Images

In the study of the impacts of land use and land cover change on hydrological responses of catchment, remote sensing images are required and can be processed by computers to produce land use/cover map. In water resource engineering, the mapping of land use/cover map in a wide area catchment, remotely sensed data plays a paramount role. Therefore, in this study Land Sat images were used for mapping LU/LC map of the Katar catchment. The characteristics of the images used in this research were presented in the following Table 3. For this study Land sat images of 1995 and 2015 were downloaded from United States Geological Survey (https:earthexplorer.usgs.gov/) website in GEOTIFF file format. The Selection of the Land sat satellite images date was influenced by the quality of the image especially for those with limited or low cloud cover and also to prevent seasonal variation of vegetation coverage. Therefore, the images were almost cloud free and almost in the same annual season.

Table 3: Characteristics of Used Satellite Images

Spacecraft_ID	Path/row	Pixel Size(XY)	Sensor_ID	Date
LANDSAT_5	168/54,55	30m by 30m	N/A	01/30/1995
LANDSAT_8	168/54,55	15m by 15m	OLI_TIRS	11/21/2015

Each land sat was georeferenced to WGS_84 datum and Universal Traverse Mercator (UTM) Zone 37N. Preprocessing such as layer stacking, mosaic king and band color combination were carried out in order to Ortho-rectify the images. The images were processed using ERDAS IMAGINE 2014 software. The satellite image of each band stacking and mosaic king was done in ERDAS IMAGINE2014. Then the study area was clipped from the mosaicked images using ERDAS IMAGINE2014. To better view the surface features clearly and the satellite images were performed color composition.

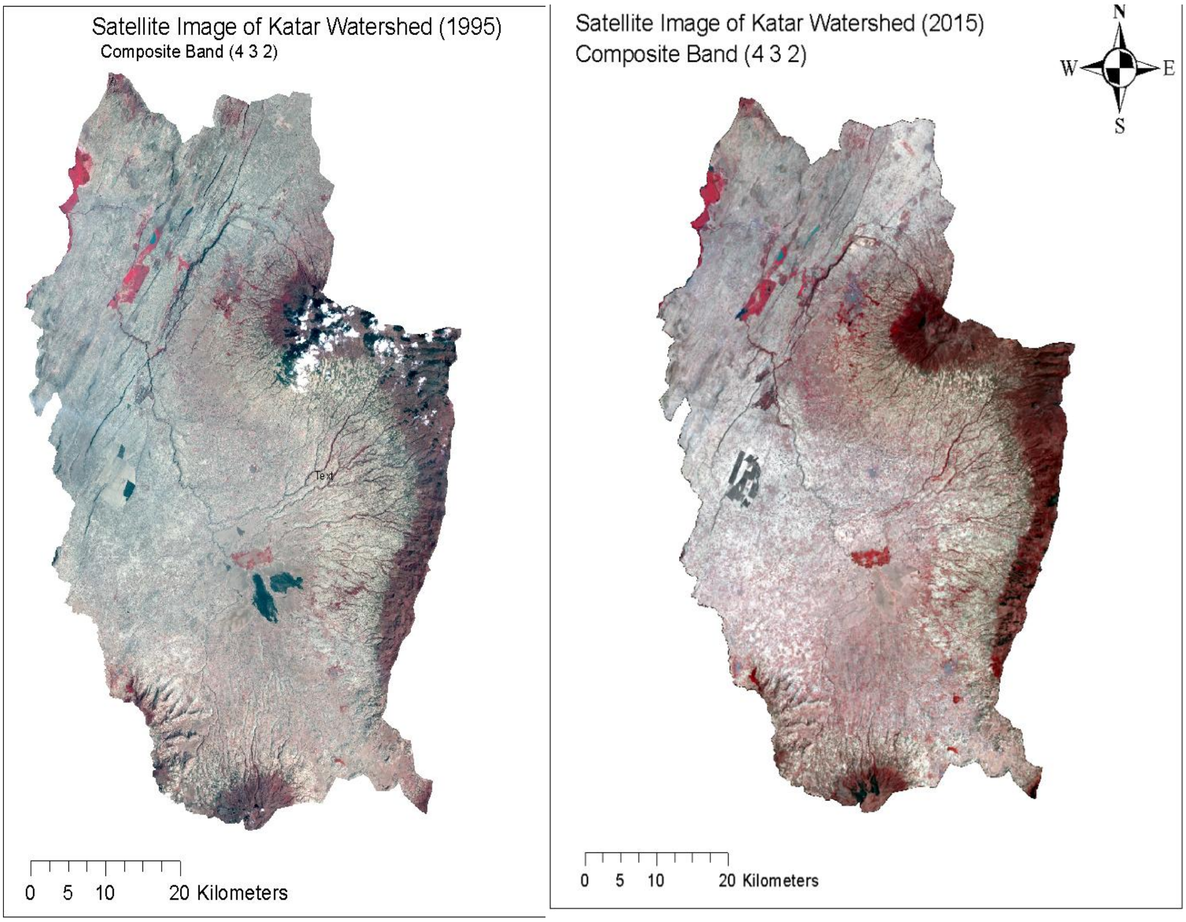

Figure 11: The Standard False Color Composite Satellite Images of the Study Area (Year 1995&2015)

Image Classification

Image classification is the process of sorting pixels into a finite number of individual classes or categories of data based on their data file values.

In remote sensing there are various image classification methods, supervised, unsupervised and hybrid. Unsupervised classification is computer controlled and the limitation is, we can't control computer's selection of pixels into clusters. In supervised image classification system, the user relies on her/his own prior knowledge and skills and can select a group of pixels belongs to a particular land use/land cover. In this system the user should have a good knowledge about the land cover to be studied. Supervised classification is the most common type of land use classification system and depends on prior information about the land use and land cover.

Supervised Classification

In this study, analyses of the different LULC classes were performed using supervised classification method. The previous study (Damtew Fufa, 2015) and (Halcrow, 2008) were used as a reference for classification number. This was done using the two Land sat satellite images, the Landsat_5 and Land sat_8.

The supervised classification was applied after defined area of interest (AOI) which is called training classes. The training sites were selected in agreement with the Land sat Image and Google Earth. In supervised land use classification, defining of training sites, extraction of signature editor and classification of image was performed using Maximum Likelihood classifier. Finally seven classes of LU/LC such as afro alpine, forest, agriculture, build up area, grass land; wet land and water body were produced.

Since there may be misclassification of pixels in supervised classification, it is necessary to test the accuracy of the classification by using field knowledge. Therefore, in this study accuracy assessment of the result was done using confusion matrix.

Accuracy Assessment

A vital step in the classification process, whether supervised or unsupervised is the accuracy assessment of the final classification produced. This involves identifying a set of sample locations that are visited in the field or using previous studies. The land use and land cover found in the field is then compared to that which was mapped in the image for the same location. Then, statistical assessment (using ERRMAT) of accuracy may then be derived for the entire study area. The error matrix (ERRMAT) produced may be used to identify particular cover types for which errors are in excess of that desired. The information in matrix about which covers are being mistakenly included in a particular class (error of commission) and those that are being mistakenly excluded (errors of omission) from that class can be used to refine the classification approach. The columns of the matrix indicate the number of pixels per class for the reference data and the rows indicate the number of pixels per class for the classified images. From this statistical accuracy assessment such as, overall accuracy, user's accuracy and producer's accuracy were derived to test the classification. The overall accuracy provides accuracy of the whole image classification (number of correctly classified pixels divided by the total number of pixels in the error matrix).

The user’s and producer’s accuracy indicate accuracy of individual classes. User’s accuracy is the probability of classified pixels representation of reference data, whereas, producer’s accuracy is the probability of reference data to be correctly classified.

In this study classification accuracy assessment was carried out using Google Earth imageries and Existing land cover maps (Halcrow, 2008). A total of 103 and 235 testing sample points were randomly collected for the year 1995 and 2015respectively and the result presented in the result and discussion section

Land Use and Land Cover Maps of the Study Area

Land use/land covers have a major impact on runoff generation of the watershed. Therefore, land use /land cover classification is a mandatory to assess the impact of land use/ land cover change on stream flow. Hence, from the previous study in the catchment (Halcrow, 2008) and (Damtew Fufa, 2015), seven different LU/LC have been identified in the Katar catchment and described as below.

Agriculture: Areas in the image that have agricultural crops present

Wetlands: Area that is saturated with water, either permanently or seasonally (waterlogged and swampy)

Grass (Pasture) land: Areas covered with grass used for grazing and bare lands that have little grass or no grass cover.

Forest land: Area covered with dense trees which includes mixed forest and plantation forest.

Afro Alpine: Areas covered with vegetations on high land areas and every year green

Built Up area: Settlement areas of residential buildings

Water: Areas covered with water

The LU/LC map of the study area was coded to the SWAT four letter codes and linked to the SWAT land use database. Hence, after preparing the look up table the land use types were made compatible with the input required by the model.

Table 4: Land use/Cover Classification of Katar Catchment

Land use/land Cover	Land Use According to SWAT Data Base	SWAT Code
Agriculture	Agricultural Law Row Crops	AGRR
Afro-Alpine	Forest Evergreen	FRSE
Forest	Forest Mixed	FRST
Grassland	Pasture land	PAST
Wet lands	Wetlands Non Forested	WETN
Build Up Area	Residential High Density	URHD
Water Body	Water	WATR

3.7.1.2 Hydro Meteorological Data

Weather Data

Weather data are one of the major input data for SWAT simulation. They are daily data of precipitation, maximum and minimum temperature, relative humidity, wind speed and solar radiation. All are obtained from the Ethiopian National Meteorological Agency. Eight weather data were collected and only five of them were used for this research due to short time recording duration of Kersa, Meraro and Sagure stations. The used stations were Arata, Assala, Bekoji, Kulumsa and Ogolcha. Figure 12 shows weather stations found in Katar Catchment.

Based on the class of the stations, the number of weather variables collected varies from station to stations. The location and parameters contained in each station are indicated in Figure 12 and Table 5. Except Kulumsa Station, the rest four stations were class three; whereas kulumsa is class one which has records of all climatic variables. The climatic data used for this study covers from 1985-2015. All Weather data were vertically prepared on excel and finally saved as notepad format with lookup table as required by the SWAT model.

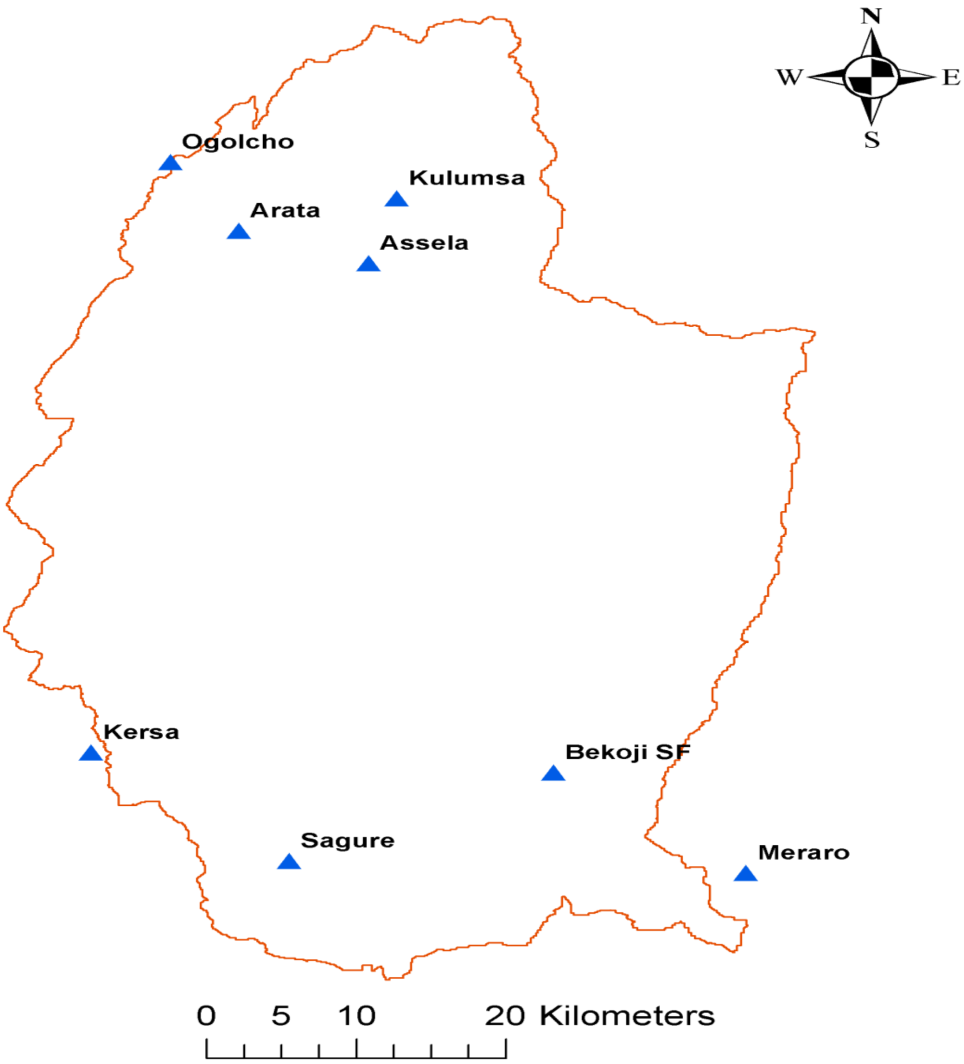

Figure 12: Location Map of Meteorological Stations in the Study Area

Table 5: Meteorological Station names, Location and Variables

Name	Year of record	XPR	YPR	Elev	Rain	Max Temp	Min Temp	Relative Humidity	Wind Speed	Radiation
Assala	1985-2016	506536	882282	1760	YES	YES	YES	NO	NO	NO
Kulumsa	1985-2015	514750	879412	2396	YES	YES	YES	YES	YES	YES
Bekoji	1985-2015	527386	832211	2793	YES	YES	YES	NO	NO	NO
Arata	1985-2016	517632	887514	2153	YES	YES	YES	NO	NO	NO
Ogolcho	1985-2014	501720	888408	1690	YES	YES	YES	NO	NO	NO
Sagure	1985-1999	509931	824602	2480	YES	YES	YES	NO	NO	NO
Meraro	2006-2015	540459	823512	2940	YES	YES	YES	YES	YES	YES
Kersa	1990-1997	496691	834550	1990	YES	NO	NO	NO	NO	NO

Stream Flow Data

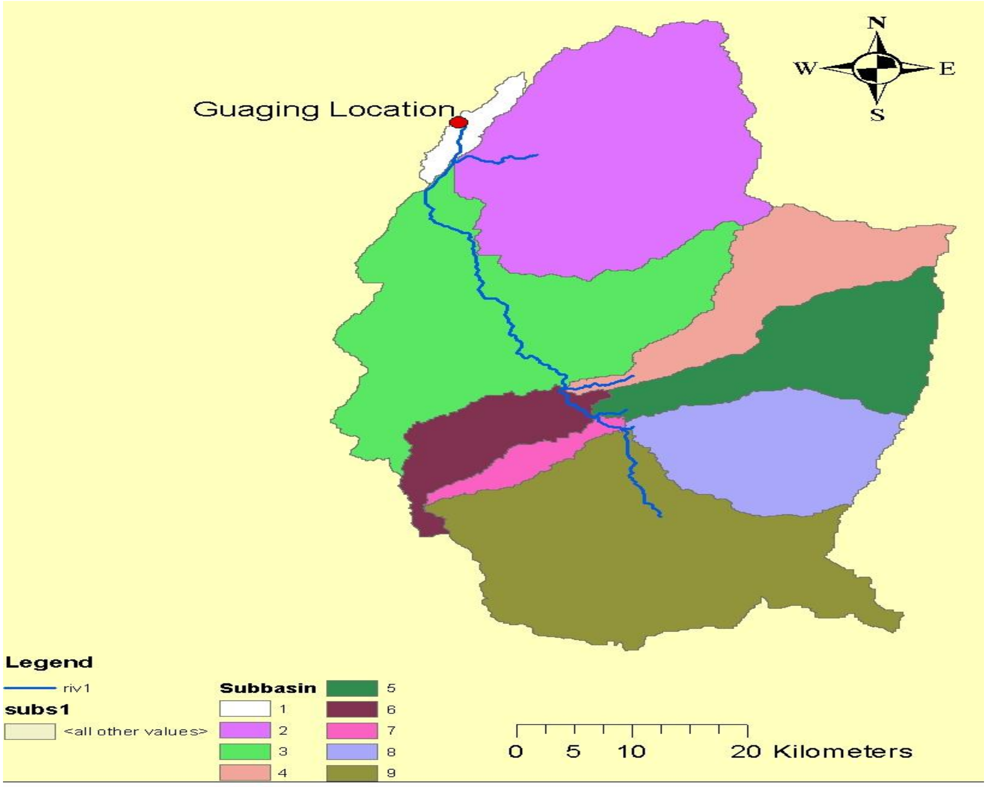

Figure 13: Location of Katar River Flow Gauge at Abura

For SWAT calibration and validation, flow data is required. Daily stream flow data was obtained from Ministry of Water, Irrigation and Electricity of Ethiopia, Department of Hydrology. According to discharge recorded at Abura Station (1990-2004), average monthly flow is shown in Table 6. The stream flow has missing data and no data is available for the year 1990. The missing and no data were excluded from calibration and validation. The calibration and validation were done on daily and monthly basis (calibration 1991-1999 and validation 2000-2004).

Table 6: Mean Monthly Discharge of Katar River (1991-2004)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Flow (m3/s)	2.1	2.1	2.7	3.9	4.7	5.6	16.3	51.1	34.0	15.0	4.3	2.2

Source: MoWIE

3.8 Rainfall Data Quality Analysis

Filling Missing Rainfall Data

The rainfall data collected from the stations may vary in their qualities. There are eight weather stations in Katar basin but Kersa, Meraro and Sagure stations were not used due to short time record of weather data. The collected data have missing values in all used stations. The missing values in all stations were assigned with no data code (-99) which then filled by the weather generator embodied in the SWAT model from monthly weather parameter.

Consistency Test

The double mass curve technique was used to check whether the collected rainfall data from Ethiopian meteorological station were consistent through the selected period of study and reveals if correction was needed. The recording rain gauge station may have undergone change during the period of record as a result of shifting of rain gauge to new location, change due to change in ecosystem such as forest and occurrence of observational error from a certain date. This technique is based on the principle that when each recorded data comes from the same parent population, they are consistent. A group of certain numbers of neighboring stations was chosen as base stations from the vicinity of a doubtful, all stations said as doubt stations unless they are checked. The data of the annual rainfall of the doubtful station and the average rainfall of the group of base stations covering a long period was arranged in the reverse chronological order (i.e the latest record as first entry and the old record as the last entry in the list.

The precipitation of station x (doubtful station) can be corrected using the following formula

$$P_{cx} = P_x \frac{M_c}{M_a} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .10$$

Where,

P_{cx}= corrected precipitation at any time period t at station X

P_x=original recorded precipitation at time period t at station X

M_c= Corrected slope of double mass curve

M_a= original slope of the double mass curve

To investigate whether there was inconsistency for gauging stations in the catchment a group of five stations were chosen. Cumulative annual rainfall data of those stations within the Katar catchment were used in this study (Appendix A- 5) in developing double mass curve. The cumulative values of the doubtful stations were plotted against the cumulative average group using Microsoft Excel spread sheet.

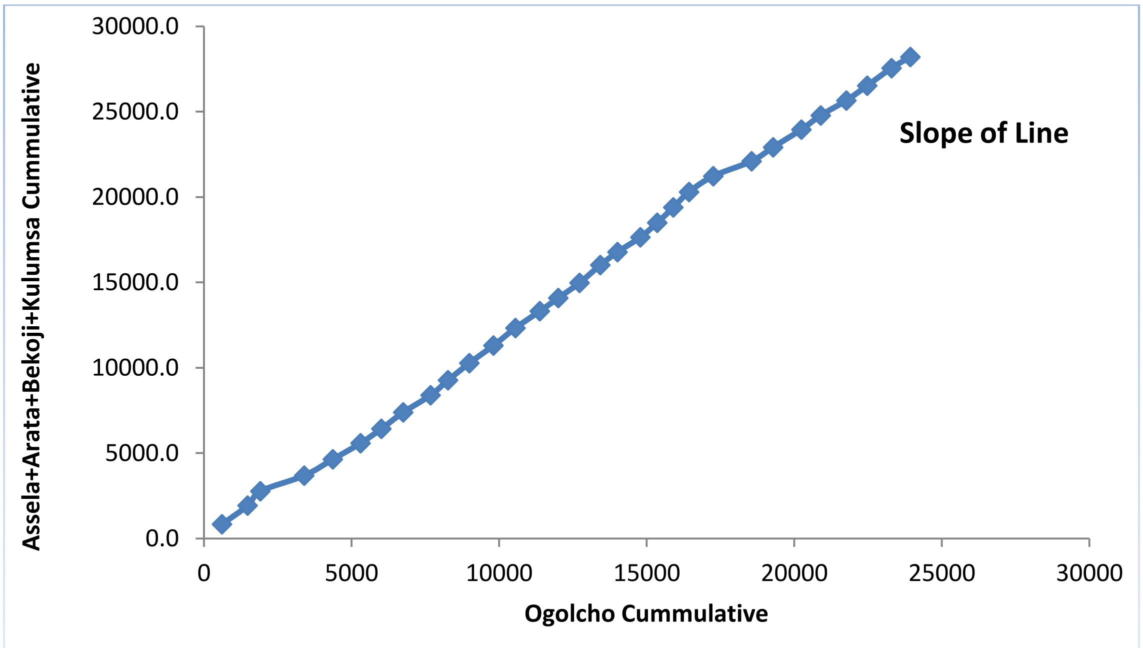

Figure 14: Daily Annual Rainfall Double Mass Curve

. The records of these stations did not show inconsistency since the graph was found to follow nearly straight line and therefore, these stations had no recording problems or subjected to any external factors during the study period.

Homogeneity Test

The homogeneity of stream flow was tested using RAINBOW. In RAINBOW the test for homogeneity is based on the adjusted partial sums or cumulative deviations from the mean (Buishand, 1982).

$$S_k = \sum_i (X_i - \bar{X}), \qquad k = 1, .. n \text{ ……………………………………………… } 11$$

Where, X_i the records of the partial duration series X_1, X_2….X_n and $\bar{X}$ the mean

For a homogeneous record one may expect that the S_k's fluctuate around zero since there is no systematic pattern in the deviations of the X_i's from their average value. In RAINBOW the rescaled cumulative deviations, obtained by dividing the S_k's by the sample standard deviation value (α_x). A statistic which is sensitive to departures from homogeneity is,

$$Q = max \left|\frac{S_k}{\alpha_x}\right|, k = 0, . . , n \text{ ………………………………………..………….. …. } 12$$

High values of Q are an indication for a change in the mean level. Another statistic which is used for homogeneity is the range, given as below

$$R = max\left(\frac{S_k}{\alpha_x}\right) - \min\left(\frac{S_k}{\alpha_x}\right), k = 0, \dots, n \text{ ……………………………………… } 13$$

In RAINBOW the maximum cumulative deviation (Q) and the range (R) are used to decide whether or not to reject the homogeneity of the data. According to the test the flow is homogeneous.

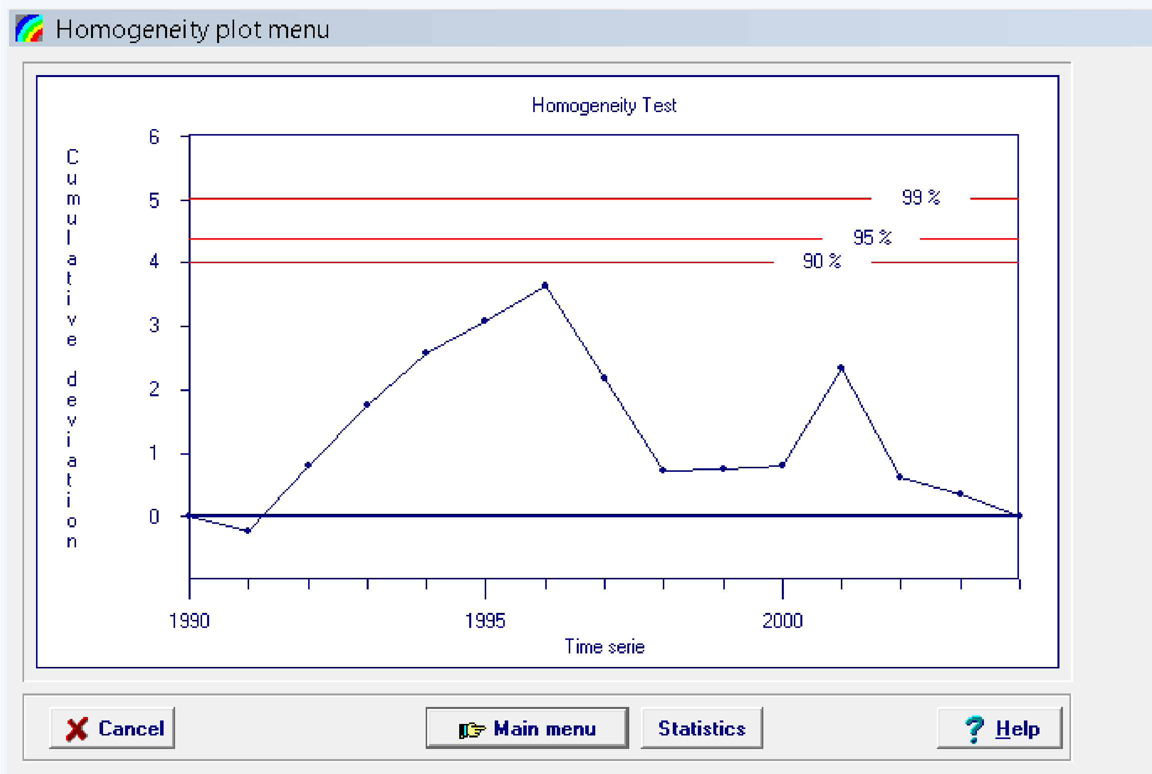

Figure 15: Graph of Stream Flow Homogeneity Test

3.9 Hydrological Modeling With SWAT

3.9.1 Model Set Up

Arc SWAT version 2012.10_4.19 was downloaded from SWAT website and its toolbar was added to Arc GIS10.4.1 for modeling process. The modeling procedure includes SWAT project setup, Watershed delineation, and HRU Analysis, Write Input Tables, Edit SWAT Input and SWAT simulation.

3.9.1 Watershed Delineation

The first step in generating SWAT model is watershed delineation. The soil map, LU/LC map and the DEM were projected using GIS 10.4.1 to the same projection prior to watershed delineation. This was done to overlap the three maps during SWAT modeling. The watershed and sub watershed delineation was performed using 90m by 90m resolution of DEM data and using Arc SWAT model watershed delineation function. The DEM was loaded and its projection was defined. There are two options for stream definition: the user can import predefined stream network in shape file format (it can be used if the location of the streams in the catchment area is known) and DEM based (Can be used if the exact location of the streams in the catchment is not known). In this study since the exact location of the streams in the watershed were not known, the DEM based option was chosen.

Since the location of gauging station was known the outlet generated by model was modified at the gauging location for later calibration purposes. The location of the stream flow gauging station (Abura) was manually added during the model set up process. Once the DEM set up was completed and the location of outlet was specified on the DEM, the model automatically calculates the flow direction and flow accumulation. Finally stream networks, sub watersheds and topographic parameters were calculated using the respective tools.

The stream definition and the size of sub basins were determined by selecting the threshold area or minimum drainage area required to form the origin of the streams to be twenty five thousands (25000 hectares) in order to decrease sub basin number. The Katar watershed was delineated into 9 sub basins having an estimated total area of 3132.19km^2.

During the watershed delineation process the topographic parameters such as elevation and slopes of watershed and its sub watershed were generated from the DEM data. The elevation of the watershed ranges from1673m to 4181m above mean sea level. The highest elevation is at the high volcanic ridges along the eastern watershed of Chilalo and Galama mountains and the lowest elevation is near Lake Ziway at the outlet (Abura). The slope of the watershed was classified into four classes as shown in Table 7 below.

Table 7: The Slope Class of Katar Catchment

Slope	Area [ha]	%Wat.Area
0-10	236742.7	75.59
10-20	56785.86	18.13
20-30	13103.4	4.18
30<	6577.2	2.1

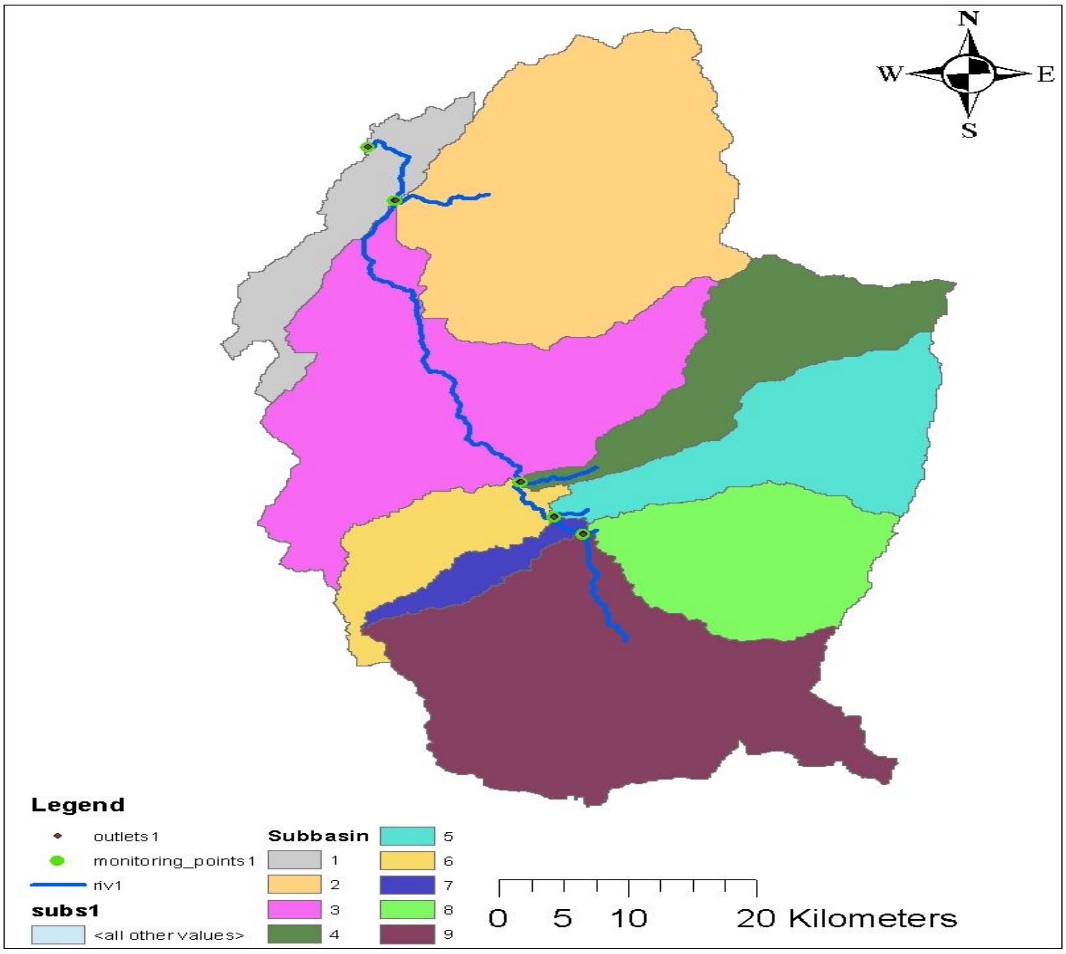

Figure 16: Map of Katar Sub basin

3.9.2 Hydrological Response Unit Analysis

After watershed delineation, land use, soil and slope characterization for watershed was performed using commands from the HRU analysis menu on the Arc SWAT Toolbar. These tools were used in loading land use and soil layers of Katar catchment into the current project, evaluate slope characteristics and determine the land use/soil/slope class combinations and distributions for the delineated Katar watershed and each respective sub watershed. The watershed was divided into hydrologic response units (HRU) which have a unique soil and land use combination.

The SWAT2012 model provides three options for defining HRU distribution. The first one is assigning Dominant Land Use, Soils and Slope which create one HRU for each sub basin. The dominant land use, soil and slope class in the sub basin are simulated in the HRU. The second is the Dominant HRU which creates one HRU for each sub basin. The dominant unique combination of land use, soil and slope class in the sub basin is used to simulate the HRU. And the third one is the Multiple HRUs which create multiple HRUs within each sub basin. This option was selected by default. The SWAT user's manual suggests that a 20% land use threshold, 10% soil threshold and 20% slope threshold are adequate for most modeling application. However according to (Melesse, 2008) suggestion HRU definition with multiple options that account for 10% land use, 20% soil and 10 slope threshold combinations gives a better estimation of runoff and sediment components. Therefore, for this study, HRU definition with multiple options that accounts for 10% land use, 20% soil and 10% slope threshold combination was used to eliminate minor land use and land covers in sub basin, minor soil within a land use and land cover area and minor slope classes within a soil on specific land use and land cover area. Due to this the Katar Watershed was divided into 71 HRUs, each has a unique land use and soil combinations.

3.9.3 Weather Data

After HRU analysis the weather data to be used in a watershed simulation was imported using the first command in the Write Input Tables menu item on the Arc SWAT toolbar. This tool helps to load weather station locations into the current project and assign weather data to the sub watersheds. The weather data definition is divided into six tabs: weather generator data, rainfall data, temperature data, solar radiation data, wind speed data and relative humidity data. The data collected from the meteorological stations have a missing value. Therefore, using weather generator solves such types of problem by generating data from the observed one (Danuso, F., 2002).The SWAT model requires daily hydro meteorological data from measured data or generated from values using monthly average data over a number of years. In this study measured data were used for all climatic variables. Since the climatic data collected from stations in the Katar Watershed had missing values, the SWAT weather generator was used to fill the missing parameters. Weather data of Kulumsa station was used as an input to determine the value of the weather generator parameters. Therefore, for weather generator data definition, the weather generator data file WGEN_user, rainfall data, temperature data, relative humidity data; solar radiation data and wind speed data were selected and added to the model respectively.

The weather generator parameters were developed by using excel (pivot table), dew point temperature calculator software, DEW02 and PCPstata to calculate average monthly and average daily precipitation, standard deviation, skew coefficient, probability of a wet day following a dry day and average number of days of precipitation in a month.

3.9.4 Sensitivity Analysis

Sensitivity analysis is defined as the process of determining the significance of one or a combination of parameters with respect to the objective function or a model output (Arnold J. G., 2012). Therefore, prior to calibration and validation process, sensitivity analysis was carried out to reduce the number of parameters that needs optimization. In this research semi automated Sequential Uncertainty Fitting (SUFI 2) was used to identify the sensitive parameters. This was done to select the most flow influencing parameters in the catchment. Two kinds of sensitivity analysis are performed, local (one at a time) and global analysis. The sensitivity of one parameter often depends on the value of other related parameters (Arnold J. G., 2012), which is a problem with local sensitivity analysis. Global analysis requires large number of simulations (Arnold et al, 2012) which can also be a problem. In this research global sensitivity analysis was performed in SUFI-2 prior to calibration and the results were examined. However, in this research the number of simulations used for calibration was 200, which is large enough to get accurate results for global sensitivity analysis. The global sensitivity analysis approach was used in SUFI2 because it takes into account the sensitivity of one parameter relative to the other in order to give their statistical significances. SUFI-2 is superior over other algorithms, because it involves stochastic calibration, where the errors and uncertainties in model are recognized and expressed as ranges accounting for all driving variables. The inclusion of large number of parameters representing different processes in the objective function, in SUFI-2 helps to make the model result enveloping most of the observations well. For example, (Asres M. and Awulachew S., 2010) were used SWAT in Gumera Watershed, Ethiopia for runoff and sediment modeling and in calibration they were used two approaches. Fully automated Parameter Solution (ParaSol) and semi automated Sequential Uncertainty Fitting 2 (SUFI-2) for the period from 2003 to 2006. They were carried out calibration using thirteen runoff producing parameters and concluded that the best performance of SUFI-2 and its flexibility over ParaSol and gave higher values for coefficient of determination and NS coefficient.

In this study the t-Stat and P-Values of the parameters were used to rank to the different parameters that may influence the flow and finally to select the ranked values

The model was run on monthly and daily time steps with observed data of the Katar River at Abura gauging station. For this analysis 20 parameters were selected based on previous literatures and only 6 parameters were identified to have significant influence in controlling the stream flow in the watershed. Flow parameters that tested for their sensitivity values for monthly and daily time steps are presented as below (Appendix A- 1).

In the sensitivity process, the SWAT simulated TxtInout was copied to the working directory and SWAT_CUP SUFI-2 was used for performing the sensitivity of selected parameters with the default lower and upper parameter bounds. The 20 parameters were included for the sensitivity analysis with default values as recommended by SWAT_CUP SUFI-2. Upon completion of sensitivity analysis a t_ test was used to identify the relative significance of each parameter. The larger in the absolute value of t_Stat and the smaller of the p_Value, the more the sensitive the parameter. The p_value tests the null hypothesis that the coefficient is equal to zero (no effect). A low p_value less than 0.05 indicate that null hypothesis can be rejected. That mean a predictor that has a low p_value is likely to be a meaningful addition to the model because changes in the predictor's value are related to changes in the response variable. Conversely, a large p_value suggests that changes in the predictor are not associated with changes with the response. So that the parameter is not very sensitive. A p_value of less than 0.05 is a generally accepted point at which to reject the null hypothesis (SWAT_CUP user manual). Based on the above criteria, parameters were selected for calibration process and the results were presented in the result and discussion section.

3.9.5 Calibration

After sensitivity analysis, the sensitive parameters were used for model calibration (1991-1999) to optimize the values of those sensitive parameters. In this research first manual calibration was done and some parameters were adjusted in the SWAT model. Then, auto calibration (SUFI-2) was applied for the calibration of SWAT model. In the SWAT-CUP calibration procedure the SWAT simulation was specified for performing the calibration and the location of the sub basin where the observed flow could be compared against simulated output (Abura Gauging Station). Then, the desired parameters for optimization, observed data and methods of calibration were selected. Hence, 6 flow parameters incase of monthly and 8 parameters incase of daily were selected in the calibration process according to SWAT CUP user manual criteria. After the calibration completed, the model was run using the best parameter output values and the simulations were compared with observed stream flow data using Nash Sutcliffe coefficient (NS), coefficient of determination (R2) and percent bias (PBIAS).

3.9.6 Validation

Validation is described as the process of demonstrating that a given site specific model is capable of making sufficiently accurate simulations, also sufficiently accurate results can vary based on project goals (Arnold et al, 2012). It is used to test the calibrated parameters with an independent set of data without further changes to the parameters. In this study the validation was performed to compare the model outputs with an independent data set without making further change to parameters obtained during the calibration process. The measured data of average monthly and daily stream flow from 2000-2004 at Abura Gauging station was used for model validation.

3.9.7 Model Performance Evaluation

There are no universally accepted existing standards describing the range of the values of the statistical parameters that would indicate acceptable performance of the model (Loague, 1991). But for evaluation of model performance during calibration and validation statistical measures as well as graphical representation at monthly and daily time steps were used. For this research the statistical parameters (NS, PBIAS and R^2) were used for model evaluation for quantification of accuracy in watershed modeling.

The coefficient of determination (R^2) describes the proportion of variance in measured data by the model. It indicates the linear relationship between simulated and observed data and ranges from zero (model is poor) to one (model is good).

The R^2 is calculated using the following equation

$$R^2 = \frac{[\sum_i (Q_m - \bar{Q}_m)(Q_s - \bar{Q}_s)]^2}{\sum_i (Q_m - \bar{Q}_m)^2 \sum_i (Q_s - \bar{Q}_S)^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 11$$

Where: R^2 is coefficient of determination

Qm measured value, Qs is simulated values, $\overline{Q}$m average measured values, $\overline{Q}$s average simulated values.

The Nash and Sutcliffe simulation efficiency (NS) describes the deviation from the unit of the ratio of the square of the difference between the observed and simulated values and the variance of the observations. The value of the coefficients varies from minus infinity to one with the latter value indicating perfect agreement between the simulated and observed data. A smaller NS value indicates poorer fit between the simulated and observed data. It is possible to obtain negative value of the NS indicating that the average of the observational data provides a better fit to the data compared to the simulated data.

NS is recommended and widely used in literature (Moriasi, 2007) therefore there is a lot of reported values for use as evaluation guidelines. NS, in a simplified explanation by (Moriasi *et al* 2007) is an indication of how well the plot of observed versus simulated data fits the 1:1 line. NS is computed as shown in the following equation.

$$\mathrm{NS} = 1 - \left[\frac{\sum_i^n (Q_m - Q_s)^2}{\sum_i^n (Q_m - \bar{Q}_m)^2}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 12$$

The percent bias (PBIS) describes the tendency of the simulated data to be greater or smaller than the observed data, expressed as percentage. The optimum PBIAS value is zero and low values indicate that the model simulation is satisfactory. Positive values indicate a tendency of the model to underestimate while negative values are indicative of overestimation. This test is recommended due to its ability to reveal any poor performance of the model.

$$\mathrm{PBIAS} = \left[\frac{\sum_i^n (Q_m - Q_s)}{\sum_i^n Q_m}\right] * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 13$$

The evaluation was performed by visual and statistical comparison of the measured and simulated data. The graphical method provided an initial overview. The statistical criteria used to evaluate the performance of the model.

3.10 Effects of Land Use/Land Cover Change on Stream Flow

The main goal of this study is to evaluate impacts of land use and land cover change on stream flow in case of Katar River Basin. As explained above, Katar Watershed has experienced land use and land cover changes in the period of 1995-2015 due to population growth rate which lead to resource competition. There was high urban and agricultural lands expansion in the marginal lands during the study period. These changes of land use/cover have an influence on stream flow.

This study was conducted for two different years from, 1995-2015. The two land use and land cover maps, soil, climatic and stream flow data values were used to evaluate the impacts of land use and land cover change on stream flow using SWAT model. The model was calibrated and validated on daily and monthly time steps. After calibration and validation for Katar stream flow, two independent simulations were run on monthly time step to evaluate stream flow variability due to land use and land cover change. The 1995 and 2015 land use/land cover were used as input variables in the SWAT model in order to compare output as a results of their differences in land use/cover change. The seasonally steam flow variability of 1995 and 2015 due to land use and land cover change was assessed and comparison was made on stream flow based on the two simulation outputs.

4. RESULTS AND DISCUSSION

4.1 Land Use and Land Cover Classification

Mapping and classifying land use and land cover is very important in hydrological study. Before the analysis of land use and land cover change each homogeneous land use and land cover should be defined. Defining of the land use and land cover of the Katar catchment was done using remote sensing data and previous studies **(**Damtew Fufa, 2015**)** and **(**Halcrow, 2008**).** Therefore, seven land use and land cover types have been identified for Katar catchment. The classified land use and land cover are described below:

Agriculture: Areas in the image that have agricultural crops present

Wetlands: An area where the ground water level is at or near surface for a long period (waterlogged and swampy) with a characteristics of aquatic plants

Grass (Pasture) land: Areas covered with grass used for grazing and bare lands that have little grass or no grass cover.

Forest land: Area covered with dense trees which includes mixed forest and plantation forest.

Afro Alpine: Areas covered with vegetations on eastern high land areas of the catchment and every year green

Built Up area: Settlement areas of residential buildings

Water: Areas covered with water

4.1.1 Land Use Classification Accuracy Assessment

The final step at classification process is accuracy assessment. It is used to assess how effectively the pixels were sampled into the correct land cover classes. Using the previous land use (Halcrow, 2008), original image and Google earth image, the reference points were randomly selected and compared with the corresponding classification. ERDAS IMAGINE2014 was used to perform method of confusion matrix to assess classification accuracy. Table 8 & Table 9 show a confusion matrix for the two Land sat images.

The overall classification accuracy which is the ration of the total number of correctly classified pixels (diagonal) to total number of reference pixels was shown to be 87.38 and 88.94 for the maps 1995 and 2015 respectively. According to (Anderson, 1976) the minimum accuracy value for reliable land cover classification is 85%. Others say the expected accuracy is determined by users. In this study Table 8 & Table 9 indicated the classification accuracy assessment according to Anderson and the result satisfies the minimum accuracy assessment criteria. The user's accuracy (error of commission or inclusion) and producers' (error of omission or exclusion) which are used to evaluate classification accuracy were also calculated.

Table 8: Confusion Matrix for LU/LC Classification of 1995

	BUA	WL	GL	WB	AA	F	A	Total	Users Accuracy
BUA	10	0	0	0	0	0	0	10	**100%**
WL	0	1	0	0	0	0	0	1	**100%**
GL	8	0	23	0	0	4	0	35	**66%**
WB	0	0	0	1	0	0	0	1	**100%**
AA	0	0	0	0	22	0	0	22	**100%**
F	0	0	0	0	0	12	0	12	**100%**
A	1	0	0	0	0	0	21	22	**95%**
Total	19	1	23	1	22	16	21	103	
Producer' Accuracy	53%	100%	100%	100%	100%	75%	100%	0	

Overall Classification Accuracy = 87.38%

Build Up Area=BUA**,** Wet Land =WL, Grass Land=GL, Water Body=WB, Afro Alpine=AA, Forest=F, Agriculture=A

Table 9: Confusion Matrix for LU/Lc Classification of 2015

	BUA	WL	GL	WB	AA	F	A	Total	Users Accuracy
BUA	29	0	3	0	1	0	2	35	**83%**
WL	0	33	1	0	0	1	0	35	**94%**
GL	1	0	31	0	0	0	3	35	**89%**
WB	0	1	0	24	0	0	0	25	**96.00%**
AA	0	0	0	0	33	0	2	35	**94%**
F	0	0	0	0	0	34	1	35	**97%**
A	0	1	0	0	0	0	34	35	**88.57%**
Total	30	35	35	24	34	35	42	235	
Producers' Accuracy	**97%**	**94%**	**89%**	**100%**	**97%**	**97%**	**81%**		

Overall Classification Accuracy = 93%

4.1.2 Land Use and Land Cover Maps

The land use and land cover maps for Katar Catchment were grouped into seven predominant classes: Afro alpine, water body, builds up area, agriculture, grass land, wet land and forest. Figure 18 indicated the LU/LC maps for 1995 and 2015 which were generated from Land sat images with supervised classification.

Figure 17 indicates expansion of land area under cultivation, build up area, wetland and slow increment of forest land from the total area. But, degradation of grass land and afro alpine during the study period (1995 to 2015). Grass land was decreased as a result of urbanization and agricultural expansion in the catchment. The afro alpine forest decreased by 14.38% due to agricultural encroachment to marginal land and expansion of settlement area. From Table 10 the land use and land cover map of built up area increased from 0.12% in 1995 to 8.5% in 2015 and agricultural land expansion from 43.45% in 1995 to 55.16% in 2015 as a result of population growth.

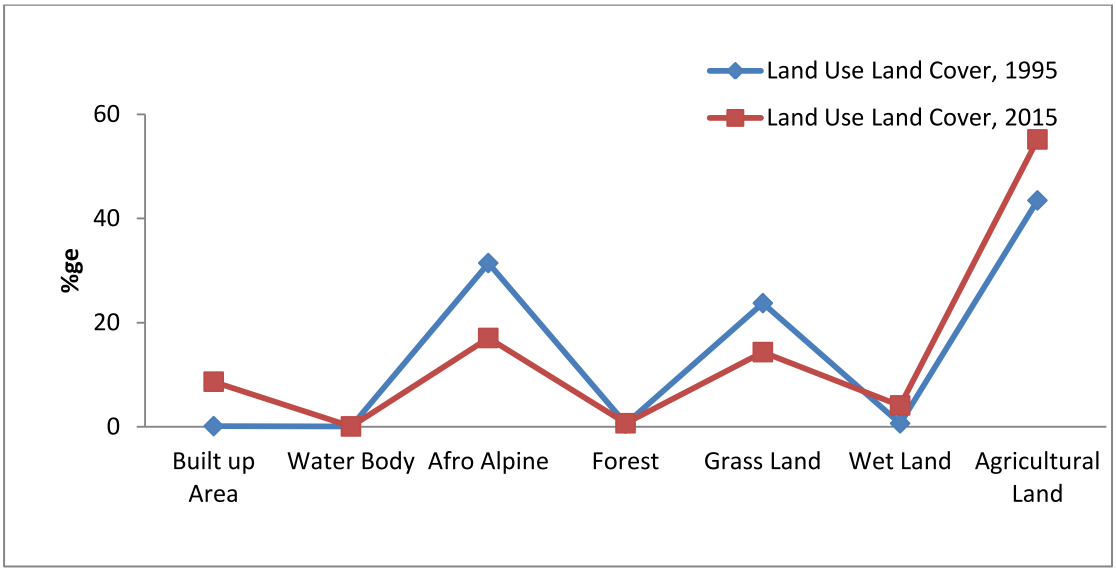

Figure 17: Graph of Land Use and Land Cover Change of 1995 & 2015

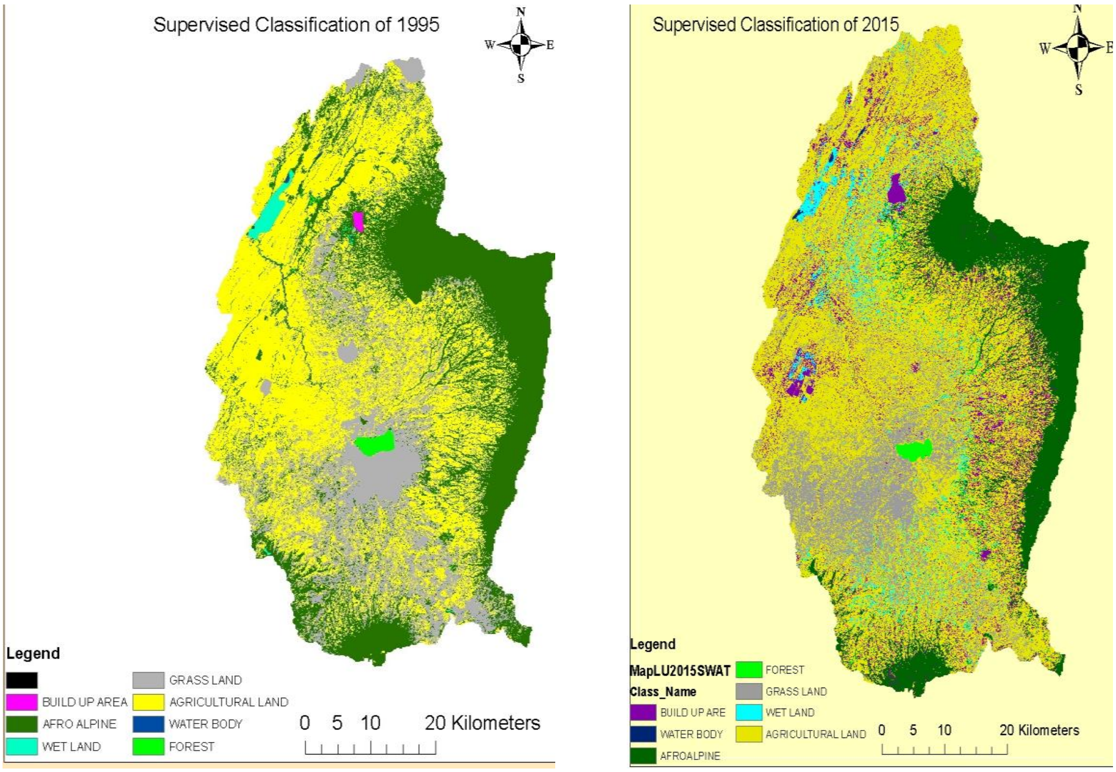

Figure 18: Major LU/LC of Katar Watershed in 1995 and 2015

The previous study approximately indicated the same results regarding land use and land cover changes. For example, (Halcrow, 2008) conducted a study on Rift Valley Lakes Basin Integrated Resources Development Master plan and reported that there is urban expansion. According to this study, the extent of afro alpine vegetations were being diminished as cultivation encroaches into this land cover types in the eastern part of the catchment and the forested areas have remained the same as in 1992 with some areas of expansion and some areas of contraction. And also forestry plantations and on farm tree planting has been practiced in some areas. But the extent of cultivated land is increasing at slower pace than the past as the most suitable areas are already used in the whole RVB. There was a conversion of grassland to cultivation land in the basin. Damtow (2015) in his study of hydrological modeling of Katar watershed, Lake Ziway Catchment, Ethiopia showed that agricultural land holds more share out of the total catchment area (46.09%). The pattern of LU/LC in different categories shows variation during the study period. Agricultural expansion is one of the major causes of LU/LC change in the study area. This implies that population pressure is believed to be one of the major driving forces for the change of land use/land cover (Molla, 2014).

Table 10: Area of LU/LC of Katar Watershed for the Study Period (1995-2015)

Land use / Land Cover Types	1995		2015		1995-2015	
	Area (Ha)	%	Area (Ha)	%	Area(Ha)	(in %ge)
Built up Area	367.77	0.12	27056.84	8.65	-26689.07	-8.53
Water Body	186.31	0.06	198.46	0.06	-12.15	0.00
Afro Alpine	98424.51	31.42	53383	17.04	45041.51	14.38
Forest	1790.24	0.57	2106.97	0.67	-316.73	-0.10
Grass Land	74330.75	23.73	44896.81	14.33	29433.94	9.40
Wet Land	2034.89	0.65	12797.34	4.09	-10762.45	-3.44
Agricultural Land	136074.71	43.45	172769.8	55.16	-36695.09	-11.71
Total	313209.18	100.00	313209.18	100		

4.2 Hydrological Modeling

4.2.1 Sensitivity Analysis of Stream Flow Parameters

For global sensitivity analysis twenty (20) flow parameters which may affect stream flow were considered from different literatures and only six (6) parameters were selected to have an influence in controlling the hydrological processes in the watershed. Appendix A- 3 indicates the relative sensitive parameters for monthly flow of stream. The parameters affecting hydrologic process of Katar watershed and used in model calibration were; maximum canopy storage (CANMX), alpha factor (ALPHA_BF), Manning's "n" value for over land flow (OV_N), effective hydraulic conductivity (CH_K2), deep aquifer percolation fraction (RCHRG_DP) and threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN).

The result of the sensitivity analysis indicated that the most sensitive parameters were canopy storage (CANMAX) with t-value of 13.54 and p-value of 0.00 to simulate Katar catchment and the least sensitive was Manning's n value for main channel (CH_N2.rte) with absolute t-value of 0.07 and p-vale of 0.945. From the previous study (Damtew Fufa, 2015), GWQMN, ALPHA_BF and CH_K2 were considered the important sensitive parameters used in calibration with 7, 11 and 1 in sensitivity ranking respectively. Therefore, the results obtained agreed with the previous research (Damtew Fufa, 2015) conducted and taken as a supportive reference for further calibration.

4.2.2 Calibration

SWAT simulated of Katar watershed with default values of parameters was showed poor statistical parameters. Therefore, after sensitivity analysis, manual calibration and then auto calibration was carried out with SWAT CUP (SUFI-2) on monthly and daily time steps (from 1991-1999). Parameters were varied several times while simulating flows to obtain high NSE, R^2 and low PBIAS. This was done until simulated flow closely matched the observed flows. The results showed a good correlation between the predicted and observed flows. The calculated NSE indicated that the predicted and the observed discharges have a good correlation and the model was very good in simulating the watershed. The three performance criteria indicated that the parameters modified during calibration represented the catchment hydrologic response. The optimized parameters during calibration were presented in Table 11..

Table 11: Parameters acquired through Calibration

Parameter_Name	Fitted_Value	Min_value	Max_value
1:V__OV_N.hru	14.488372	0.01	30.0
2:V__CH_K2.rte	162.755875	0.025	250
3:V__ALPHA_BF.gw	0.213449	0	1
4:V__GWQMN.gw	4999.762695	0	5000
5:V__RCHRG_DP.gw	0.095722	0	1
6:V__CANMX.hru	96.428040	0	100

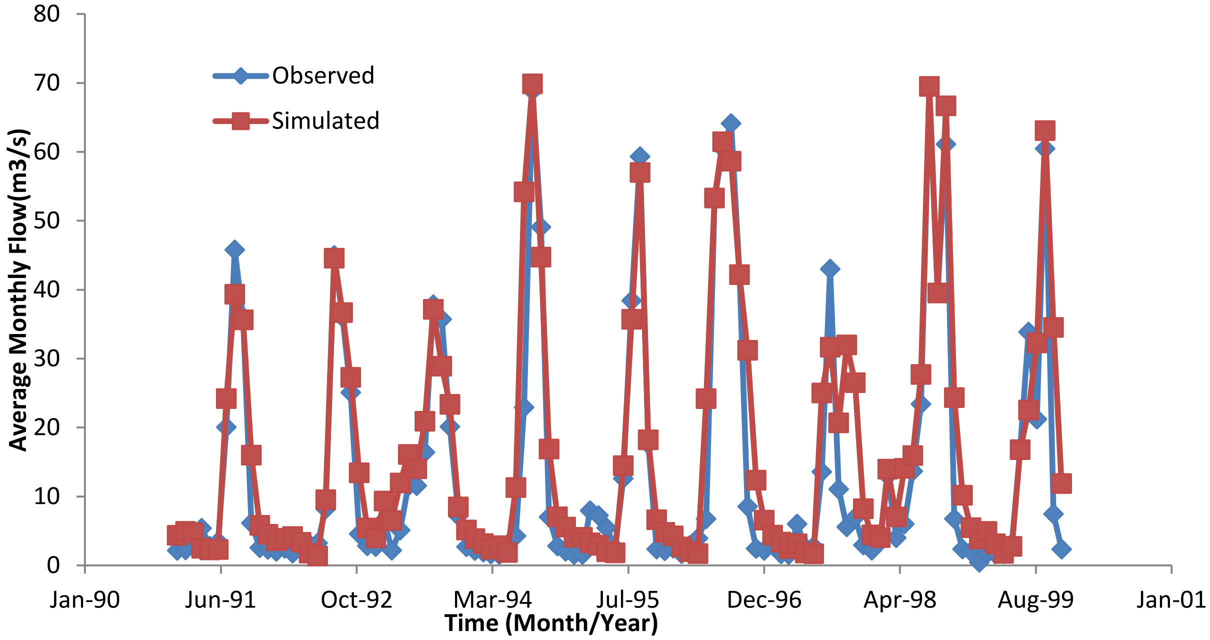

Figure 19: Simulated and Observed Discharge for Calibration Period (1991-1999)

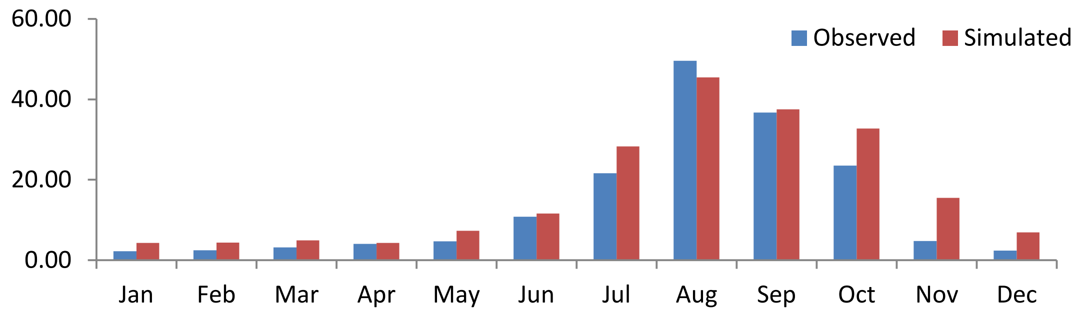

Figure 20: Graph of Monthly Observed and Simulated Flow during Calibration

4.2.3 Validation

Model validation was done for the period 2000 to 2004 and the results indicated that the model is capable of predicting the catchment response. NSE indicates acceptable accuracy for the model to predict the catchment response. However performance is lower than that for calibration. This agrees with the case study reported by (Damtew Fufa, 2015). In his work the calibration results showed a better match than validation. Regardless of the low performance during validation, the results indicated that the model could satisfactorily simulate hydrologic response of the catchment. Figure 21 indicates validation results for the study area.

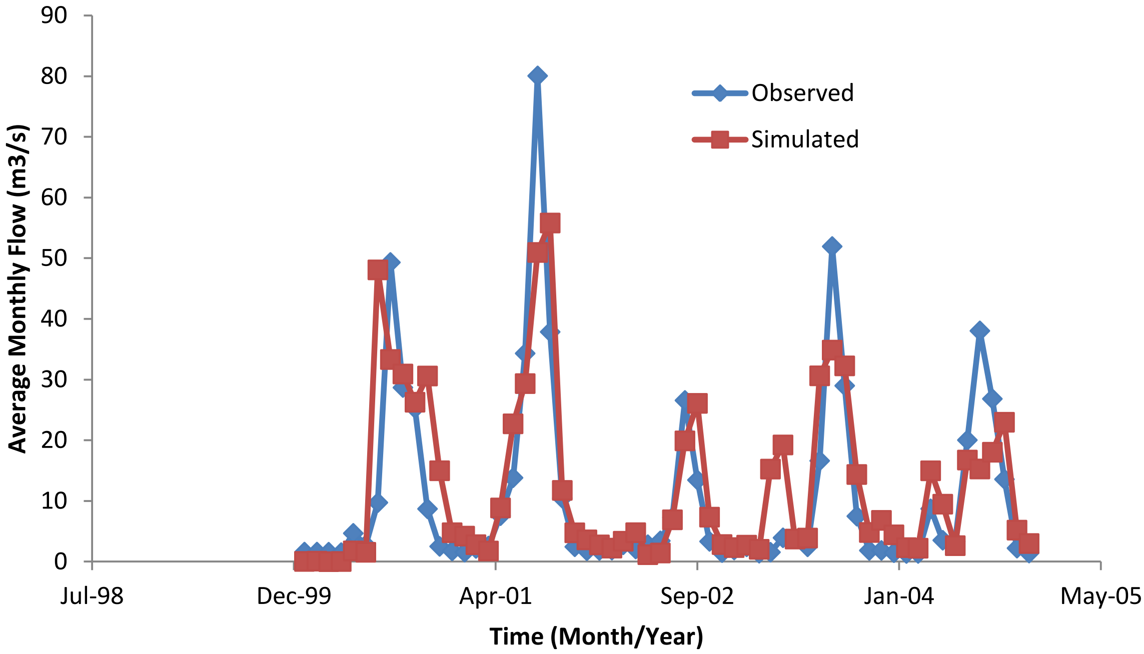

Figure 21: Simulated and Observed Discharge for Validation Period (2000-2004)

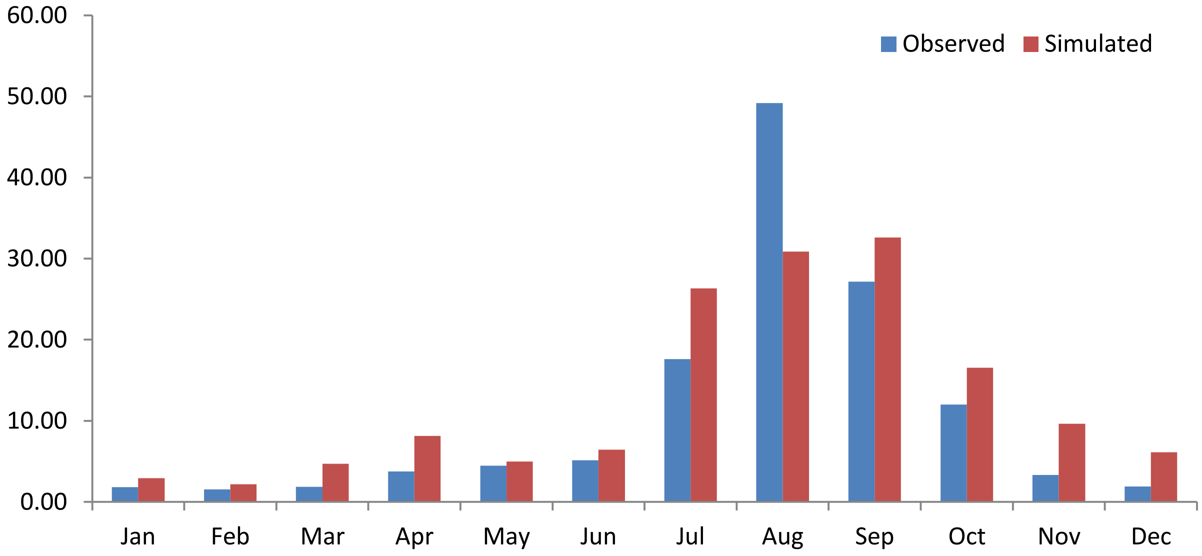

Figure 22: Graph of Monthly Observed and Simulated Flows during Validation Period

Generally, the graphical and statistical results both during calibration and validation period showed adequate model performance but the model over predicted the flow in all months except August both in calibration and validation period. From Thiessen polygon area (**Error! Reference source not found.**) it is indicated that the most parts of the watershed is covered with Bekoji and Assela stations which have higher precipitation as compared to the rest stations. This will lead to over prediction and there may also be inflow to the catchment from other watershed during this month (Figure 2). Peak flows seem to be underestimated during validation. This may be due to local rainfall storms that were not well represented by the rainfall data used in the hydrologic simulation because of uneven weather stations distribution and some missing data. The over estimation of the model could be also attributed to uncertainties that might be exist in Katar Catchment, such as surface or subsurface water abstractions for irrigation, water detention, industrial and rural or urban water supply which were unaccounted for in this study due to data limitation, and also quality of observed data may affects. Some of basin activities are indicated in appendix B (Appendix B-1, Appendix B- 2, Appendix B- 3,Appendix B- 5 and Appendix B-6) If these uncertainties are considered, the calibrated SWAT model can efficiently predict flow in the Katar catchment for management purpose. The statistical results of calibration and validation periods are presented below.

Table 12: Monthly Time Step Calibration and Validation Statistics

Period	Evaluation Criteria		
	R^2	NS	PBIAS
Calibration (1991-1999)	0.87	0.84	-21.5
Validation (2000-2004)	0.62	0.60	-16.7

Table 13: Daily Time Step Calibration and Validation Statistics

Period	Evaluation Criteria		
	R^2	NS	PBIAS
Calibration (1991-1999)	0.56	0.52	-7.7
Validation (2000-2004)	0.5	0.4	-18.5

4.3 Impacts of Land Use/Land Cover Change on Stream Flow of Katar Catchment

One of the most important parts of the study was to evaluate the hydrological responses of Katar Catchment to LU/LC change. Therefore, surface runoff, lateral flow and ground water flow were the most important catchment processes and the evaluation was done depending on these processes at the catchment outlet. These processes can be affected with changing of LU/LC change. It was done to see the stream flow change as a result of LU/LC change during the years of 1995 to 2015.

To evaluate the effects of LULC change on stream flow, SWAT model was calibrated and validated for stream flow. After calibration and validation of SWAT model, the model was run using the two land use maps (1995 and 2015) while maintaining the other parameters the same to estimate the change of stream flow due to LULC changes. The simulated stream flows due to the two land use/land cover were compared to estimate the effects of LULC change on the stream flow. The output discharges of the stream were classified as the wettest months (July, August & September) and the driest months (October to June) to see the impacts on stream flow during these months. The simulated flows of mean wet and dry month's stream flow are presented in Table 14.

The result shows that the mean wet monthly stream flow increased by 17.15% (from 50.38m^3/s in1995 to 59.02m^3/s in 2015) and the mean dry monthly flow decreased by 28.15% (from 22.91m^3/s in 1995 to 16.46m^3/s in 2015) as indicated in Table 14 during the study period (1995-2015) due to LU/LC change when compared wet season stream flow is less sensitive than dry season flow due to the reason ground water contribution during the dry season was reduced because of less infiltration that largely caused less cover. Figure 23 presents the comparison of mean wet and dry monthly flows simulated by both land use and land cover maps (LULC 1995 and LULC2015).

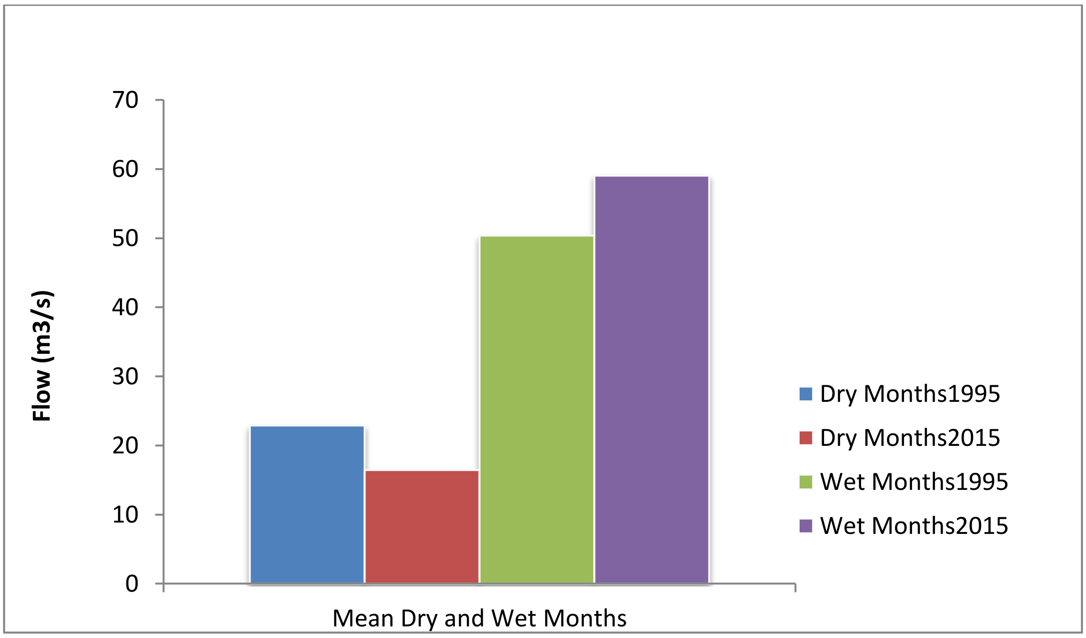

Figure 23: Simulated Mean Wet and Dry Monthly Flow of Katar Stream

Table 14:Simulated Mean Wet and Dry Monthly Flow Using LU/LC of 1995 and 2015

Wet Months (July, August & September) in m^3/s			**Difference**
MON	**Land Use Map of 1995**	**Land Use Map of 2015**	
Average Flow	**50.4**	**59.0**	**+8.6**
Dry Months (November, December &January) in m^3/s			
Average Flow	**22.4**	**13.1**	**-9.3**

For assessing change in contribution of stream flow components due to LU/LC change, analysis were made on surface runoff (SURQ) and ground water flow (GWQ).

Table 15: Mean Monthly Simulated Surface Runoff and Ground Water Flow Using LU/LC of 1995 and 2015

Land Use Map of 1995		**Land Use Map of 2015**		**Difference in SURQ and GW_Q**	
SURQ (mm)	GW_Q (mm)	SURQ (mm)	GW_Q (mm)	SURQ (mm)	GW_Q (mm)
8.7	12.1	10	10.2	+1.3	-1.9

The mean monthly contribution of surface runoff (SURQ) and ground water flow (GW_Q) to the Katar stream due to LULC change is indicated in Table 15. As it can be seen from the above table the simulated SURQ and GW_Q using land use and land cover map of 1995 were 8.7 mm and 12.1 mm while using land use and land cover map of 2015 were 10 mm and 10.2 mm respectively. The surface run off increased from 8.7 mm to 10 mm whereas, the ground water contribution was decreased from 12.1 8mm to 10.2 mm. The variation was associated with the land use/land cover change during the study period. This is attributed to expansion of agricultural land and urbanization over forest evergreen and pasture land that results in the increase of surface runoff following rainfall events and causes variation in soil moisture content and ground water storage. This expansion also results in reduction of water infiltrating into the ground and supplying the shallow aquifer. Therefore, discharge during the dry months (base flow) decreased and discharge during wet month increased. The result indicates that changes in LU/LC can affects infiltration rates, water storage capacity of soils, base flow and runoff.

The base flow values during the dry period was decreased for land use land cover map of 2015 indicating that the degraded watershed could reduce infiltration which can leads to the reduction of base flow. The lowering of infiltration rates were associated with expansion of settlement land (urbanization in the Katar Catchment) due to pavement (impervious or urban areas produce greater volumes of runoff and reduce base flow in stream) as well as agricultural land due to soil compaction from tillage activities. In addition, the expansion of agricultural land over forest every green in the upstream of the catchment resulted in the increase of runoff during the wet season. Because crops need less soil moisture as compared to forests.

Different studies have been worldwide conducted to evaluate the impacts of land use/land cover change on stream flow. The study conducted by applying SWAT model to evaluate impacts of land use changes on the hydrology and erosion in the Nile River Basin (Marwa Ali, Okke Batelaan and Willy Bauwens, 2011) concluded that decreasing forest cover can cause the risk of increasing frequent flooding. A study conducted on Angereb Watershed (Haile E. Getachew and Assefa M. Melesse, 2012) concluded that the wet season flow increased by 39% for the most recent year, while the dry season flow decreased appreciably by 46%. According to this study the reason is due to conversion of forest to agriculture which intern increased surface runoff during wet season and reduced base flow during the dry seasons. The result also indicated that the decrease in forest land and grass land are accompanied by the increase in agricultural and built up areas.

In general from this study the impact of land use/land cover change on hydrological components of Katar stream flow showed that the base flow and surface flow have been changed in the study period. The base flow decreased while surface runoff increased as a result of urbanization, agricultural land expansion and decrease of forest evergreen.

Developing Scenario

In order to analyze the different land use effects on the Katar stream flow, it is necessary to develop scenarios. The water resource management and planning strategies are analyzed depending on future scenarios. Therefore, in order to use the SWAT model as a tool for analyzing the effects of different land use changes on stream flow, scenarios were developed as indicated below.

a. 60% forest every green land is changed to agricultural land and the others land uses are remain constant
b. 70% pasture land is changed to agricultural land and the others land uses are remain constant
c. 80% pasture land is changed to forest land and the others land uses are remain constant

Depending on the above LU/LC change scenario the amount of stream flow component variation was analyzed.

Table 16 Mean Monthly average ground water and surface water flow

	Scenario(a)	Scenario(b)	Scenario(c)
SURQmm	18.0	19.1	19.1
GW_Qmm	13.2	13.1	13.2
Average Dry Months Stream Flow(m^3/s)	20.3	20.3	20.3
Average Wet Months Stream Flow(m^3/s)	66.7	66.9	66.7

5. CONCLUSION AND RECOMMENDATION

CONCLUSION

In this study SWAT model was applied to evaluate the impacts of land use/land cover changes on hydrologic regime of Katar watershed. To do this, satellite images were used to produce the map of the different cover classes of the Katar Catchment using Erdas IMAGINE2014 during the past twenty five years (1991-2015). This was done to map the land use/cover classes and assess classification accuracy. Then, the effects of land cover dynamics on the hydrology of the watershed were evaluated. The SWAT model was calibrated and validated in the Katar Catchment and Statistical performance of the model was seen. Then, the evaluation of the impacts of land use/cover change on stream flow was done.

The preparation of hydro meteorological data and land use/land cover data, sensitivity analysis, calibration, validation and evaluation of model performance were done prior to evaluation of land use/land cover impact on hydrologic response of the Katar Catchment. Processing of soil and DEM data were done using GIS whereas, land use/land cover processing was done using Erdas IMAGINE2014. From the results the following conclusions were drawn.

The land use /land cover analysis during the study period (1995-2015) indicated a significant change of LU/LC in the Katar Catchment. The study shows the expansion of land area under cultivation by 11.71% and build up area by 8.53% of a total area. But degradation of grass land during the period of 1995 to 2015. Grass land was decreased as a result of urbanization and agricultural expansion in the catchment during the study period. The afro alpine decreased by 14.38% due to agricultural encroachment to marginal land and expansion of settlement area during the study period. Generally, the change of LU/LC is due to the population increment which leads to increase demand for cultivation land.

For global sensitivity analysis using SWAT CUP (SUFI-2) twenty (20) flow parameters which may affect stream flow were considered from different literatures and only six (6) parameters were selected to have an influence in controlling the hydrological processes in the watershed.

The graphical and statistical results both during calibration and validation period showed adequate model performance with NS values of 0.84 and 0.60 and R^2 0.87 and 0.62 for calibration and validation respectively. But the model over predicted the flow in all months except August both in calibration and validation period. The over estimation of the model could be attributed to uncertainties that might be exist in Katar Catchment, such as surface or subsurface water abstractions for irrigation, industrial and rural or urban water supply which were unaccounted for in this study due to data limitation, and also quality of observed data. But from the statistical parameters it can be concluded that SWAT model, using the identified parameters could simulate the catchment hydrologic response for the study area.

The impacts of land use/land cover change on stream flow were done after calibration and validation of the model at the gauging location (Abura). The result shows that the mean wet monthly flow increased by 17.21% (from 50.38m^3/s in1995 to 59.05m^3/s in 2015) and the mean dry monthly flow decreased by 41.69% (from 22.43m^3/s in 1995 to 13.08m^3/s in 2015) during the study period (1995-2015). The mean monthly contribution of surface runoff (SURQ) and ground water flow (GW_Q) to the Katar stream due to LU/LC change indicated a variation with change in LU/LC. The simulated SURQ and GW_Q using land use and land cover map of 1995 were 5.53mm and 11.98mm while using land use and land cover map of 2015 were 8.21mm and 8.27mm respectively. The surface run off increased from 5.53mm to 8.21mm (48.46%) whereas, the ground water contribution was decreased from 11.98mm to 8.27mm (30.97%).

RECOMMENDATION

Depending on the results of the study the following recommendation was made for the Katar catchment

- In order to improve the quality of the model result the weather stations should be evenly distributed in the basin both in quality and quantity
- It is recommended that for better calibration and validation and for management purpose, future research should be done considering the different sources of uncertainties like water abstraction and water detention in the basin.
- Reforestation of marginal land at the upstream of the catchment should be implemented to develop the hydrology
- Further researches like impact of climate change on basin hydrology should be done

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7. APPENDICES

7.1 Appendix A. Tables

Appendix A- 1: Parameters Used in Sensitivity Analysis

parameters	definition
CN2	SCS runoff curve number
SURLAG	Surface runoff lag coefficient(dimensionless)
OV_N	Manning's "n" value for overland flow
SLSUBBSN	Average slope length (m)
HRU_SLP	Average slope steepness (m/m)
EPCO	Plant uptake compensation factor (dimensionless)
ESCO	Soil evaporation compensation factor (dimensionless)
CH_K2	Effective hydraulic conductivity in main channel alluvium (mm/h)
ALPHA_BF	Base flow alpha factor (days)
GW_REVAP	Ground water revap coefficient (dimensionless)
GW_DELAY	Ground water delay (days)
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)
REVAPMN	Threshold depth of water in the shallow aquifer for revap to occur (mm)
RCHRG_DP	Deep aquifer percolation fraction (dimensionless)
SOL_AWC	Available water capacity of the soil layer (mm H_2O/mm soil)
SOL_BD	Moist bulk density (Mg/m^3)
SOL_Z	Depth of soil (mm)
SOL_K	Saturated hydraulic conductivity (mm/h)
CH_N2	Manning's "n" values for the main channel
CANMX	Maximum canopy storage

Appendix A- 2: Sensitivity Analysis of Parameters (Daily)

Parameter Name	t-Stat	P-Value
7:V__ESCO.bsn	0.09	0.93
15:R__SOL_AWC(..).sol	0.18	0.86
1:R__CN2.mgt	0.26	0.79
19:R__CH_N2.rte	0.29	0.77
17:R__SOL_Z(..).sol	0.35	0.72
18:R__SOL_K(..).sol	0.47	0.64
5:R__HRU_SLP.hru	-0.66	0.51
4:R__SLSUBBSN.hru	-0.77	0.44
16:R__SOL_BD(..).sol	-0.92	0.36
6:V__EPCO.bsn	1.36	0.18
11:V__GW_DELAY.gw	-1.60	0.11
10:V__GW_REVAP.gw	-1.63	0.10
2:V__SURLAG.bsn	-2.22	0.03
14:V__RCHRG_DP.gw	-2.42	0.02
12:V__GWQMN.gw	2.48	0.01
13:V__REVAPMN.gw	2.53	0.01
8:V__CH_K2.rte	7.27	0.00
9:V__ALPHA_BF.gw	-8.07	0.00
20:V__CANMX.hru	8.35	0.00
3:V__OV_N.hru	14.51	0.00

“V_” indicates replacement by a new value; “R_” indicates relative change; suffixes rte, sol, gw etc are SWAT file extensions.

Appendix A- 3: Sensitivity Analysis of Parameters (Monthly)

Parameter Name	t-Stat	P-Value
19:R__CH_N2.rte	-0.07	0.95
13:V__REVAPMN.gw	-0.19	0.85
16:R__SOL_BD (...).sol	0.19	0.85
15:R__SOL_AWC (..).sol	0.28	0.78
17:R__SOL_Z(..).sol	0.28	0.78
4:R__SLSUBBSN.hru	0.38	0.71
11:V__GW_DELAY.gw	-0.63	0.53
6:V__EPCO.bsn	0.80	0.43
2:V__SURLAG.bsn	-0.93	0.36
10:V__GW_REVAP.gw	-0.98	0.33
1:R__CN2.mgt	1.05	0.29
7:V__ESCO.bsn	1.13	0.26
5:R__HRU_SLP.hru	-1.60	0.11
18:R__SOL_K(..).sol	1.64	0.10
12:V__GWQMN.gw	2.69	0.01
14:V__RCHRG_DP.gw	-2.91	0.00
8:V__CH_K2.rte	4.16	0.00
3:V__OV_N.hru	5.78	0.00
9:V__ALPHA_BF.gw	-8.91	0.00
20:V__CANMX.hru	13.54	0.00

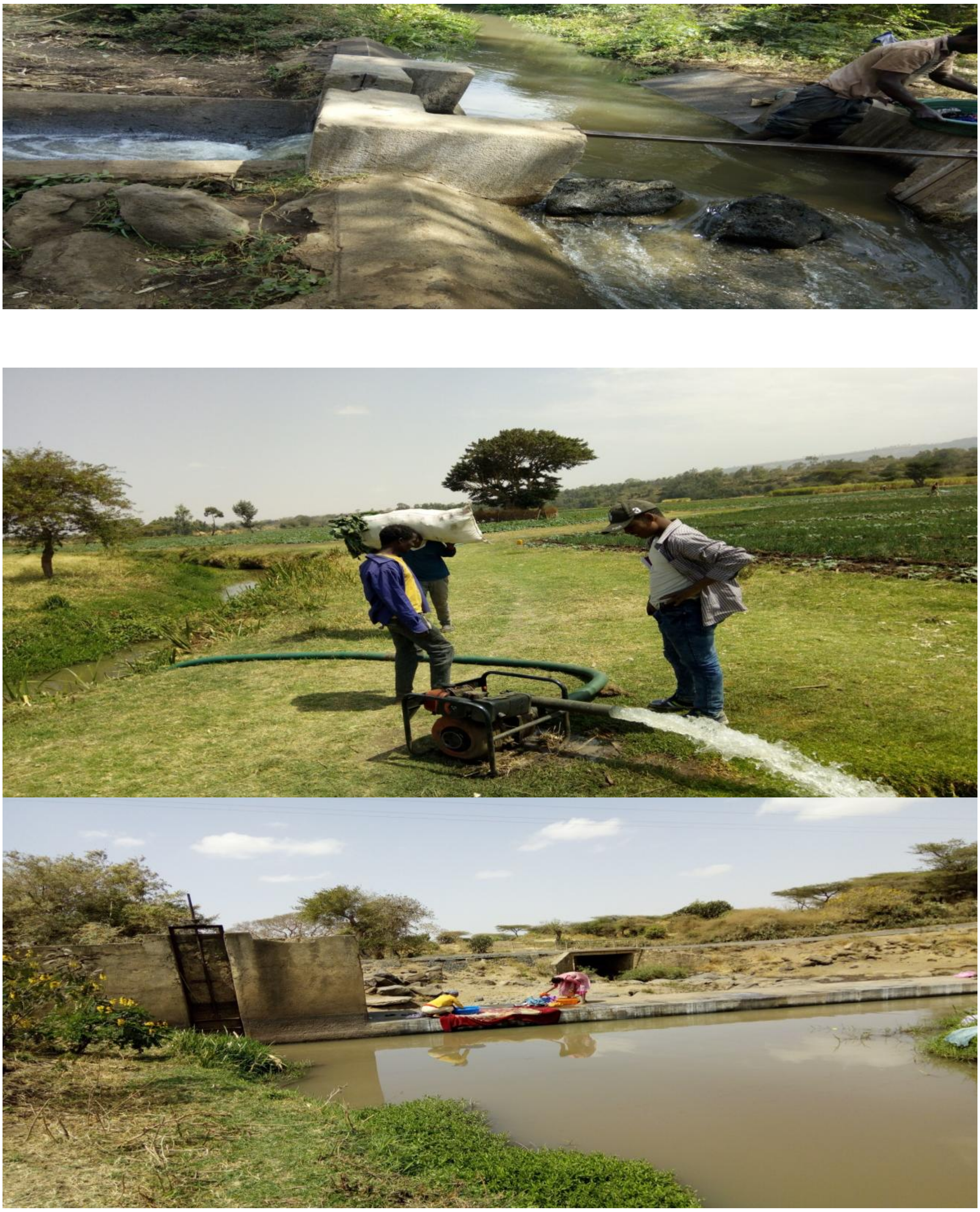
Appendix A- 4: Mean Monthly Flow of Katar River (m3/s)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	2.16	2.24	3.76	5.39	2.77	3.44	14.05	45.78	36.07	6.14	2.56	2.31
1992	2.02	2.46	1.76	3.04	3.07	3.23	8.18	65.98	53.99	25.08	4.56	2.83
1993	2.71	6.55	2.19	5.10	11.51	11.56	16.41	52.83	35.71	20.12	7.17	2.70
1994	2.14	1.92	1.64	1.56	4.05	4.27	22.93	68.87	49.09	7.02	2.81	2.04
1995	1.56	1.58	7.94	7.23	5.44	2.54	12.60	48.41	59.32	4.59	2.35	2.11
1996	2.48	1.69	2.86	3.93	6.74	17.94	21.50	64.12	24.38	8.54	2.44	2.16
1997	2.91	1.67	1.56	6.00	2.60	2.73	13.57	20.98	11.05	5.58	6.96	2.94
1998	2.19	3.45	5.01	2.38	5.99	3.66	13.40	69.19	49.60	28.12	6.76	2.36
1999	1.99	0.43	1.71	1.65	1.69	3.19	17.00	33.86	21.21	44.47	7.45	2.34
2000	1.58	1.58	1.56	1.49	4.67	2.75	9.73	49.31	28.69	25.27	8.70	2.51
2001	1.76	1.55	2.17	2.57	7.57	13.82	34.32	80.05	37.86	10.45	2.45	1.79
2002	1.84	1.90	2.77	2.08	2.80	3.43	7.29	26.57	13.45	3.33	1.48	1.92
2003	2.44	1.39	1.55	3.93	3.80	2.44	16.62	51.94	28.99	7.49	1.84	1.85
2004	1.47	1.34	1.35	8.71	3.52	3.32	20.03	38.03	26.83	13.57	2.22	1.41

Appendix A- 5: Annual Rainfall Stations used in developing double mass curve

Year	Assela	ArataRF	OgolchRF	KulumsaRF	BekojiRF
1985	1094	660.4	611.2	596.3	1000.6
1986	1372.6	981.1	867.7	938	1078.9
1987	934.9	678.5	432	775.5	967.1
1988	908	717	1487.3	874.4	1163.6
1989	1162.6	670.9	970.1	916.3	1078
1990	967.7	747	939.4	984	1066.1
1991	784	755.4	704.7	796.3	1039.7
1992	1061.1	826.5	739.8	809.5	1153.8
1993	1056.8	841.7	928.7	930.6	1186.2
1994	1097.1	638	589.2	727	1051.4
1995	1080.3	1025.2	724.2	866.9	1030.9
1996	1241.4	922.4	816	877	1085.8
1997	1154.9	882.6	747.2	911.6	1157.2
1998	1142.1	928.3	824.5	874.5	1005.2
1999	857.2	672.9	626.5	746.6	798.7
2000	1061.8	805.2	719.7	797.5	891.1
2001	1438.8	837	703.7	938.9	952.8
2002	779.5	575.2	583.3	708.4	980
2003	978.7	771.2	775.5	758.6	959.1
2004	1077.2	602.2	571	728	988.5
2005	1082.8	785.4	543.9	743.3	996.6
2006	1083.6	723.9	534.5	805.7	984.4
2007	1194.1	791.8	820.1	835.9	883.7
2008	960.1	848.9	1299.1	815.1	877.9
2009	957.1	563.1	729.7	787.9	959.8
2010	1139.1	961.4	957.5	917.8	1128.4
2011	1032.7	741.4	656.6	849.7	692.8
2012	852.1	806.4	867.3	961.2	872.4
2013	1071.7	788.9	706.9	749.8	867.9
2014	1196.6	788.6	824.3	865.7	1259.6
2015	819.2	433.5	638.8	583	785.3

7.2 Appendix B. Figures



Appendix B- 1: Water Abstraction by Diversion and Pumping at Upstream

Appendix B- 2: Water Abstraction at Abura Town

Appendix B- 3: Furrow Irrigation at Upstream of the Catchment

Appendix B- 4: Some of the Agricultural Activities in the Basin Using Irrigation

Appendix B- 5: Developed Wetland and Water body in the Basin

Appendix B- 6: Natural and Artificial Detention of Water in the Basin

Appendix B- 7: Katar River Guaging Station at Abura