Estimation of Monthly Flow for Ungauged Catchment
(Case Study Baro - Akobo basin)

By
Mesgana Berhane

Addis Ababa University
October, 2013

Addis Ababa University
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A thesis submitted and presented to the School of Graduate Studies of Addis Ababa University in Partial fulfillment of the Degree of Masters of Science in Civil Engineering under Hydraulics Engineering

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Advisor
Dr. Daneal Fekersillassie

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I, the undersigned, certify that I read and hear by recommend for acceptance by Addis Ababa Institute of Technology a dissertation entitled **"Estimation of Monthly Flow for Ungauged Catchment (Case Study Baro – Akobo basin)"** in partial fulfillment of the requirements for the degree of Master of Science in Hydraulic Engineering.

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ABSTRACT

This paper deals with predicting discharge at ungauged catchments, the case of Baro-Akobo river basin, using the WATBAL conceptual lumped rainfall-runoff model. Parameters calibrated with the model are extrapolated from gauged catchments to ungauged catchments of similar physical characteristics with Regionalization technique. In the Baro-Akobo river basin, most of the catchments are ungauged. Hydro-meteorological data from fifteen metrological and eleven hydrological gauging stations of the basin are used to calibrate and validate the model parameters. Sizes of gauged catchments whose data are used vary from about 52.5km^2 to 2800km^2. Key model parameters considered consist of sub-surface runoff coefficient (α), surface runoff coefficient (ε), and maximum water holding capacity of catchments (Smax). These parameters are calibrated using an automatic optimizing routine of the WATBAL model and through routine iteration; Smax is found to vary from 3025mm to 138mm, α from 20.50mm/day to 0.004mm/day and ε from 2.91 to 0.08. Some more model parameters, namely, direct runoff coefficient (β), subsurface runoff coefficient (γ), and base flow (Rb) are calibrated manually. The hydrograph characteristics of observed and simulated events are compared using various evaluation criteria consisting of Coefficient of Efficiency (R^2) greater than 0.7, relative volume error (E) between -10 and 10%, and coefficient of determination (r^2) greater than 0.7. Among the catchments of the basin that are used in the modeling work, 80% fulfilled the criteria. Based on availability of required data, five physical catchment characteristics are selected among those commonly used in many regionalization studies. These are catchment area, mean annual precipitation, mean annual evapotranspiration, average catchment slope and mean catchment elevation. In addition to the physical catchment characteristics, input data including precipitation, observed flow, temperature, relative humidity and sunshine are used in the WATBAL rainfall-runoff model. The WatBal model combined with the Priestly-Taylor for climate impact assessment on river basins reveals the insensitivity of the basin to the existing precipitation changes, where precipitation was almost fairly uniform, and it behaves fairly well given its simplicity. After that, regionalization methods by developing regression equations, which is the most commonly used method, were applied to transfer model parameter values from the gauged to the ungauged catchments.

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List of Acronyms

Hr	hour
Km	Kilometer
ha	hectare
Km^2	Square kilometer
M^3	Cubic meter
M^3/sec	Cubic Meter per Second
Mw	Mega Watt
GWh	Giga Watt hours
GMT	Green witch mean time
MCM	Million Cubic Meter
BMC	Billion Cubic Meter
m.a.s.l.	Meter above sea level
Alpha	Sub-surface runoff parameter in WATBAL model
Beta	Direct runoff parameter in WATBAL model
Epsilon	Surface runoff
R_b	Base flow
r^2	Coefficient of Determination
R^2	Coefficient of Efficiency
Smax	Maximum catchment water-holding capacity Parameter in WATBAL model
PET	Potential evapotranspiration
Peff	Effective Precipitation
Zi	Relative storage
WATBAL	An integrated water balance model
NS	Nash-Sutcliffe coefficient
DEM	Digital elevation model
GIS	Geographic Information System
Dd	Drainage density
LAI	Leaf Area Index
NDVI	Normalized Difference Vegetation Index
N. Server	NASA Server
MoW&E	Ministry of Water and Energy
NMA	National Meteorological Agency
EMA	Ethiopian Mapping Agency
NMSA	National Metrological Service Agency
EEPCO	Ethiopian Electric Power Corporation Organization
IAHS	International Association of Hydrological Science
GPCC	Global Precipitation Climatology Center

CHAPTER ONE

1 Introduction

1.1 Background

The successful realization of any water resources activity is vital to a country like Ethiopia for the development of the national economy. The proper planning, design, construction and operation of water resource uses are therefore, essential.

Among the twelve river basins in Ethiopia, the Baro-Akobo basin has abundant water resources which up to now have not been developed to any significant level. The Baro-Akobo basin has of great unrealized potential, under-populated by Ethiopian standards, and with plenty of land and water.

The abundance of water combined with the relief of the basin, from the high plateau at above 2,500m elevation down to the Gambela plain at an altitude of 430m provides favorable conditions for hydropower in this region.

For that reason this study will be helpful on one hand for proper utilization and management of the basin, and on the other hand for reasonable share and allocation of the water of this trans-boundary river for future negotiation with the riparian countries, TAMS & ULG (1997).

1.2 The Study Area

1.2.1 Location

The Basin is located in the southwestern part of Ethiopia. It covers approximately 75,912km^2. The area includes all or part of the four administrative regions: SNNPRS (Southern Nations & Nationalities People Regional State) in the south, Oromiya in the northeast, Gambela in the central western part and Benishangul Gumuz in the north-western extremity.

The Baro-Akobo basin is the 4th largest basin in the country, after the Wabi Shebelle, Abbay and Tekeze river basins. It is located in the south west of the country, between latitudes 5^0 31' and 10^0 54' north and longitude 33^0 and 36^0 17' east and covers an area of some 76,000km^2. The western, north western and south western side of the basin borders with the Sudan, while in the northern and north east it is bordered by the Abbay river basin and in the east and south east it is bordered by the Omo-Ghibe river basin.

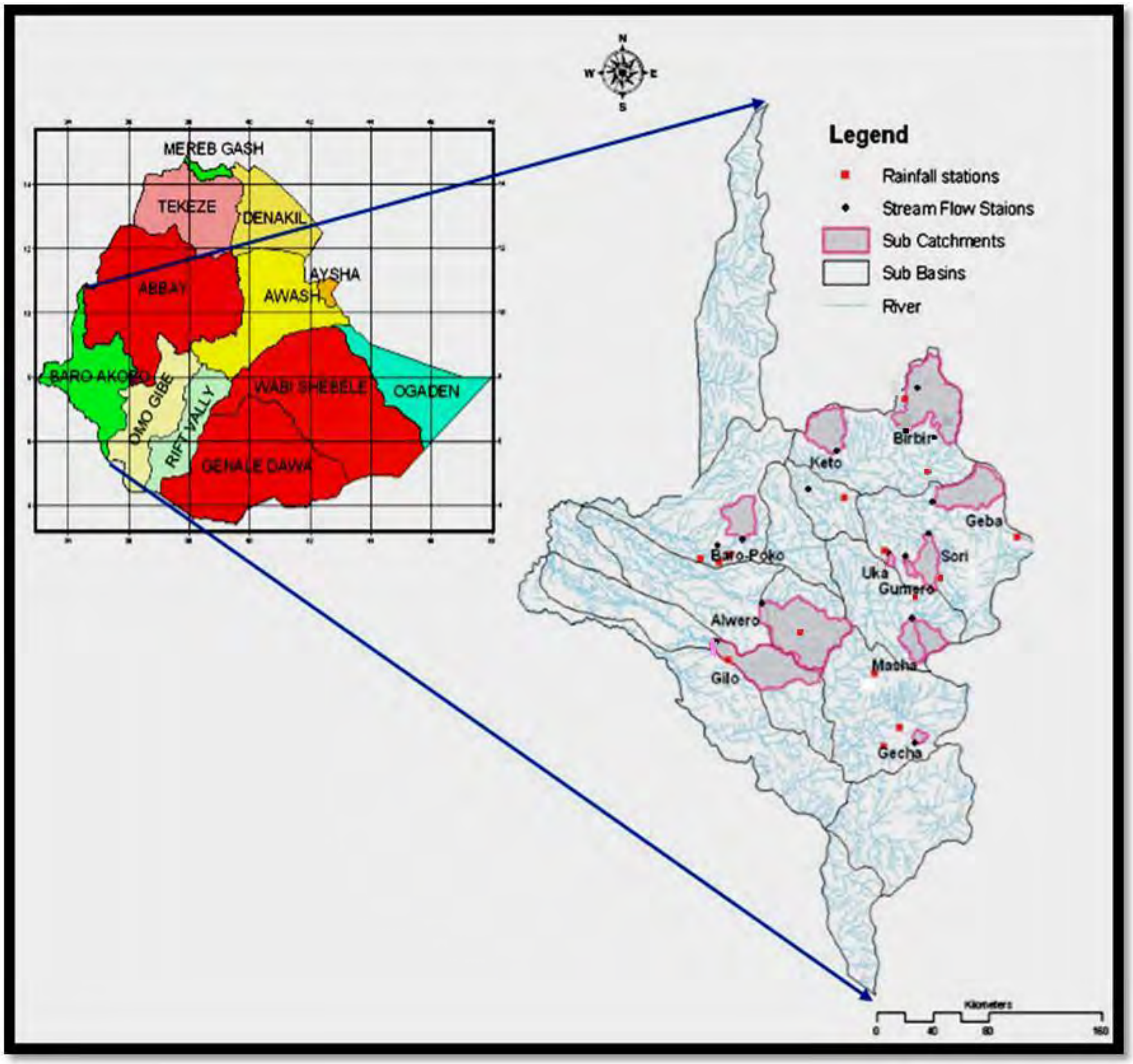


Figure 1.1 study area

1.2.2 Topography

Half of the basin lies below 1000m altitude and its highest elevation, mainly the eastern part, exceed 3000m. The north-south escarpment separates the basin in to two parts namely upper basin which is cool and moist and the lower basin of the Illubabor plain which is warm and humid.

Major rivers include the Baro and Akobo, both of which are perennial tributaries of the White Nile. The flow of major rivers closely matches the rainy season with peak discharge occurring during September.

1.2.3 Climate

The entire area is characterised by a single monsoon wet season that runs from late May or early July to the end of September / late October. The wet season is followed by a long dry season. Rainfall is highest at altitudes of 2,000masl and over, where it reaches 2,400mm but is only 900 to 1,500mm in the lower areas.

The basin receives the highest rainfall in the country. The north eastern parts, in addition to being the highest rainfall zone, experience equitable rainfall throughout the year. The mean annual rainfall is estimated to be 1588 mm. The mean annual evaporation over the basin is 1468 mm. Mean annual air temperatures also vary with altitude from a high 28^0c in the lowland to a low of 17^0c in the mountains. December is usually the coldest month and March, April and May are the hottest months, but the variability over the year is not large.

1.2.4 River System

The major rivers within the Baro-Akobo basin are Baro and its tributaries (Birbir, Geba, Sor and Baro), Alwero, Gilo and Akobo. The general flow direction of the rivers is from east to west originating from the highlands and falling to the Gambela plain. The river Akobo joins the river Pibor which borders the south western of the basin with Sudan at Trigol. The river Gilo joins the river Pibor at the border, just before a village called Madeng. The Baro River flows down to the west till it reaches Jikawo, a border town in the Sudan. It then keeps on flowing to the west till it joins the River Pibor at Burbey, a village near the border, which is the outlet of the entire basin‘s drainage to the Sudan. The river flow regime is closely connected to the monsoon climate with stream flows increasing through May to September, where they reach a maximum mostly in the month of September. When the wet season drastically turns down, the river levels decline and the flows are smallest from December to April. The catchment areas and mean flows in the main rivers of the basin are summarised in table 1.1.

Table1.1 Summary of surface water resources

Basin	Catchment area(km²)	Mean annual runoff(MAR) (million cubic meter)
Baro	30,004	12,784
Akobo Upper	6,036	1,774
Akobo Lower	7,209	2,118
Gilo	12,815	3,224
Alwero	8,019	1,375
Serkole	7,702	1,320
Tirmatid	2,690	419
Pibor	1,435	224
Total	75,910	23,237

Source: TAMS & ULG (1997)

1.3 Statement of the problem

A better understanding of the hydrological characteristics of different watersheds of Baro-Akobo River Basin is of considerable importance because of the country's interest in the utilization of its water resources, the need to improve and expand development and management activities of these resources, and the potential danger from negative impacts of climate change in the future. In Ethiopia most river basins have less coverage of hydro-meteorological gauging stations. Baro-Akobo basin is one of these river basins. However, the country is on the way of exploiting its water resource potential. Full exploitation of the available water resource potential requires knowledge of the basin water balance. This in turn requires knowledge of the contribution of ungauged catchments of the basin. Since, in the Baro-Akobo basin, hydrometric network is not evenly distributed, large areas lack gauging stations and only few gauging stations have long years of data. Consequently, there is a need to develop a method for predicting flow at the ungauged sites. Thus in this study, an attempt is made to estimate runoff in gauged and ungauged catchment to understand the temporal and spatial variability of water yield since it has a great comportment on local developments and downstream users.

1.4 Scope of the study

Rainfall-runoff models are often used to predict stream flow in space and time domain for operational and scientific investigations. Extrapolation and regionalization processes enable us to simulate response of catchments for which time-series are not available. Due to the presence of several factors, prediction of discharge regimes in ungauged and gauged catchments involves some degree of uncertainty. In predicting gauged catchments, the factors that cause uncertainty include different model structures representing the real world differently, inadequacy of data required by the models and the model calibration parameter. For better water management these predictions should be done accurately by reducing the uncertainties. Since observed data are not available or not sufficient for model calibration, to predict the model parameters in ungauged catchments depends on other sources of information. This introduces high degree of uncertainty in discharge prediction of ungauged catchments unlike that of gauged catchments.

1.5 Objective of the Study

1.5.1 General objective

The general objective of this study is to apply a hydrological model and regionalization technique, and simulate runoff for ungauged catchments of Baro-Akobo river basin.

1.5.2 Specific objectives

- To identify catchment characteristics that can be used for predicting flow for ungauged catchments.
- To analyze the response of river basins to potential climate change by combining a WATBAL model with Priestley-Taylor method.
- To determine WATBAL model parameters required to estimate monthly flow for ungauged watersheds
- To determine the possibility for regionalizing parameters of selected lumped rainfall runoff models on the basis of catchment characteristics, and using these to estimate flow of ungauged catchments.

1.6 Research questions

- What are effective and efficient WATBAL model parameters to relate to physical catchment characteristics?
- Which physical catchment characteristics are available and suitable to relate to WATBAL model parameters?
- What appropriate regionalization methods can be used to extend the observed hydrologic regimes to ungauged basins?

1.7 Outline of the Thesis

Chapter 2 contains rationalization of the Baro-Akobo Basin, and a brief description about the review of Rainfall-Runoff model. Hydrologic processes are covered in this chapter, which describe the scientific principle governing hydrologic phenomenon that is a system concept.

Chapter 3 describes the study area. The types of catchment and flow characteristics selected for use in this study, and justification for this selection are presented. A description of the variation of these characteristics among the selected sub-catchments is also given.

Chapter 4 would be collection of data suitable to the application of the method. These are Catchment physiographic data, the metrological data (rainfall) and the hydrological data (Stream flow data).

Chapter 5 the applied methodology with respect to model calibration and validation is described. In more detail, the model parameters used in calibration, the approach of calibration and in what way model calibration is evaluated are expounded.

Chapter 6 analyze the response of river basins to potential climate change by combining a water balance model for selected representative catchment parameters with Priestley-Taylor method for computing potential evapotranspiration.

Chapter 7 is detailed discussion on the results of model calibration and validation and Regionalization processes. The feasibility of regionalizing and the WATBAL model, which is a lumped conceptual model, are investigated in this chapter. The possibility of predicting model parameters from catchment characteristics is examined. And finally chapter 8 will be conclusions and recommendations of this study.

CHAPTER TWO

2 Literature Review

2.1 The Baro-Akobo Basin

The Baro-Akobo basin has an irrigable land resource of 483,000 ha and total arable land resources of 1,118,300 ha. According to the data collected, the potential irrigable site in the upper basin was estimated to be 114, 000 ha, TAMS & ULG (1997).

The Baro-Akobo, Alewero, Gilo, Birbir and Sor together discharge an estimated 11.81 bm^3 of water annually. According to Water Sector Development Program (2002-2016) Water Resources Program, the long term mean annual flow of Gambella flood plain is estimated to be 23.6 bm^3 but at the outlet of the basin it is only 11.8 bm^3. The difference of 11.8 bm^3 is lost through evaporation and overflows.

The Egyptian Hydrologist, Shahin (1985) also indicates losses on the Baro are mainly due to spillage over its banks, ARDCO-GEOSERV (1996). The loss from Gambella to the Baro-Pibor junction, without taking account of all the run-off that should be discharged in the Baro, the average loss was 4 bm^3 /yr. The drainage basin of the river Baro is characterized by the loss of not less than 35% of its annual yield, due to spillage over the plain and also the feeding of khors which flow through the Machar swamps. The mean annual open water evaporation was estimated for Gambella and Akobo about 4.3 and 5.3 mm/day respectively.

2.2 Irrigation Potential of the Basin

As stated in the earlier chapter Baro Akobo river basin has an area of 75,912 Km^2, covering parts of the Benishangul-Gumz, Gambella, Oromia, and SNNPR. The basin has a lowest elevation of 390 m. and highest elevation of 3244 m. The total mean annual flow from the river basins is estimated to be 23.6 BMC. Twenty two large-scale potential irrigation sites are identified in the basin, with an estimated irrigable area of 1,019,523 hectares. Figure 2.1 shows Irrigation Potential of the Baro-Akobo River Basin**.**

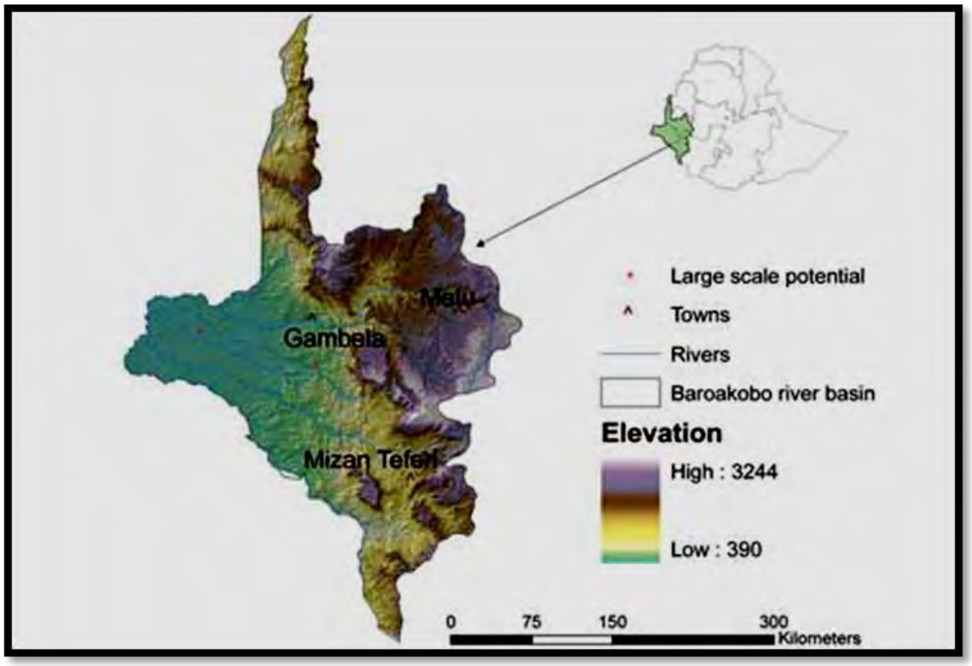


Figure 2.1 Irrigation Potential of the Baro-Akobo River Basin**.** (Source: The Nile Basin Development Forum [NBDF] 2006)

According to the assessment of TAMS-ULG (1997), provisionally 18 potential irrigation projects selected by ARDECO GEOSERV in the upper basin, of the 15 sites have been tentatively identified as run-off diversion schemes having no identifiable storage sites. Most of the 17 sites tentatively identified for irrigation development were found to be unsuitable for irrigation. The only promising area is the Baro River in the Bonga area. In contrast with the upper basin, the lower basin, in Baro-Akobo Basin Master Plan Study of Water & Land Resources of the Gambella Plain Final Report (SELKHOZPROMEXPORT, 1990) the top priority irrigation projects are presented in the table 2.1.

Table 2.1 Lower Basin Priority Irrigation Projects.

No.	Projects	Irrigated areas in thousand ha.
1.	Baro River Basin	205
A	Left Bank	80
B	Right Bank	125
2	Alwero River Basin	29.2
A	Alwero Reach	10.4
B	Abobo Reach	18.8
3	Gilo River Basin	69.4
A	Right Bank	39.4
B	Left Bank	30
	Total of Gambella Plain	303.6

Source: TAMS & ULG (1997)

On the recent study of the Baro-Akobo Master Plan by TAMS & ULG (1997), 14 basic irrigation systems and 8 variants were identified.

The Baro-Akobo basin is the second most important basin, next to Genale Dawa, as far as irrigation potential is concerned. The population is settled sparsely in the lowlands of the basin which offers a conducive environment for water resources development. As a consequence of regular flooding, the lowland areas are mainly used as pastures for grazing and no major water resources development has taken place to-date.

The irrigation study by TAMS & ULG (1997) clearly indicates that the potential for development lies in the Gambella plain in the lower basin where the ultimate development potential is in the order of 600,000 hectares gross area or 480,000 hectares net area. Further the Baro right bank-Itang Dam project with a potential for about 50,900 ha irrigation development studied at pre-feasibility level by TAMS & ULG (1997).

2.3 Hydropower Potential of the Basin

In the WAPCOS (1990) study 11 hydropower sites were identified on the Baro River with a gross potential energy of 3,532 Gwh/yr. But the Soviet team of experts SELKHOZPROMEXPORT (1990) study identified 14 dam storage/multipurpose projects for power generation in the Baro-Akobo basin. The primary purpose of the storage dams is not always hydroelectric power but all have been presented with a hydropower component. These on the Baro River are Gambella, Bonga and TAMS projects. The Geba, Birbir and Sor projets are on the Baro river tributaries, the Gilo 1 and Gilo 2 projets on the Gilo River. These are listed on table 2.2.

Table 2.2 Dam Storage projects Proposed by Selkhozpromexport.

No.	Project Site	Project Name	Installed Power(MW)
1	Baro River 15 km upstream of Gambella	Gambella	258
2	Baro River 30 km upstream of Gambella	Bonga	372
3	Baro River 50 km upstream of Gambella	TAMS	519
4	Birbir River	Birbir	304
5	Geba River	Geba	180
6	Sor River	Sor	16
7	Gilo River	Gilo 1	72
8	Gilo River	Gilo 2	27
9	Mei River	Mei	0.2
10	Alwero River	Alwero	3

Source: SELKHOZPROMEXPORT (1990)

In addition to the above mentioned water works located in the river's upper reaches, some projects shall be constructed in the rivers lower reaches. Except for the power generation and flow regulation, these projects are intended for diversion of water for irrigation purposes. Characteristics of diversion water works are presented in table 2.3.

Table 2.3 Diversion Water Works proposed by Selkhozpromexport.

No	Project Site	Project Name	Effective Storage of Reservoir (Mm3)	Head (m)	Intalled Power (MW)	Potential Power Generated (MKWh/Y)	Approx. Irr. Area (thousands, ha.)
1.	Baro River b/n Gambela and Itang	Itang	249	5.5	20/15	91/65	Up to 37
2.	Aiwero River 5km from Abebo Village	Abebo	57	-	-	-	10.4
3.	Chiru River, the Alwero River tributary	Chiru	257	33	2	6.8	18.8
4.	Gilo River 25Km Upstream Agenda Village	Gilo 21	552	26	27/15	175/75	69
5.	Gillo River near the Agenda Village	Gilo 3	930	20	20/15	100/60	69

Source: SELKHOZPROMEXPORT (1990)

Those projects proposed to connect to the ICS should be compared with other candidate projects on a nation-wide basis. As a preliminary approach, these projects have been compared on the basis of cost per kW of installed capacity. This is, of course, an approximate method of comparison since the plant factors vary to some degree from project to project. The average discounted cost of EEPCO projects at January 1996 price levels has been estimated to be $2,406 per kW of installed capacity. Table 2.4 compares the better projects from the baro-Akobo basin with those projects that already appear in EEPCO's expansion plan.

Table 2.4 Comparison with projects in other basins**.**

Project	Installed capacity(MW)	Unit cost(US$/kW)
Baro- Akobo Basin Projects		
Baro-A 1&2	210	1,331
Geba- A 1&2	171	1,392
Birbir A&R	508	1,918
Birbir-R	422	1,964
Other basins in Ethiopia		
Gilgel Gibe	180	1,534
Aleltu East 1	186	2,053
Aleltu West	165	2,856
Halele-Warebesa	332	2,400
Chemoga- Yeda I & II	630	1,816

Source: TAMS & ULG (1997)

Of all the above projects Geba and Gumero were studied by the Master Plan up to pre-feasibility level. Also the Baro 1 and Baro 2 hydropower projects were studied by NORPLAN (1999), pre-feasibility level with detail design and developed as cascade schemes suitable for energy export. The basin is capable with plentiful potential hydropower resources, more than sufficient to meet the projected demands of the entire nation for many decades to come. This study also identifies local projects for the Baro-Akobo basin in table 2.5.

Table 2.5 Candidate Projects for Basin Supply.

Project	Installed capacity MW	Energy Cost (US$/KWhr)
Kashu	60	0.040
Gumero	50	0.049
Baro 1	40	0.050

Source: TAMS & ULG (1997)

2.4 An over view of Rainfall Runoff Model

2.4.1 Rainfall Runoff Process

The surface subsystem of the hydrologic cycle is where the rainfall and runoff interaction takes place. The input to this system is the rainfall and the output taken as the stream flow at the outlet of the system.

2.4.1.1 Rainfall

In the hydrologic cycle, moisture comes from the atmosphere to the surface as precipitation. The rainfall pattern and intensity greatly influences the runoff. If the rainfall intensity is lower than the equilibrium capacity, then all the water reaching the land surface will infiltrate. If the rainfall intensity is greater than the equilibrium infiltration capacity, but less than the initial infiltration capacity, at the beginning all the water will infiltrate, but when the infiltration capacity drops below the rainfall intensity, some of the water will remain on the ground surface. Finally, if the rainfall intensity is greater than the initial infiltration capacity, some water will immediately remain on the land surface.

Therefore, the nature of rainfall pattern is of great importance in dealing with runoff process. A summary of the cycle is given by Chow et al. (1988) and a brief description illustrated in Figure 2.2.

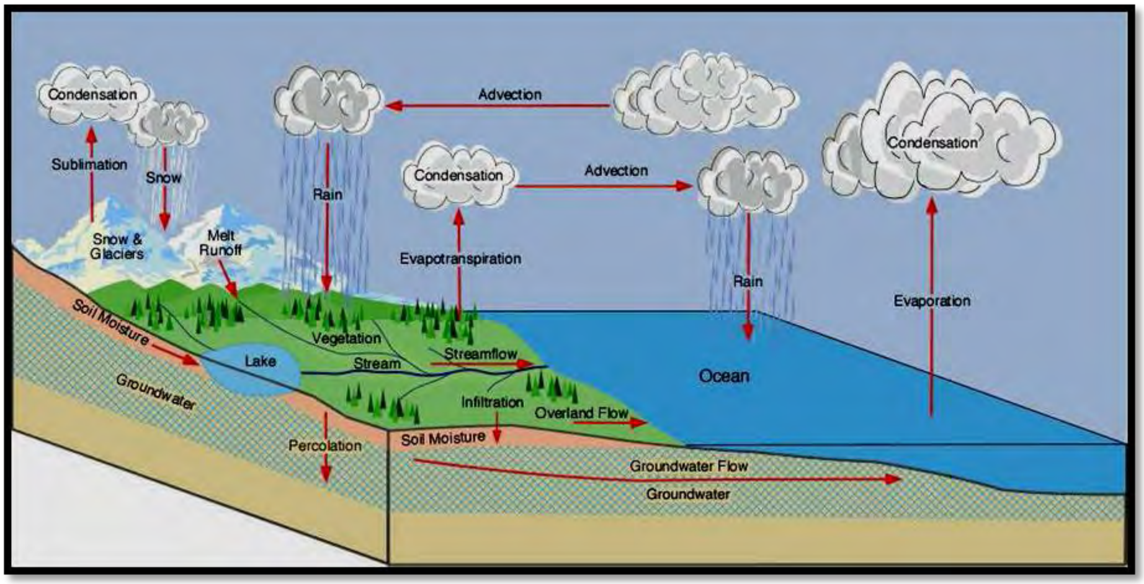


Figure 2.2 Hydrological cycle, Chow et al. (1988).

Rainfall is extremely variable both in time and space. The variation is brought about by differences in the type and scale of development of precipitation-producing processes, and is also strongly influenced by local and regional factors, such as topography and wind direction at the time of rainfall. It is, however, assumed that each individual rain-gauge is representative of a very considerable area around it. This assumption is not correct. Because of the very considerable spatial variation of precipitation depth and intensity, particularly for short durations and for sever convectional storms as is the case in most parts of Ethiopia. There is no guarantee that point rainfall will in any way provide a reliable guide to the rainfall of immediate surrounding areas.

Hence to account the spatial and time variation of rainfall, one can derivate the areal rainfall from a number of point rainfall data. The simplest and most obvious initial approach to the derivation of areal rainfall is to calculate using the arithmetic-mean method. This method is satisfactory if the gauge is uniformly distributed over the area and the individual gage measurements do not vary greatly about the mean. The Thiessen polygon method is the second and generally more accurate than the arithmetic-mean method. The Isohyetal method is flexible than Theissen polygon but it is more time-consuming, Chow et al. (1988).

2.4.1.2 Runoff

A considerable portion of water from the hydrologic cycle after flowing on land is returned as stream flow, which is defined as the movement of water under the force of gravity through well-defined channels. Sometimes the water that moves in defined channel or all the water that moves over the land in undefined channel is termed as runoff, Chow et al. (1988).

During precipitation, some of the rainfall is intercepted by vegetation before it reaches the land surface. This may later fall to the ground or evaporate. Meteoric water which is not intercepted by the vegetation cover falls on the ground surface, where it evaporates, infiltrates into pervious soils, lies in the ground depression or flows down giving rise to runoff. The runoff process is strongly influenced by infiltration capacity. The infiltration capacity varies not only from soil to soil, but is also different for dry versus moist conditions in the same soil. After a certain time it reaches a regime value which is called equilibrium infiltration capacity, Chow et al. (1988).

The water, which does not infiltrate, forms puddles or flows as a thin sheet across the land surface which is called overland flow or surface runoff. Hydrologists refer to the water trapped in puddles as depression storage.

The overland flow, sometimes called Horton overland flow, occurs only when the rainfall intensity exceeds the infiltration capacity. In areas in which soils have a high infiltration capacity, this process may occur only during very intense storms or when the soil is saturated or frozen.

If the unsaturated zone is uniformly permeable, most of the infiltrated water percolates vertically (percolation). If layers of soil with a lower vertical hydraulic conductivity occur beneath the surface, then infiltrated water may move horizontally giving rise to what is called interflow. This interflow is substantial in some drainage basins, and contributes significantly to the total stream flow. Thin permeable soil overlying fractured bedrock of low permeability would provide a geological condition contributing to significant interflow, Chow et al. (1988).

The infiltrated water that percolates into the saturated zone below the water table becomes stored in the groundwater reservoirs or aquifers. This is not a static storage, as groundwater is in constant movement. While freshly infiltrated water is entering the groundwater reservoir, other groundwater, known as base flow, is discharged into a stream.

Water that infiltrates into the soil on a slope can move down slope as lateral unsaturated flow (through flow). The difference between through flow and interflow is that through flow emerges as seepage at the foot of the slope rather than entering a stream, as does interflow.

Thus, through flow appears as overland flow before entering a stream channel. This peculiar overland flow is called return flow which is different from the Horton overland flow. Direct precipitation is also very important for the stream flow, especially when it falls onto the surfaces of large lakes or reservoirs.

2.4.2 A Brief Description of Rainfall-Runoff Model

2.4.2.1 System Concept

Hydrologic phenomena are extremely complex, and difficult both to measure and understand in full detail. In the absence of perfect knowledge, however, they may be represented in a simplified way by means of the system concept which is a set of connected parts that forms a whole.

The **hydrologic cycle** may be treated as a system, whose components are precipitation, evaporation, snowmelt, infiltration, runoff and other processes in the hydrologic cycle. The different components can each be grouped together into subsystem or broken down into new sub-processes, depending on the level of detail in the analysis and the purpose of the analysis. For most practical applications, only a few processes of the hydrologic cycle are Considered at a time, and only for a small part of the earth‘s surface, usually in a catchment, Killingtveit A. et al. (1995).

A hydrological system can be defined as a structure or volume in space, surrounded by a boundary that accepts water and other inputs operates on them internally and produces an output. The objective of hydrological system analysis is to study the system operation and predict its internal states and output.

A **hydrological system model** is an approximation of the actual system. Its inputs and outputs are measurable hydrological variables and the model‘s structure is a set of equations linking input and output. Central to the model structure is the concept of system transformation. The input and output can be expressed as functions of time I (t) and Q (t) respectively. A system performs transformation of the input into the output by a transformation operator or equation.

The watershed can be looked upon as an operator transforming the moisture input (I (t): Precipitation) into outputs (Q (t): runoff, evaporation, transpiration). A simplified Representation (a model) of this transformation operator can be written by mathematical equations and logical statements, describing the structure for a precipitation-runoff model for the catchment. The figure 2.3 below shows a watershed seen as hydrological transformation operator.

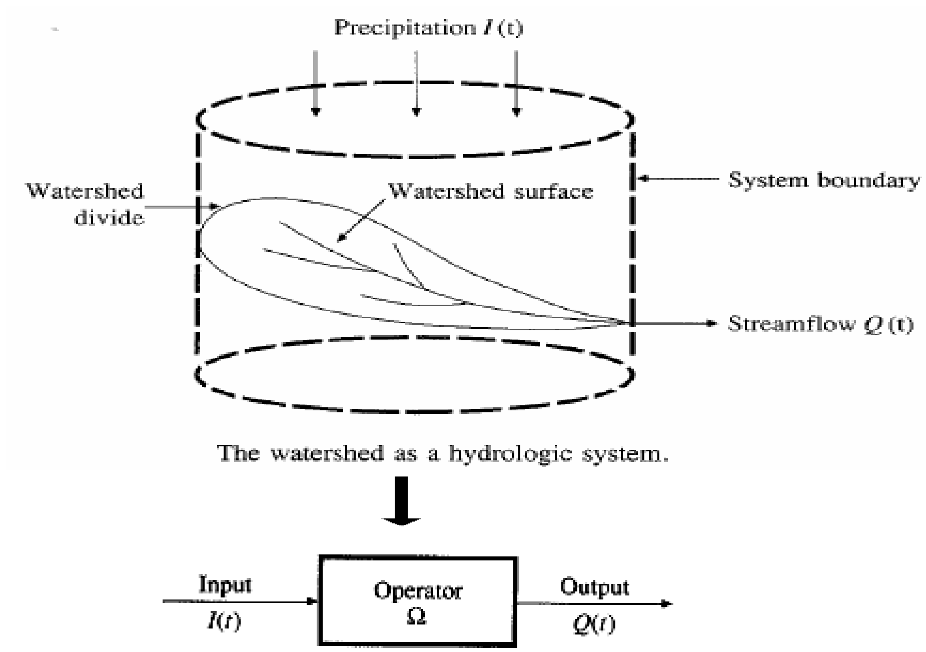


Figure 2.3 Watershed seen as hydrological transformation operator.

Because of these great complications, it is not possible to describe all the physical processes within the watershed with exact physical laws. Using the physical system concept the effort is instead directed to the construction of a model representing the most important processes, and their interaction within the total system. A conceptual knowledge of the physical system will still be valuable to determine the main processes, and develop a simplified but useful model. The term conceptual modeling is used for this type of analysis, Killingtveit A. et al. (1995).

2.4.2.2 Classification of Rainfall-Runoff Models

Hydrological models are commonly divided into two main categories; physical models and abstract models. Physical models include scale models such as hydraulic models of a spillway, and analog models which use another physical system having properties similar to those of the real system. Abstract models represent the system in mathematical form. The system operation is described by a set of equations and logical statements, Killingtveit A. et al. (1995).

Several systems for classification of hydrological models have been used. One such system for classification of input-output type of model is shown in Figure 2.4 (Beven 2001). The models are classified according to three main criteria;

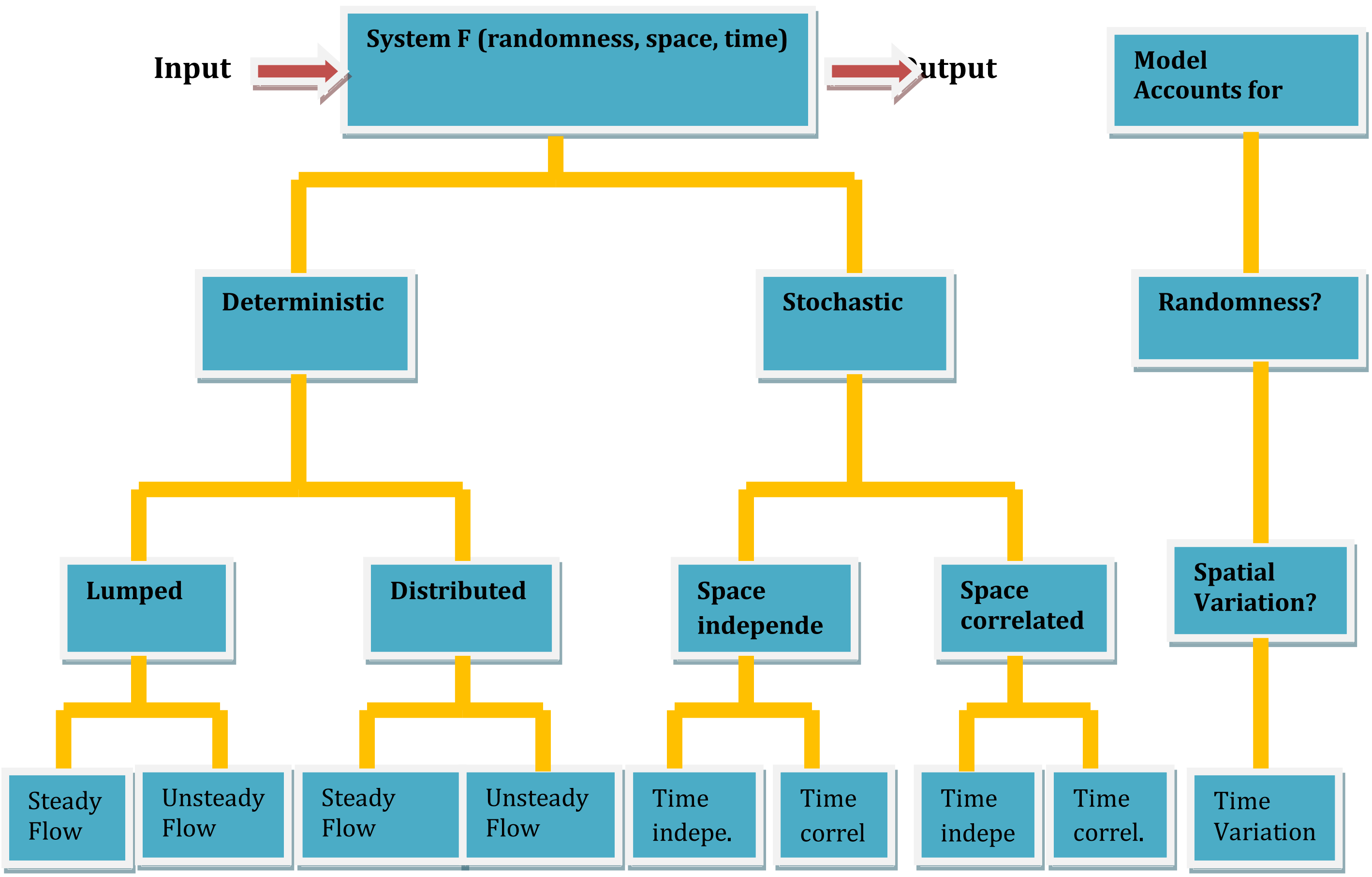


Figure 2.4 Classification of hydrological models.

1) Randomness (deterministic or stochastic)

2) Spatial variation (lumped or distributed)

3) Time variability (time-dependent, time-independent)

In total, a number of different model classes are classified in this system. The simplest type of model will be a deterministic lumped time-independent model. The most complex type of model would be a stochastic model with space variation in three dimensions and with time variation, Killingtveit A. et al. (1995).

There are quite a number of hydrological models. Some available model covers many possible applications (with varying degree of availability). Some make approximate estimate from limited information, and others require a great deal of descriptive data and use large amount of computer time and detailed computations.

There are numerous criteria which can be used for choosing the suitable hydrologic model (Juraj M, 2003). These criteria are always project-dependent, since every project has its own specific requirements and needs. Furthermore, some criteria are also user-dependent and subjective. The following criteria are most commonly applied for comparison and selection of an appropriate hydrological model:

a. Temporal scale: The time step used in the model.
b. Spatial scale: For what basin size is the model developed or recommended to be used
c. Cost: Price of the model.
d. Set-up time: Approximate time needed to set the model into operational use.
e. Expertise: What scientific expertise is required to use the model adequately?
f. Documentation: What documentation is available about the model, such as user‘s guides, reference manuals, web pages, newsletters, etc…?
g. Ease-of-use: Describes computer-related user-friendliness of the model, taking into account GUI, input-output (I/O) operations, and visualization options.
h. Operating System: Computer operation system required for the model [UNIX, DOS, Mac, Win 95, 98, Me, 2000, XP].
i. References: Lists the key reference(s) to the model in the literature.

An attempt is made to select hydrological model that addresses the stated objectives of the study based on the above criterion.

Thus, the lumped conceptual model selected for use in this study is WATBAL. It is chosen because it suites the objectives of the study, data availability, low set up time, Ease of use and it is recommended for giving good results in predicting model parameters that are used to estimate flow of ungauged catchments.

2.4.3 WATBAL: An Integrated Water Balance Model

The WatBal, water balance hydrological model was used in this study to estimate monthly flow of the Baro-Akobo basin. It is a lumped conceptual model which represents the water balance in the use of continuous functions of relative storage to represent surface outflow, sub-surface outflow and evapotranspiration (Kaczmarek 1993; Yates 1996).

It has essentially two main modeling components. The first is the water balance component that uses continuous functions to describe water movement into and out of a conceptualized basin. The second is the calculation of potential evapotranspiration using the well known Priestly Taylor radiation approach. The mass balance is written as a differential equation and storage is lumped as a single, conceptualized ‗bucket' with the components of discharge and infiltration being dependent on the state variable relative storage (Yates 1996).

CHAPTER THREE

3 Physical Characteristics of the Study Area

3.1 Climatology and Relief

3.1.1 Climatology

The Baro-Akobo basin enjoys varied climate conditions due to its wide elevation differences ranging between 300 meters and 3000 meters. It has been observed that rainfall and temperature are correlated with altitude. As a result, temperature varies from about 40˚C in the lowlands around Abebo and less than 22˚C around Kombolcha. Similarly rainfall varies between less than 1000mm in the western lowland and more than 2500mm in the far eastern highland of the basin, ARDCO-GEOSERV (1996).

In terms of the circulation of the atmosphere the weather systems affecting the area, Kiremt is the main rainy season which results from the ITCZ activity, interaction between the mid latitude depressions and tropical air mass from the southern Atlantic ocean across central Africa; disturbances from northern Indian ocean, coupled with occasional easterly waves. During the Bega (dry) season, the Baro-Akobo basin is predominantly influenced by warm and cool dry air masses from the Saharan and Siberian or Arabian anticyclones, respectively. The area shows mono-modal (single peak) rainfall pattern, and Tropical rainy climates dominate the area. Appendix B illustrates climatic zones of the Baro-Akobo basin, ARDCO-GEOSERV (1996) and its rainfall distribution.

3.1.2 Relief

Recurrent dissection and highland rolling and Steep slopes are basic features which characterizes the basin physiographic Characteristics. Highlands with altitude ranging between 1500m and 3000m and peaks rising over 3000m constitute the basin. Half of the basins topography is lowland, ranging from 300m up to1000m in elevation. Due to dissection and associated erosion, the north-south escarpment separates the basin in to two parts namely upper basin which is cool and moist and the lower basin of the Illubabor plain which is warm and humid. The rainy season peaks during August. Major rivers include the Baro and Akobo, both of which are perennial tributaries of the White Nile. The flow of major rivers closely matches the rainy season with peak discharge occurring during September, TAMS & ULG (1997).

The diverse physiographic characteristic of the basin creates both potentials for development and margins on development. The highland mass causes the rain-bearing air masses to uplift, leading to the dominantly plentiful rainfall, which provides for both agriculture and hydropower. The wide range of altitudes and associated climates offer potential to grow a wide range of crops, from temperate to tropical species. On the contrary, the frequent and deep dissection creates major barriers to communication, while the associated steep slopes creates direct and indirect impediments to agriculture, resource management and infrastructure development, TAMS & ULG (1997). Figure 3.1 shows different Relief of the catchments.

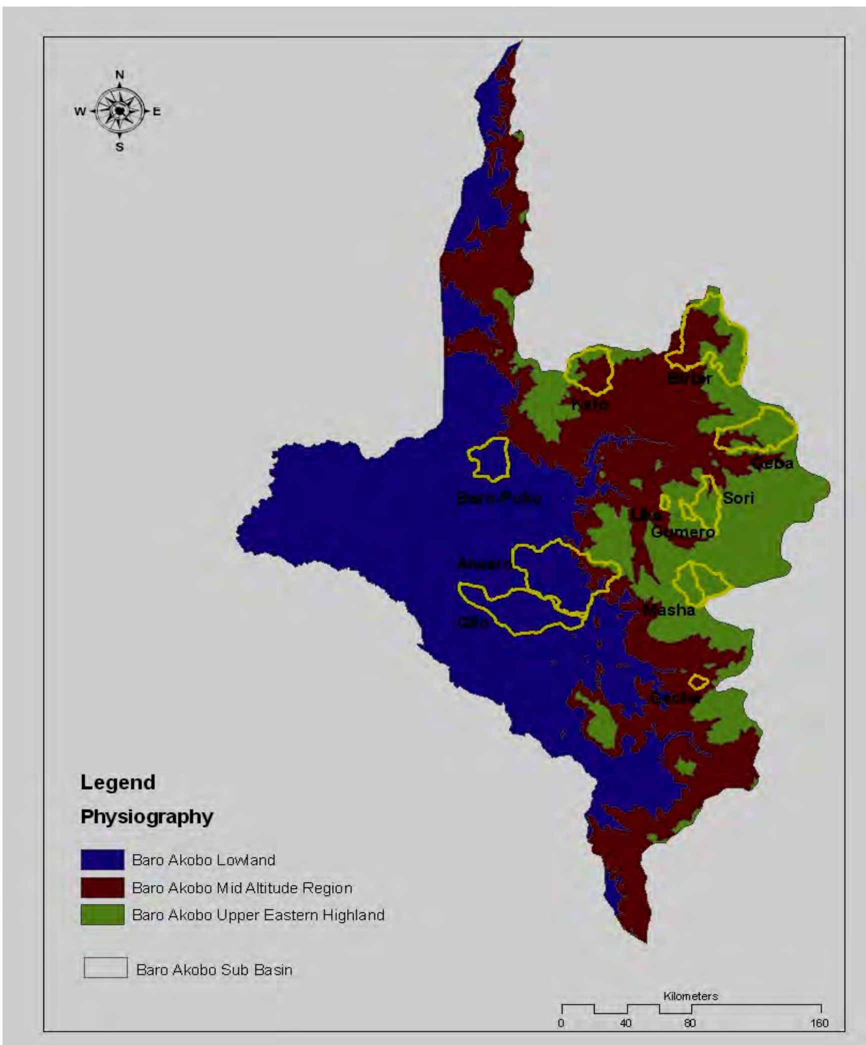


Figure 3.1 Catchment relief derived from the DEM.

3.2 Land cover and Soil type

3.2.1 Land Cover

The land covers of the basin follow the divide between highland and lowland. The landscape is made up of numerous westerly flowing rivers and their contributing basins; the area is an important watershed of the White Nile. Its drainage covers about 76,000km^2. Figure 3.2 Shows Land Escapes of the Baro-Akobo River Basin (Mow&E team January, June, 2011). The natural vegetation of the area reflects differences between the plains and uplands in landscape, soil, climate, and history of land use. Daviesson (1999) classified Ethiopia's natural forests as being:

- Riparian,
- Mixed deciduous
- Coniferous, and
- Transitional zone(Oleo spp),

Upper watershed Landscape of Sori River near Mettu January 2011, (elevation > 2000 meter above sea level).

Keto River near Canka area.

Baro River near Itang Town.

Alwero Irr. canal near Abebo.

Getcheb River in Megenger zone.

Figure 3.2 Land scape of different areas of the Baro-Akobo River Basin, January, June 2011.

Agriculture with dense Forest or with woodland (cultivated area with perennial crop) is largely the land property of upper basin, where they are either under active conversion to cultivation or are ‗protected' through serving as shade for coffee trees. Other agricultural land with cultivated area of nearly 60 % exists along the mid altitude highland-lowland divide defined fault escarpments, generally on rolling and hilly slopes, and in the eastern highland tips of the basin. The other major highland land cover is forests with very distributed forest range, which occurs primarily either in poorly drained depressions or no level (and often poorly drained) and exposed high altitude locations are inhabited in the eastern regions of the study area. Extensive areas of grassland also occur within the farmland. Similarly, bush and shrub occur as inclusions thought the landscape, but rarely form significant areas, TAMS & ULG (1997).

On the other hand, the lowlands, by contrast, are still largely untouched by development. This is not to say, however, that they are uninfluenced by man. Indeed, most of the lowland vegetation probably represents fire climax vegetation, with resistance to the frequent burning that occurs. The dominant vegetation is Combretum woodland underlain by tall grasses. Woodland is the second most important map unit and the third most important cover, most of it occurs in the lowlands. Large area of grassland, bush land and shrubland also occur, responding to local edaphic condition. There are two vegetation types of economic importance. Extensive areas of bamboo occur, primarily on lower areas (often associated with the break between the highland and the lowlands) characterized by moderately deep soils (Cambisiols). Land use in these regions is largely of traditional. Such uses include fishing, hunting and gathering, scattered cultivation primarily with hand tools, and animal husbandry, TAMS & ULG (1997).

In addition to types composed principally of highland bamboo, Aningeria ssp, and Acacia ssp occurs. Although the area contains different type of forests, its coverage is declining from time to time. Daveisson (1996) observes how even two decades ago much of the area was forested, but that now its forest area is depleted due to large scale farming and to a certain extent due to fuel wood consumption. FAO (1990) computed Ethiopia's fuel wood requirement to exceed increment yield by 60 %, Daviesson believes the current imbalance to be 80%. Therefore projected fuel wood demands show that current stocks could last about 30 years before being depleted. Like many of Ethiopia's forests, those of the study area are not monitored (Daviesson, 1996). TAMS & ULG (1997), The following Figure 3.3 shows the land cover found in the selected sub catchments derived from the DEM.

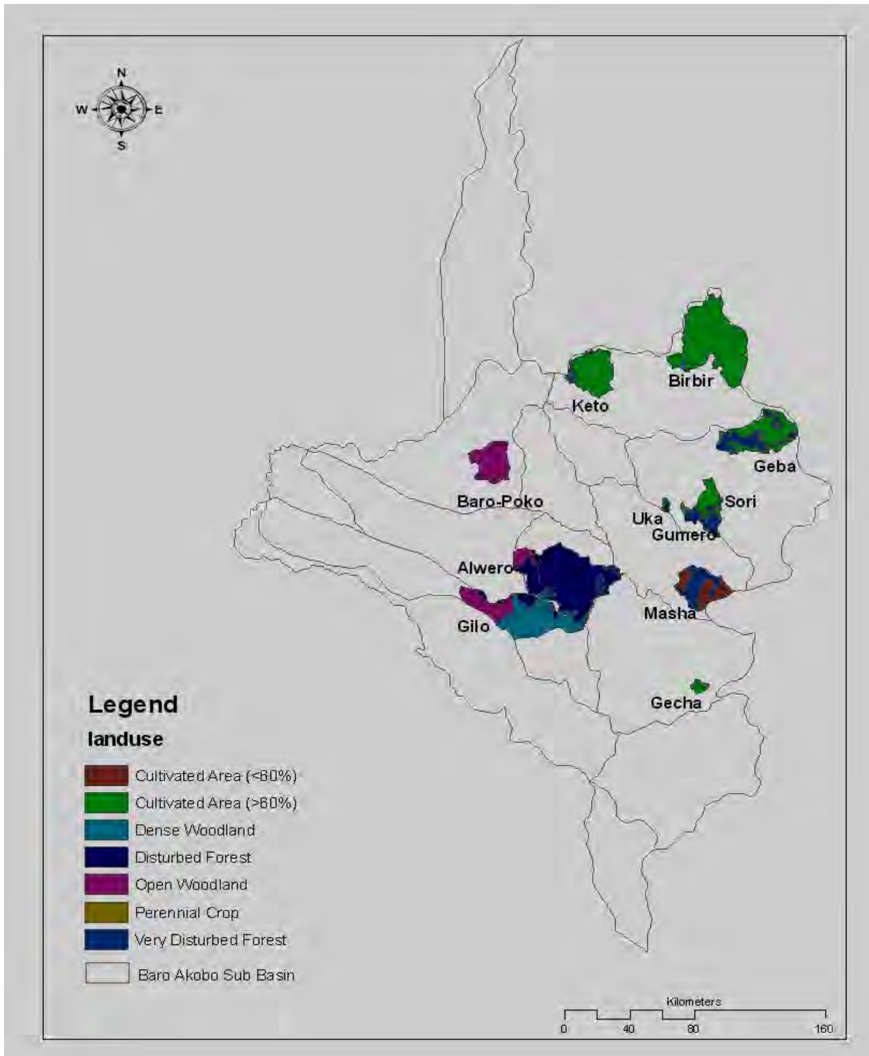


Figure 3.3 Land Cover in the selected river basin derived from the DEM.

3.2.2 Soil Type

The output of the land suitability evaluation will include description of land utilization types; land suitability, and land resource. In the land suitability study, land uses that are being considered are rain-fed agriculture, forestry, irrigation, wildlife conservation and livestock production. Besides, soil association is one of the major aspects of land suitability. Soils of the Baro-Akobo basin reflect the collective effects of the five factors of soil formation-geology (primary fine grained, weathering to produce clays); climate (moderate to high rainfall); topography, with distinctive variations between sites of water buildup or restricted drainage (Vertisiols) and well drained sites on slopes (red soils); and time, the western lowland soils especially reflecting the long period of stability that produces soils similar to those of the highlands which generally receive much higher rainfall. The fifth factor, the biotic factors, is more complicated. The highland soils in particular were developed first and foremost under conditions of forest with a regular cycling of nutrients between the trees and the topsoil, and with the subsoil deeply leached under conditions of high rainfall. However, in the present day the dominant biotic factor is human being who has vacant the forest and placed the land under cultivation but with insufficient management; many (most) soils now truncated profiles due to the impact of erosion, TAMS & ULG (1997).

Orthic Acrisols (4287 Km^2) and Dystric Nitosols (18,900 Km^2) are the predominant soil associations, with inclusions of dystric Cambisols (2540 Km^2) and Lithosols (1559 Km^2) on the steep slopes. The Nitosols are normally found in undulating topography with good drainage. Inherent fertility is usually good and agricultural potential high. The next most significant soils are the black Acrisols (1239 Km^2) which has no critical importance for cultivation because it creates drainage difficulties and workability problem for both hand tillage and mechanized farming. Cambisols (1534 Km^2) also are widespread in areas that range from moderate to steep slopes where the land is continuously cultivated and eroded. Regardless of the fact that these soils are shallow and stony: they are chemically rich, ARDCO-GEOSERV (1996).

In areas of inadequate drainage and/or moisture inflow weathering has produced expanding clays which fracture severely and become very hard when dry, but swell and become sticky when wet. These Vertisols are self mulching in that the repeated shrinking and swelling tends to mix and remix the upper soil layers. This, plus the recurrent high water table, reduces leaching and produces a fertile soil with fertility well dispersed through the profile. Under the right conditions, these soils are highly productive, and are definitely often favored by smallholders. Nevertheless, the soil properties--especially the firmness when dry and the adhesiveness when wet--make them difficult to cultivate, especially with traditional tools. These are only a narrow window of opportunity when the soils are moist, but not wet, when they can be easily cultivated. That window is broadened with mechanization, but the difficulties remain. They also tend to remain saturated for long periods, and are often not cultivated for this reason; however, on such sites in the highlands (normally broad, shallow alleys) they provide favored grazing land, including critical dry-season forage. The most important soil texture within the basin is Dystric Nitosols, and clay soil being least abundant, ARDCO-GEOSERV (1996). Figure 3.4 show the basin soil shape.

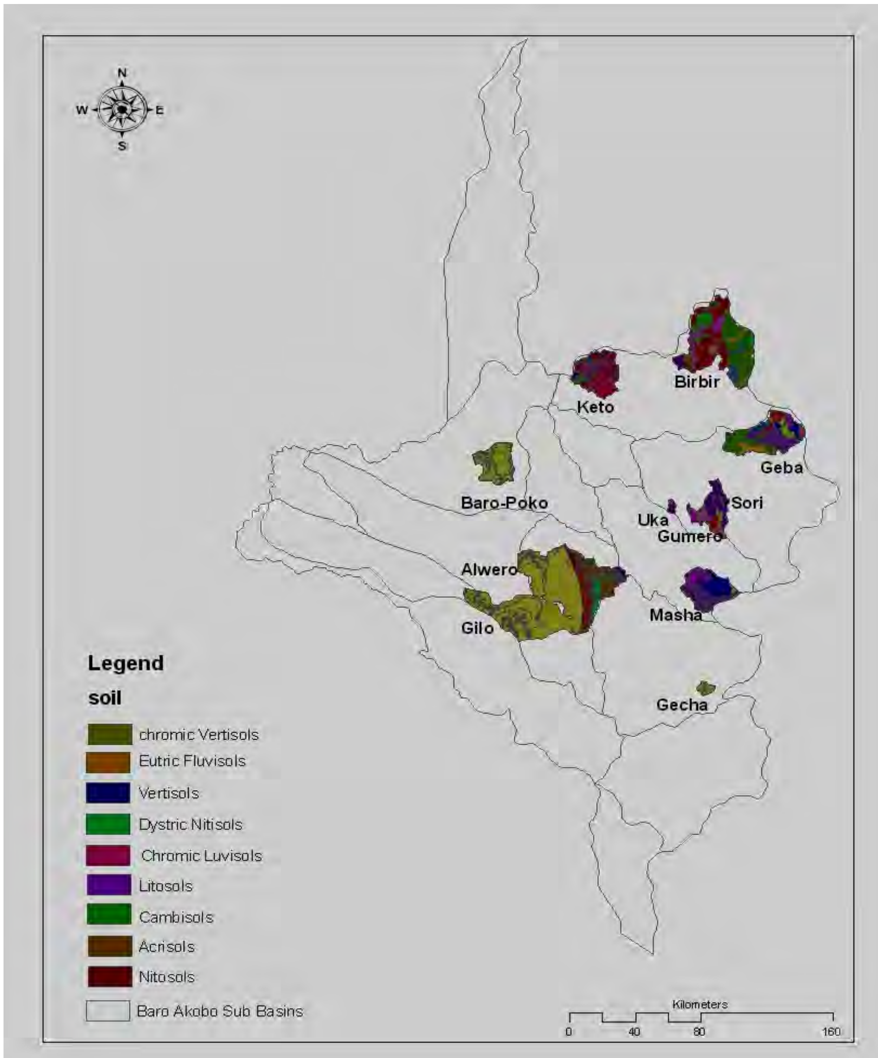


Figure 3.4 Soil type of the basin derived from the DEM.

Soil types of Chromic Vertisols, Eutric fluvisols are characterized on landscape units of western and most western seasonally wetlands (Gambela, Itang, Jikawo, and Akobo plains) with comparatively very lowland areas having geomorphology (seasonal swamps and marshes, meander belts and alluvial plains). On the other hand, plains and undulating landscapes of the Asosa, Kumruk, begi and Kelem areas i.e. north of Gambela plain, the geomorphology (Alluvial/Colluvial slopes and out wash fans, piedmont zones strongly influenced by Colluvial processes) with soils of Eutric fluvisols, chromic Vertisols and Eutric Nitosols , and dystric Nitosols are dominant ones, ARDCO-GEOSERV (1996).

The lowland and highland divide dissected fault escarpments with landscape units of moderately dissected plateau, plateau with hills and rolling, and moderately dissected side slopes and dissected plains with geomorphology (severely dissected side slopes and piedmont zones, moderate to high relief hills) are having soil type features of dystric Nitosols, chromic Luvisols, Lithosols, ARDCO-GEOSERV (1996).

Eastern highlands of the Baro-Akobo basin with better drained sites of moderate slopes, particularly in areas of high altitude and or rainfall having geomorphology (rolling to hilly plateau, moderate to high relief hills) are characterized by the predominant soil features as Lithosols, Cambisols, acrisols, and Nithosols. These are deep, non-swelling clay soils, with favorable physical possessions (drainage, structure, workability) but are deeply leached, ARDCO-GEOSERV (1996).

All the above illustration of the basin soil type gives a broad-spectrum optimistic picture of soils within the basin. On the other hand, 34 % of the basin is covered by shallow and moderately profound soils with undulating topography, good drainage and fertility, i.e. dystric Nitosols (24.9 %), orthic Acrisols (5.6 %) and dystric Cambisols (3.3 %). The major important area of such soils is in the dissected plateau of the highland and lowland divide escarpments, and in areas of high rainfall regions of the eastern and southeastern regions of the basin. This area also characterizes Cambisols (5.5%), moderate to steep slope with shallow and stony soils. These restricted soil depth with shallow and very shallow soils without question result from clearing and cultivation, without proper management, on slopes which are steep to very steep. While soils with seasonal swamps and marshes, meander belts and alluvial plains are characterized with soils types of chromic Vertisols, Eutric fluvisols. In general, soils of the basin are reasonably fertile, and are capable of producing satisfactory yields for a range of fields and cash crops.

3.3 Slope

There is high interrelation between slope and total runoff. Slope is important feature of a catchment as it gives an indication of the kinetic energy available for water to move towards the basin outlet. Slope is variable within a basin. Table 3.1 gives the composition of the topography of the project area by Slope class. It shows that more than half the landscape is flat or undulating, about one-third is rolling or hilly, and the remainder is steep, TAMS & ULG (1997).

Table 3.1 Slope classes by area.

Slope class (%)	Description	Area of slope (%)
0-2		25.6
2-8	Flat	31.5
8-16		19.7
16-30	Hilly	14.2
30-50		6.6
>50	Steep	2.4

Source: Copeland, 1996 Area= 76,098 km^2

The landscape is flat and low-lying (elevation less than 450 m) in the most western extent at Ethiopia's joint border with the Sudan. Deep, cracking clays make up its soils and its vegetation is reminiscent of Guinean savannah (coarse grasses, Acacia spp., and Combretum spp.). Further inland (about longitude 34^0E) the terrain becomes slightly undulating, while soils remaining deep and become more variable with isolated areas of ironstone and leached surface from which the iron, aluminum, and organic matter have been removed. Clay alleviations becomes increasingly pronounced as does surface drainage, although the effects of the latter remain subject to large-scale flooding during the rainy season, an average of 3530 km^2 inundate annually (Cowx, 1995). Channels, free from the controls imposed by the terrain of higher elevations, migrate; join with other channels, separate, and occasionally from transient lakes, which supply an important part of the region's aquatic habitat, TAMS & ULG (1997).

About longitude 34^0 30^lE (east of Gambela), the terrain abruptly becomes first hilly and then steely dissected as one climbs the escarpment separating the eastern boundary of the plains from the western plateau and mountains of central Ethiopia. The leading edge of the plateau summit is about 500 m above the altitude of the plains, causing its climate to become both cooler and more humid, TAMS & ULG (1997).

Moving eastward, the general impression is one of persistently increasing elevation, occasionally by climbing the leading edge of small escarpments, at other times by climbing ridges whose summit is always higher than the one preceding. By the time one reaches the divide of the catchment the elevation is over 2000 m. This study uses a 90m resolution DEM to estimate slopes for all sub catchment. Furthermore, slopes for all sub catchment can also be found either in TAMS & ULG, (1997) and/or in ARDCO-GEOSERV (1996).

The following Figure 3.5 shows the basin slope.

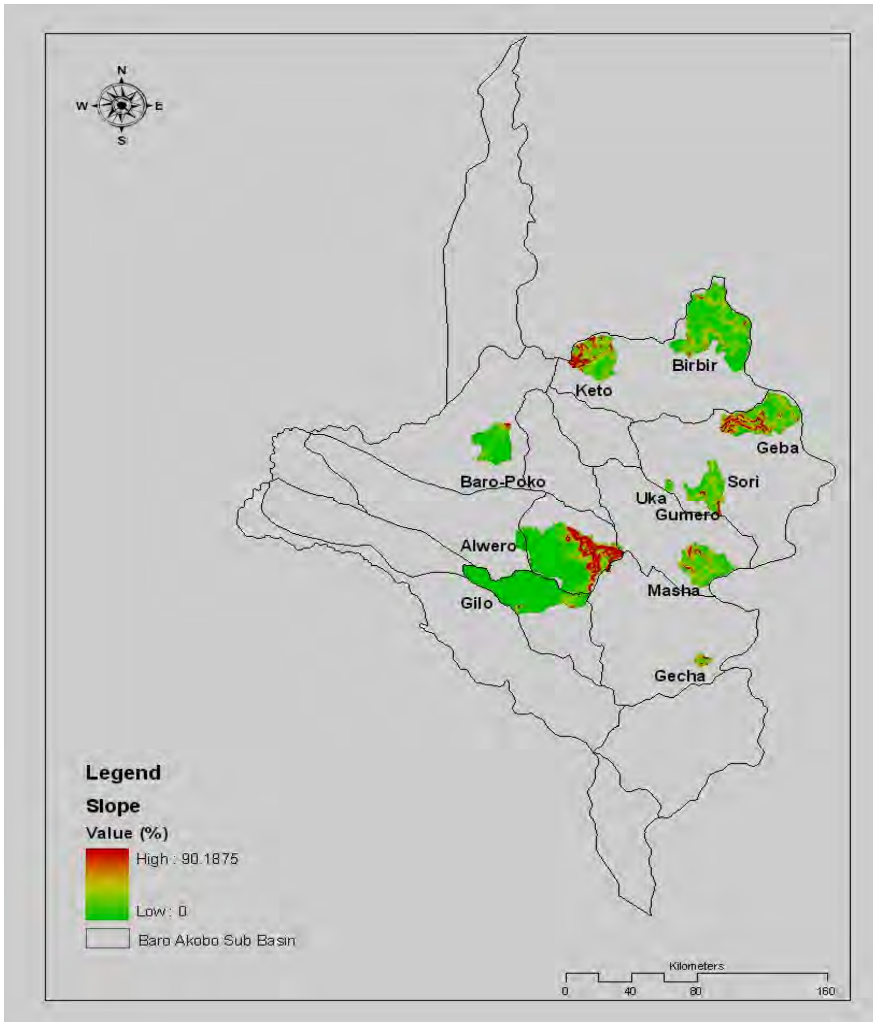


Figure 3.5 Slopes of the study area derived from the DEM.

3.4 Geology

The origins of quantitative geological indices that express the geological effects on runoff Process at the basin level are a major challenge in hydrology. Hydro geological Characteristics like permeability and depth to the water table that have been used in some studies are highly variable in space. Hence, most regionalization studies used the scope of catchments with different lithologies.

This study uses the same approach since detailed geological mapping has not covered the whole of Baro - Akobo. The generalized GIS Hydro geological data put the different geology that occurs in the selected sub-catchment of Baro-Akobo.

The generalized geological feature of the basin can be expressed as follows. The western lowlands of the Baro-Akobo basin which includes Gambela, Akobo, Itang, Jicawo, and parts of Gog plains are characterized by Quaternary alluvial deposits: sand, silt and clay. Asosa Benishangul areas from the north tip of Kurmok to Asosa and extending up to the north of Gambela town is characterized by the Tertiary volcanic, pre-and Syniecionic granitoid plutonic rocks, and middle proterozic to archean gneisses and migmatites as almost equal land proportions of these three geological formations, ARDCO-GEOSERV (1996). Figure 3.6 below shows the different types of lithologies occurring within the study.

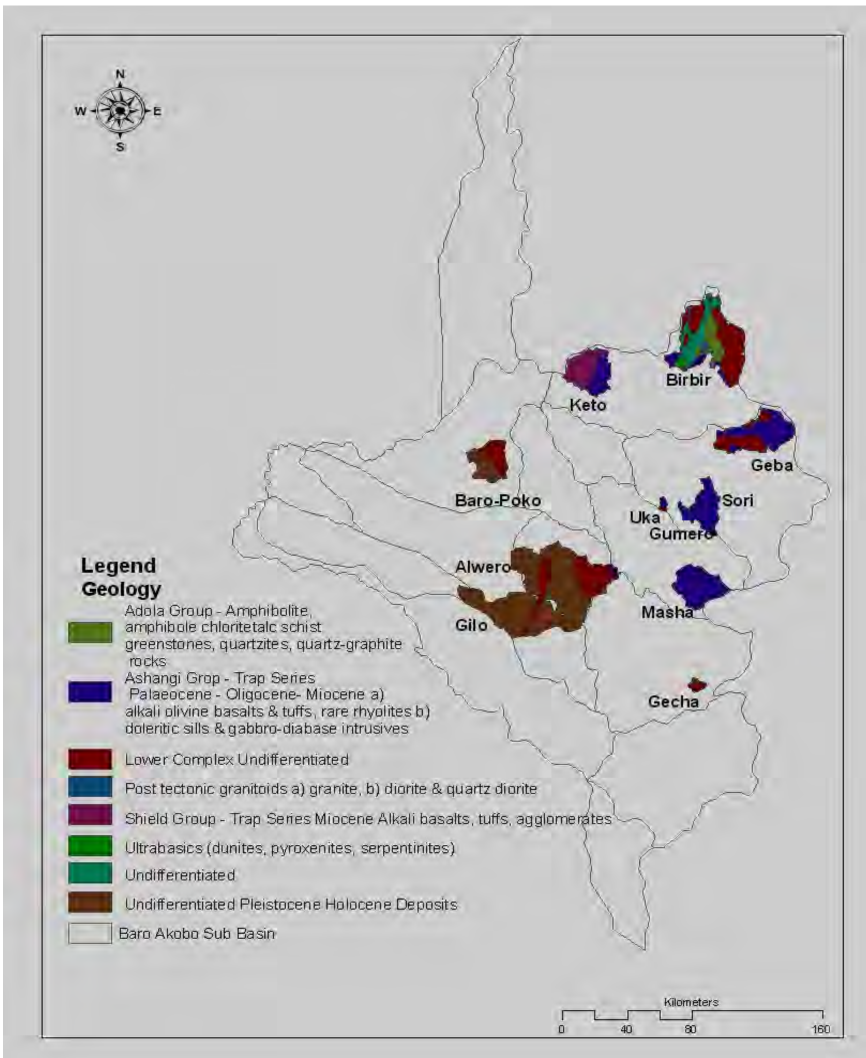


Figure 3.6 Different types of geologies within the study area derived from the DEM.

The central dissected highland and lowland divide escarpments extending from the central north to the central south (Chanka—Dembidolo—Giara—Dodi—to the southern tip) is dominantly featured by Late-and post-tectonic plutonic rocks, and middle proterozoic met volcanic and meta sedimentary successions. Lastly, the highland regions of the eastern upper parts of the basin which include Guliiso-Masha regions of the basin are predominant with Tertiary Volcanic geological features.

The geology of the plains is one of sediments deposited by millennia of floods. Older rocks, often gneisses, form the Precambrian basement rock of the plateau, over which erosion has exposed Tertiary basalts. The subsurface weathering of upland gneisses, basalts, and granites is fairly rapid, so that rates of soil formation are high. Once exposed to the air, however, these same basalts and granites break down much slowly.

3.5 Drainage density

Drainage density (Dd) is derived by dividing the total stream length within a catchment by the catchment area, and is regarded as an important landscape characteristic (Gregory and Walling, 1973; Seyhan, 1977). It is a measure of how dissected a basin is, and it is expected that Dd affects the transformation of rainfall into runoff. The main deterrent to the use of Dd is that it is laborious and time consuming to estimate from aerial photographs or topographical maps. In addition the definition of a stream is not consistent among mapping agencies (Gregory and Walling, 1973; Seyhan and Keet, 1981). It is possible to use assumed 1:50,000 topographical maps produced by Ethiopian Mapping Agency (EMA) which is representative of stream networks. While drainage densities estimated from these maps may not be accurate in an absolute sense, they allow a comparison of the effects of differing intensities of dissection on runoff among catchments. For this reason, this study uses DEM to estimate Drainage density values.

Drainage density (Dd) varies from 0.22 to 6.30 km per km^2 (Bastiaanssen, 1998; Meijerink, et al., 1994). In general the western lowlands of the basin have the lowest Dd values, while the central dissected regions and western parts of upper regions have the highest values. Dd is positively correlated with the median slope, and relief. Areas with steep slopes and high Dd values are expected to have fast channel flow. Low Dd is associated with sedimentation (sheet wash plains) and therefore low groundwater contribution to stream flows. Geological processes such as faulting, fracturing, uplifting, and pediplanation influenced the creation of current drainage networks. Current precipitation patterns have not had major effects on the development of the main drainage lines. There is no relationship between Dd and the proportion of the catchment that is covered by different litho logy. The type of litho logy underlying a particular area may not be as important in affecting drainage density as geomorphologic processes that have shaped the landscape. The following Figure 3.7 Shows estimated Drainage density from DEM.

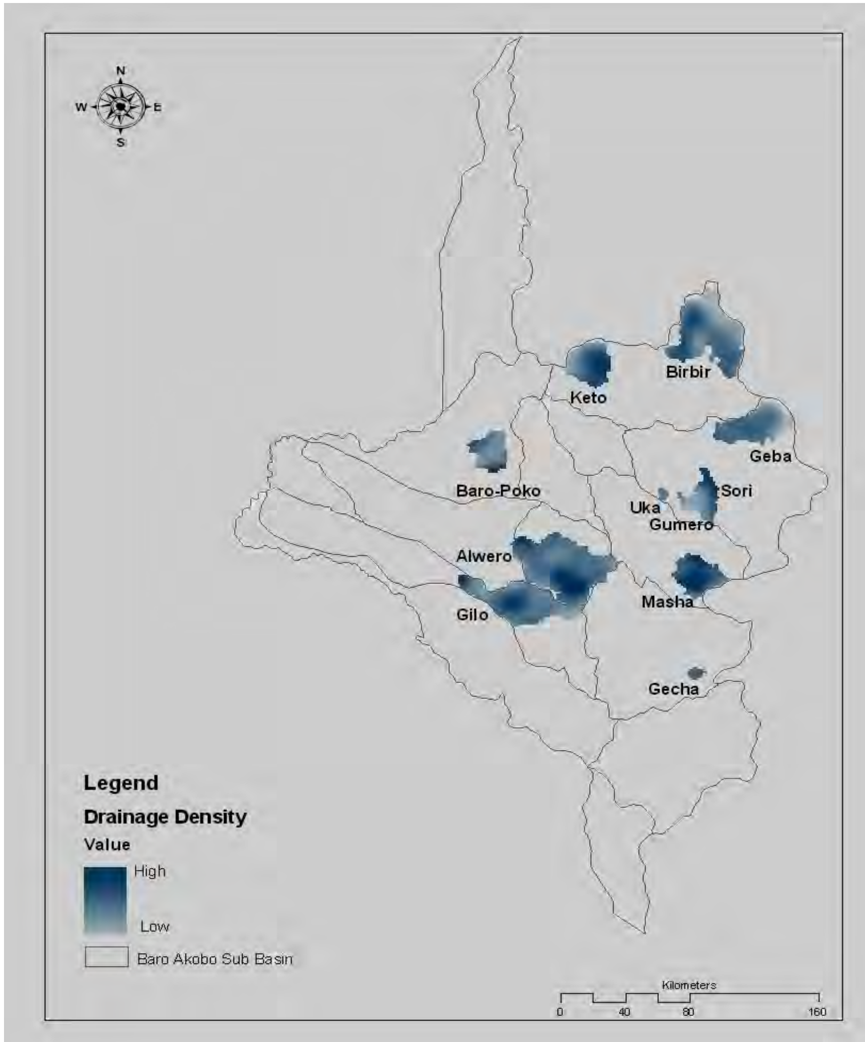


Figure 3.7 Drainage densities in the selected river basin derived from the DEM.

3.6 Normalized Difference Vegetation Index

The normalized difference vegetation index (NDVI) gives an indication of the photosynthetic activity of vegetation, and is related to vegetation density (Bastiaanssen, 1998; Meijerink, et al., 1994).

Several studies have found a relationship between NDVI and rates of evaporation, which suggests that NDVI is likely to affect flow characteristics. NDVI is therefore selected as one of the catchment characteristics.

The average annual NDVI values of a catchment vary from 0.24 to 0.44 (Bastiaanssen, 1998; Meijerink, et al., 1994).The central north eastern catchments and the upper eastern catchments which occur on the eastern upper parts of the basins show some interesting differences in NDVI values due to presence of untouched dissected forest, while lowland vegetations have lower NDVI values. Figure 3.8 shows estimated NDVI values.

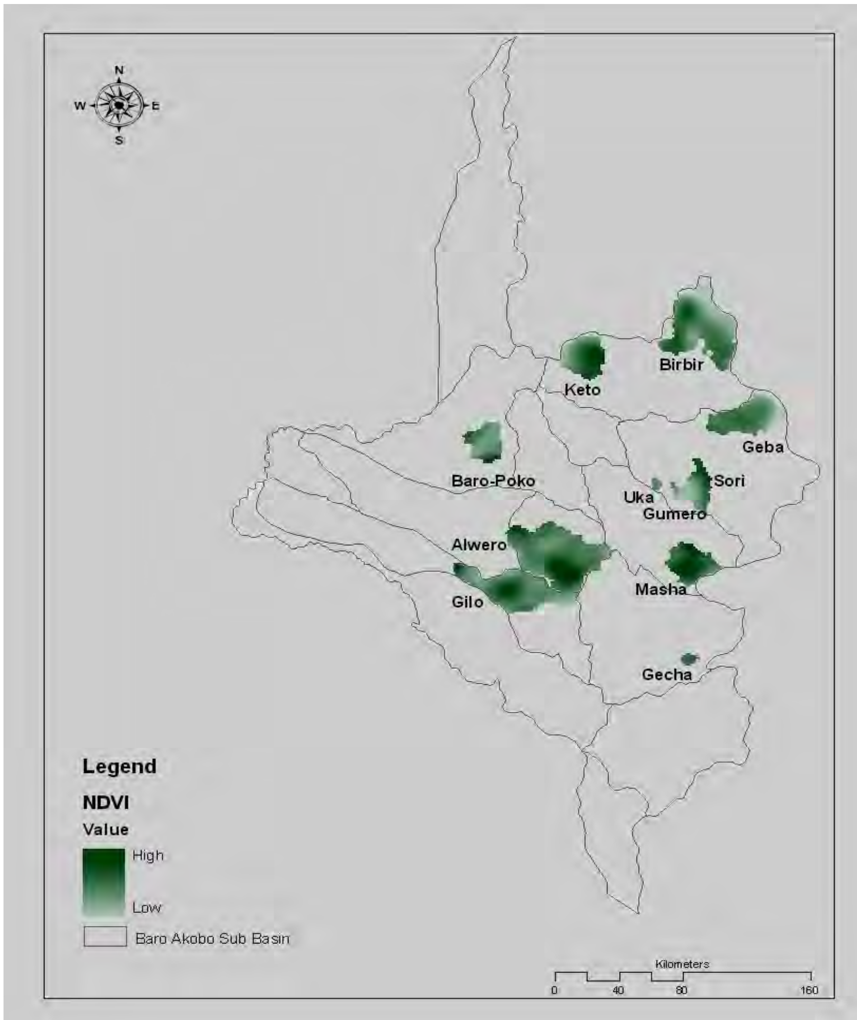


Figure 3.8 Average annual NDVI estimated from remote sensing (N. Server) for values from October 2009 to October 2010.

The increase in NDVI from the western lowlands of the basin to the dissected central regions of the basin and then up to the high NDVI value areas of the eastern high relief regions of the basin reflects the close relationship between NDVI and the leaf area index (LAI). An approximately linear relationship exists between NDVI and LAI, up to LAI = 3 to 4, after which the NDVI does not change significantly. This is a reflection of active vegetation growth in areas with high rainfall, which is the case in the Eastern Highlands, and poor vegetation cover in areas with low rainfall in the western lowlands.

3.7 Selection of the Catchment

Selecting catchments for use in developing method to estimate flow for ungauged catchments require good understanding of the physiographic characteristics of the area. Preferably those catchment characteristics (physiographic characteristics) that have the strongest influence on flow of interest should be selected, Mazvimavi, D. (2003).

The main consideration in selecting catchments for inclusion in this study is the availability of flow data on each catchment to enable accurate estimation of monthly flow. Flow data should not have magnified gaps in most of the seasons. Previous studies showed that a minimum of 10 years of flow data gives a reasonable estimation of most flow. This condition is used in selecting catchments to be included in this study, (Abnet A. 2008).

This study take into account that selected catchment characteristics should be derived from sources that are readily available to practicing hydrologists, i.e., maps, satellite imagery, and national databases, (Abnet A. 2008). Selected catchment characteristics are given Table 3.2.

Table 3.2 Catchment characteristics Selected for use in the study.

Catchment Characteristic	Description and Data Source
1. Mean monthly and annual rainfall	Estimated from rain gauge data
2. Maximum, average, and minimum catchment elevation and Slope	Derived from a digital elevation model(DEM)
3. Proportions of the catchment with different lithologies & soil types	Derived from GIS directorate of MoW&E
4. Proportions of the catchment with different Soil types	Derived from GIS directorate of MoW&E
5. Drainage density (Dd) & (NDFI)	Derived from Hydrology directorate of MoW&E and DEM.

Three physiographic regions exist in the Baro-Akobo basin. 1) The cool wet part occupying areas above 2000 meters in upper eastern highland region. 2) The hot rather dry Baro-Akobo falling to an altitude of 300 meters. 3) The mid altitude areas in between. The highly contrasting differences in altitude have a strong impact on the climatic condition, geomorphology and soils, land cover, irrigation distribution and human activity. Information on altitude zones is an important means of gaining a first impression of the environmental character of a catchment, because altitude is strongly related to temperature and, to a lesser extent, moisture. ARDCO-GEOSERV (1996), Figure 3.9 shows the three Physiographic regions of Baro-Akobo Basin.

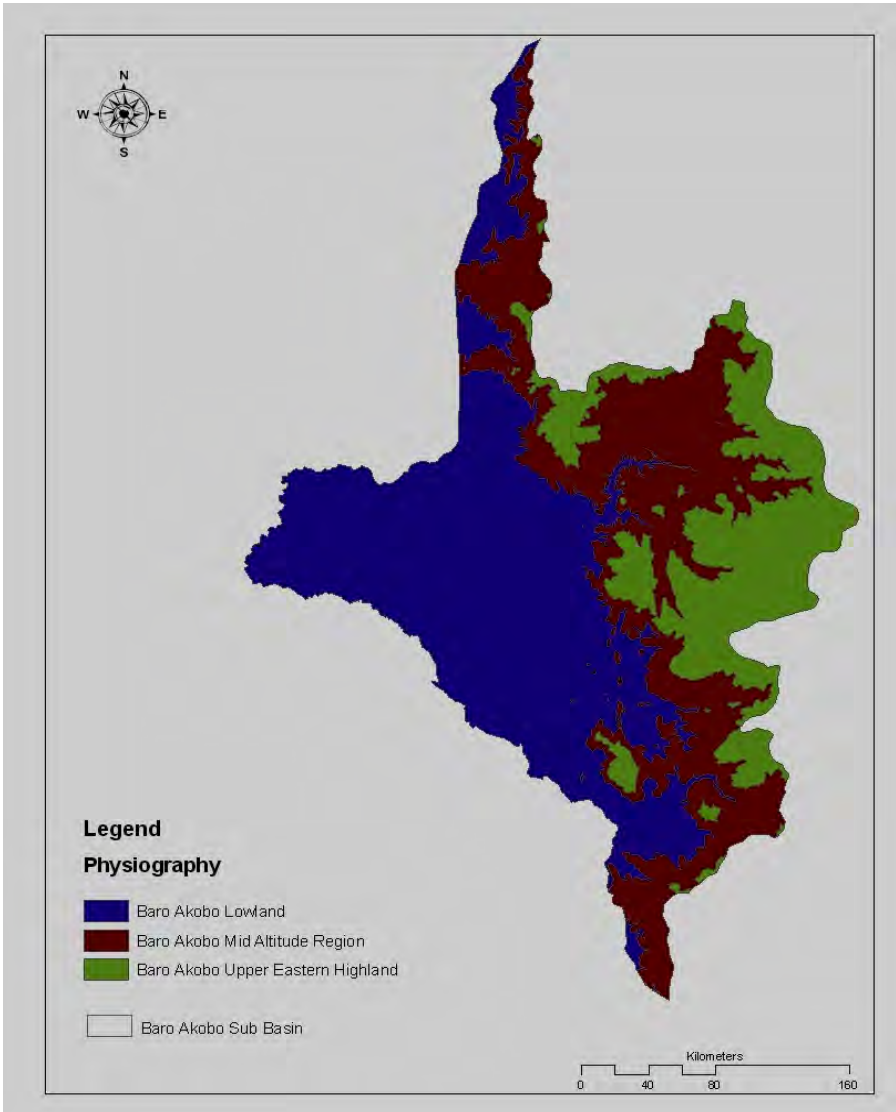


Figure 3.9 Physiographic regions of Baro-Akobo Basin derived from the DEM. (Sourse: Gioinformation and Information Technology Directorate [GIS], MoW&E)

Baro-Akobo Master plan studies classified the basin in to two main sub-basins as upper and lower Baro-Akobo basins. And ARDCO-GEOSERV (1996) further classify the upper baro-Akobo basin in to two major sub-basins as eastern highland sub-basin (Mettu and Illubabor regions) and the southeastern highland sub-basin (kefa region); comprising a total of three major sub basins as Gambela plain, Mettu and Kefa with in the Baro-Akobo basin boundary. The Assosa and Tirma Tid (the north and south tip two sub basins are out of the Baro-Akobo basin boundary. The contribution of the Northern Assosa plains and undulating landscapes to the Baro-Akobo Basin is nil, with catchments forming scrappy water logged pond surfaces; i.e. it is an adjacent water area not accounting to the Baro-Akobo Basin. ARDCO-GEOSERV (1996)

However, based on recent Baro-Akobo Sub-basin study from the Geoinformation and Information Technology Directorate of the Ministry of Water and Energy, there exist thirteen sub-basins having two of the sub-basins (Sirkole and Tirmatid)with almost nil contribution to the basin as explained earlier. Figure 3.10 shows Baro-Akobo sub-basin maps.

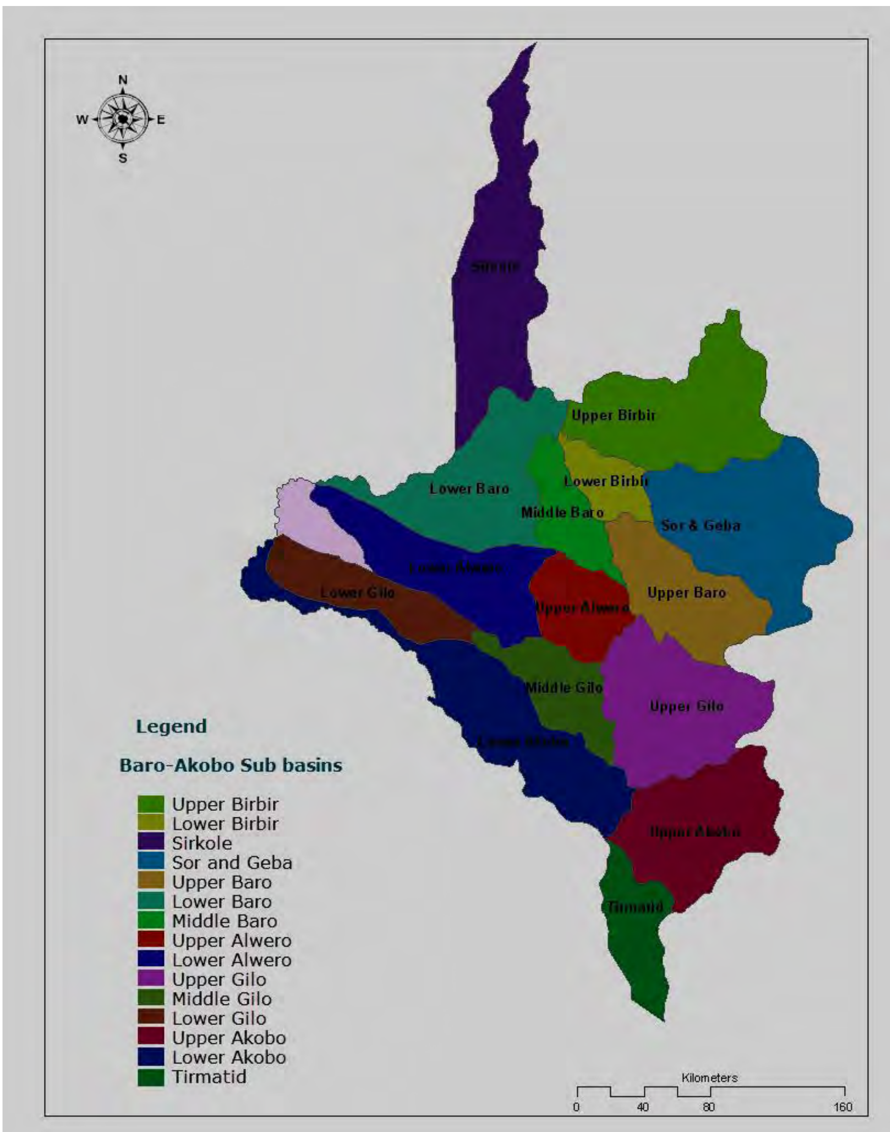


Figure 3.10 Baro-Akobo Sub-basin maps derived from the DEM, MoW&E GIS Directorate.

The number of selected sub-catchments is totally eleven that found within the seven sub-basins, which are Uppr Birbrir, Sor and Geba, Upper Baro, Lower Baro, Upper Alwero, Upper Gilo and Lower Gilo. In the remaining six sub-basins that are Lower Birbir, Middle Baro, Upper Akobo, Lower Akobo, Middle Gilo and Lower Alwero do not have hydrological and metrological data's. The location of these sub-catchments with their respective sub-basins within the Baro-Akobo basin are shown in Figure 3.10 while Figure 4.1 shows Location of the Rainfall and Stream flow gauging stations, for each of these sub-catchments. The station codes are designated as (UB1, UB2, SG1, SG2, SG3, SG4, UB, LB, UA, UG and MG) and are listed in Table 3.3 with their respective stations.

Table 3.3 Lists of Selected Catchments.

Code	St. Name	River	Lat. (⁰N)	Long. (⁰E)	Area (Km2)
UB1	Birbir	Nr. Yubdo	8.95	35.48	2563.0
UB2	Keto	Nr. Chanka	8.78	35.05	1006.0
SG1	Geba	Nr. Sopi	8.48	35.65	1894.0
SG2	Sori	Nr. Metu	8.32	35.60	1622.0
SG3	Gumero	Nr. Gori	8.15	35.48	106.0
SG4	Uka	@ Uka	8.17	35.37	52.5
UB	Baro M.	Nr. Masha	7.63	35.56	1653.0
UG	Getcha	Nr. M. Teferi	7.02	35.55	97.0
UA	Alwero	Nr.Dumbong	7.76	34.67	2800.0
MG	Gilo	Nr.Pugndo	7.62	34.27	2437.0
Lb	Baro P.	Nr. Pokwo	8.24	34.43	978.0

3.8 Description of the sub-catchments in the study

The number of sub-catchments considered for the study, which have both hydrological as well as the necessary metrological data, is eleven. This is because of the lack of hydrological plus metrological data. Hence for the rest of watershed that has no gauging data (ungauged watershed) this paper gives parameters that have similar physiographic characteristic. The sub catchments are situated in all the three physiographic regions of the Baro-Akobo basin. As a result, all the topographic, climatic, geologic and hydrologic features described above apply to the sub catchments depending on where they are situated.

3.8.1 Catchments in Upper Birbir Sub-Basin

Birbir, and Keto rivers are situated in this sub-basin. These rivers are gauged near the towns of Yubdo, and Chanka respectively. Birbir River has the shape of more or less circular. Geology of much of Birbir catchment is characterized by nearly granite, 13 % quartz diorite and the remaining 12 % diorite. Keto River is Spillane in shape, and the catchment is characterized by granite, quartz diorite, alkali olivine basalts and tuffs, and rhyolites. The dominant land use in the catchments of these rivers is constituted by Forest or with woodland. Acrisols, and Nithosols are the major soil type found in these sub-catchments. Elevation of the areas ranges between 1400m to 1600m a.s.l. Total watershed area of these sub-catchments is about 2569km^2.

3.8.2 Catchments in Sori and Geba Sub-Basin

Geba, Sori, Gumero, and Uka rivers are situated in this sub-basin. These rivers are gauged near the towns of Sopi, Mettu, Gori, and Uka respectively. Half of Geba catchment is made of Alkali olivine basalts and tuffs, and the remaining half is rare rhyolites. Sori catchment is mostly characterized by Ashanti trap series Paleocene (40 %), and the remaining equal proportions of Oligocene and Miocene. Gumero and Uka rivers are characterized by a narrow mountainous valley with elongated river courses and geologically made of Adola group Amphibolites, Chloritetalic Schist, green stones, quartz granite rocks, and olivine basalts. Landcover in the catchments is dominantly cultivated with dispersed forests. Lithosols, and Cambisols are the major soil type found in these sub-catchments. Elevation of the areas ranges between 1500m to 2500m a.s.l. Total watershed area of these sub-catchments is about 5674.5km^2.

3.8.3 Catchments in Upper Baro Sub-Basin

Baro-Mesha River is situated in this sub-basin. The river is gauged near the towns of Mesha. This is longitudinally stretched narrow valley with an area of 1653 km^2 some 100km north of Mizan Teferi town and located mid between Getcha and Gumero catchments. The catchment is enclosed between altitudes of 2000-2500 m a.s.l. The geology of the catchmet is dominated by lower complex pre camberian rock. The Vegetation cover is dominted by dence forests and forests with very distributed forest range, which occurs primarily either in poorly drained depressions or no level (and often poorly drained) and exposed high altitude locations. The soil cover is dominantly dystric nitosols and chromic vertisols.

3.8.4 Catchments in Upper Alwero Sub-Basin

Alwero River is found in upper Alwero sub-basin. This river is gauged near Abebo town. Topography of the watersheds for these rivers varies from the gentler to steep Slope with meandering behavior, with elevations ranging from 400m-500m a.s.l. and reaching up to 1200m i.e. the central north south escarpment that separates the Baro-Akobo basin in to two parts namely upper basin which is cool and moist and the lower basin which is warm and humid. The flow of this river closely matches the rainy season with peak discharge occurring during September.

3.8.5 Catchments in Upper Gilo Sub-Basin

Getcha River is found in Upper Gilo Sub-Basin. The river is gauged near Mizan Teferi town. Topography of the watersheds for this river can be characterized as moderate relief hills and dissected side slopes having relief ranging from 1400m-1500m a.s.l. The watershed area of this sub-catchment is about 97 km^2. 75 % of geology of the catchment is characterized by alkaline granite and Syenite. The remaining 25 % is covered by Oligocene and Miocene of tertiary volcanic rocks. The Vegetation cover is Agriculture with Forest or with woodland (cultivated area with perennial crop). The soil cover is dominantly with soil type features of dystric Nitosols, chromic Luvisols, and Lithosols.

3.8.6 Catchments in Lower Baro and Lower Gilo Sub-Basins

Poko River is found in Lower Baro, and Gilo in Lower Gilo Sub-Basins. These rivers are gauged near Poko (or Gambela) and Pugnudo towns respectively. Topography of the watersheds for these rivers is having flat to undulating landscape with elevations ranging from 390m-450m a.s.l. Most of the lowland vegetation probably represents fire climax vegetation, with resistance to the frequent burning that occurs. The dominant vegetation is Combretum woodland underlain by tall grasses, in addition Scattered forests, Shrub land, bamboo, Grazing and limited farmland are land cover characteristics of these sub-catchments. Geology of the catchments are characterized by Quaternary alluvial deposits: sand, silt and clay; and the geomorphology with seasonal swamps and marshes, meander belts and alluvial plains are characterized with soils types of chromic Vertisols, Dystric Nitosols, Dystric Cambrisols and Eutric fluvisols. The total watershed area of these catchments is 978Km^2, 2437km^2 for Baro-Poko, and Gilo. As described by TAMS & ULG (1997) the western low land is nearly half of the Baro-Akobo basin with almost the same Physiographic characteristic in all directions of the sub-basin.

Chapter Four

4 Hydro-Meteorological Data Collection and Analysis

4.1 Hydro-Meteorological Data Collection

Previous chapters give an insight for the study area, these chapter deals with collection of data suitable for the application of the methods. According to the theories discussed, three basic data sets are necessary for the modeling work. These are:

- Meteorological data (rainfall),
- Hydrological data (stream flow) and
- Catchment physiographic data.

4.1.1 Meteorological Data

In Ethiopia, the source of raw metrological data is the National metrological service agency (NMSA). A request for monthly rainfall and temperature data of 30 years of period, in addition monthly relative humidity and sunshine duration data was made to the agency. Following the approval of the agency‘s higher official monthly data of up to 20 years period used in the model work were collected.

From the entire available automatic recording stations those which are in or proximate to the watersheds considered for the research work were selected. As a result a total of eleven rainfall stations were selected for use in the research work. These rainfall stations are used in conjunction with stream flow stations, and the location of these rainfall stations is shown in Figure 4.1.

The rainfall records that obtained from NMSA cover the length of years from 1989 to 2008 depending on the available stream flow records particular to catchment being considered. Besides, record years and mean annual rainfall (mm) are listed in Table 4.1 based on TAMS & ULG (1997) and NMSA. The collected data stretched over these years to obtain adequate match between the rainfall events and the resulting stream flow records.

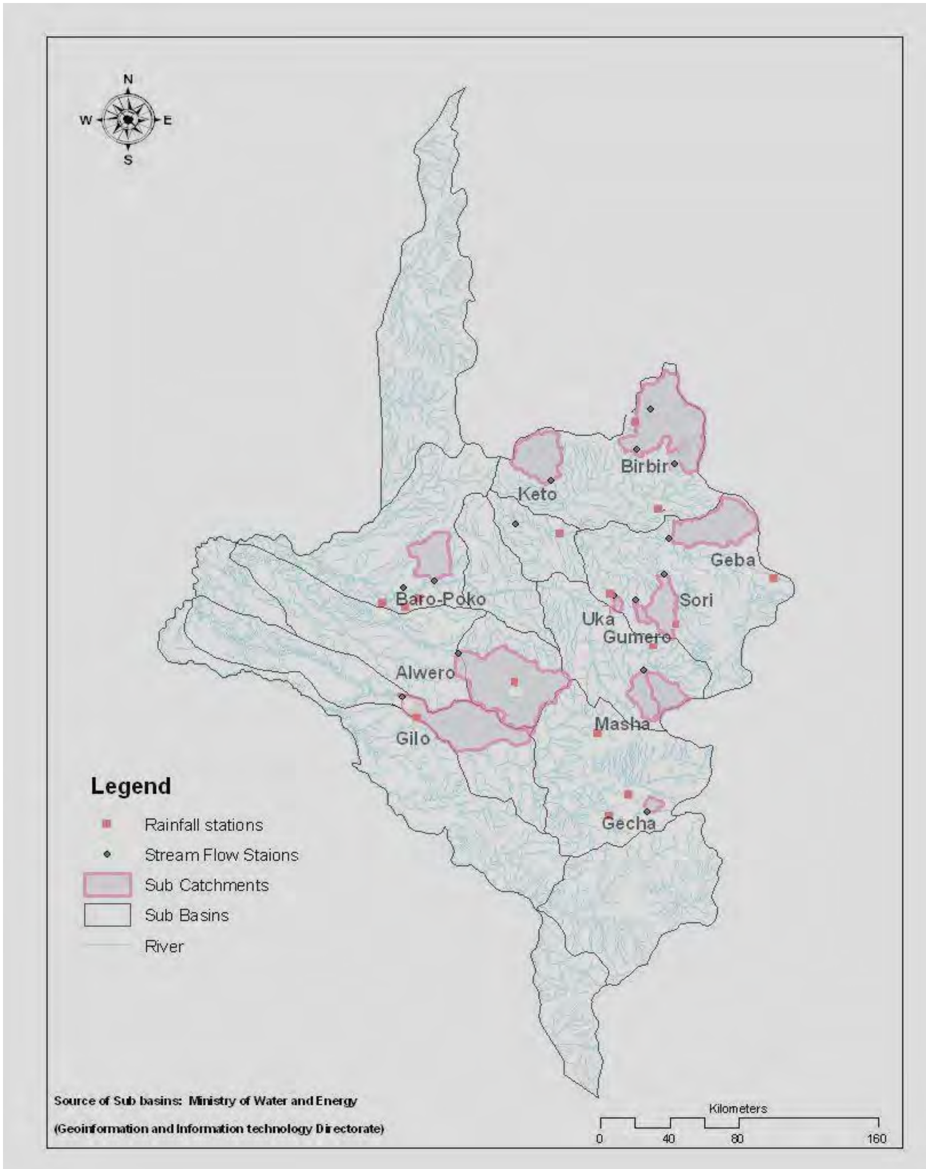


Figure 4.1 Location of the Rainfall and Stream flow gauging stations.

In the basin, for the watersheds considered, rainfall records are scarcely available; with sudden interruptions of records occur in the rainy season. The search for good match between the rainfall and stream flow records called for a big effort due to the gaps encountered. Table 4.1 shows the description of the rainfall stations with years of average annual rainfall recordings selected for the modeling work.

As per the NMSA the metrological parameters such as monthly mean relative humidity (%) are taken every six hours at 0600, 1200 and 1800 GMT. Maximum and minimum air temperature (˚C) and sunshine duration (Hr) are taken as an observed input data for the model works.

Table 4.1 Summary of the rainfall stations.

No.	Station Name	Region	Lat. (Deg.)	Long. (Deg.)	Elev. (m)	Years of Data Used	Mean Annual Rainfall (mm)
1.	Gambella	Gambela	8.15	34.35	440	1985-2008	908.7
2.	poko	Gambela	8.10	34.28	425	1989-2008	906.8
3.	Alwero Abebo	Gambela	7.51	34.33	455	1989-2008	912.6
4.	Itang	Gambela	8.12	34.16	415	1973-2008	901.4
5.	Gilo Punydo	Gambela	7.60	34.25	453	1989-2008	912.6
6.	Uka-Gore	Illubabor	8.10	35.33	2024	1989-2008	2232.5
7.	Sori-Bedele	Illubabor	8.27	36.20	1617	1989-2008	1128.7
8.	Gumero	Illubabor	8.18	35.35	1760	1989-2008	1703.2
9.	Birbir Yubdo	Welega	9.16	35.41	1560	1988-2007	1580.2
10.	Keto Chanka	Welega	8.30	35.08	1500	1988-2007	1012.5
11.	Gimbi	Welega	8.30	35.58	1970	1989-2008	1835.7
12.	Geba-Lalo	Welega	8.08	36.05	1510	1989-2008	1044.6
13.	Tepi	Kefa	7.00	35.35	2200	1990-2008	2754.7
14.	Getcha Mizan	Kefa	7.11	35.45	1417	1985-2008	1157.6
15.	Baro Mesha	Kefa	7.38	35.25	2130	1989-2008	2702.1

4.1.2 Hydrological Data

Hydrological data were the principal data set in the research work. Other sets of data were all collected depending on the availability and suitability of data from the hydrological stations. The hydrologic gauging stations in the Baro-Akobo basin with automatic water level recordings are very limited. About fifteen gauging stations with continuous water level records are available in the basin. TAMS & ULG (1997)

The chart readings of these continuous water level recording stations were obtained from the Ministry of Water and Energy, Hydrology Directorate. Generally, data were preliminarily collected for gauging stations with catchment size not exceeding 2800km^2, following the recommendation of Shaw, 1999. Then, depending on the availability of rainfall recording station in or near the boundary of the stream-gauged catchment, the station was considered for further analyses and data acquisition.

Based on this criterion; out of the fifteen gauging stations, only eleven of those having hydrological plus meteorological data‘s were adequately selected and used in the modeling work. And these eleven stations are consecutively listed from 1 up to 11 in Table 4.2 below. The location of these gauging stations is shown in association with the rainfall stations in Figure 4.1. The stream flow data used in the model are given in the same Appendix D for the same stations. A summary of the stream flow recording stations used in the thesis is given in Table 4.2.

Table 4.2 Description of the Stream flow recording stations.

No.	Sub-Basin	Station No	River	Site	Latitude (Degree)	Longitude (Degree)
1.	Upper Birbir	BA1005	Keto	Nr.Chanka	8.78	35.03
2.	Upper Birbir	BA1002	Birbir	Nr. Yubdo	8.95	35.48
3.	Sor and Geba	BA1001	Sori	Nr. Mettu	8.32	35.60
4.	Sor and Geba	BA1006	Uka	@ Uka	8.17	35.37
5.	Sor and Geba	BA1003	Geba	Nr. Sopi	8.48	35.65
6.	Sor and Geba	BA1010	Gumero	Nr. Gori	8.15	35.48
7.	Upper Baro	BA1010	Baro	Nr. Mesha	7.63	35.56
8.	Lower Baro	BA1014	Baro-Pokwo	Nr.Poko	8.24	34.43
9.	Upper Alwero	BA2005	Alwero	Nr. Dumbong	7.76	34.67
10.	Upper Gilo	BA2007	Getcheb	Nr. M. Teferi	7.02	35.55
11.	Lower Gilo	BA2006	Gilo	Nr. Pugndo	7.62	34.27
12.	Upper Gilo	BA2003	Begwuha	Nr. Tepi	7.20	35.44
13.	Sor and Geba	BA1008	Meti	Nr. D/Dolo	8.55	34.85
14.	Upper Birbir	BA1009	Uwaha	Nr. Guliso	9.17	35.55
15.	Upper Birbir	BA1020	Elekei	Nr. Suppi	8.96	35.73

4.1.3 Physiographic Data

It is remembered that selection of sub-catchments has been made based on availability of automatic recording stations. Once decision has been reached on the selection of the sub-catchments, next was to collect materials for obtaining catchment physiographic data.

The catchment physiographic data were generally collected from topographic maps and 90mx90m resolution DEM. Other data pertinent to the modeling process– which include the watershed area (A), Land use, land cover, soil type and geology of the catchments were obtained from GIS data that found in Ministry of Water and Energy directorate of GIS.

Attainment of Physiographic data from such maps was greatly influenced by the accuracy of data of geographic coordinates of the gauging stations. Both the stream gauging and rainfall station geographic coordinate data were slightly inconsistent from document to document and/or deviate slightly from the course of the river indicated on the topographic map.

Similarly, some rainfall stations which were initially presumed to be within a watershed of a certain gauging station from available GIS arc view document happen to be not in the watershed, and reverse most of the efforts made. Then a search for a better adjacent gauged watershed to efficiently use data from this rainfall station is conducted. The most reliable geographic location of the stations were then mostly adjusted and used by means of other descriptive notes provided with the locations like, the nearby towns or other known establishments described with the locations of the stations. Therefore, the activity was so cyclic that data acquired for the watersheds in the study area were not at instant. See Table 4.3 for the description of the physiographic Characteristics of the Sub-catchments.

Table 4.3 Summary of physiographic Characteristics of the Sub-catchments.

No.	River Name	Site	Physical Characteristics		
			Catchment Area (KM2)	Elevation (m)	Slope (%)
1.	Baro-Pokwo	@ Poko	978.0	446	5.10
2.	Alwero.	Nr. Dumbong	2800.0	454	6.80
3.	Baro M.	Nr. Mesha	1653.0	2175	6.00
4.	Uka	@ Uka	52.5	2011	14.20
5.	Sori	Nr. Mettu	1622.0	1687	3.01
6.	Keto	Nr. Chanka	1006.0	1485	11.00
7.	Gilo	Nr. Pugnudo	2437.0	452	8.70
8.	Birbir	Nr. Yubdo	2563.0	1543	3.41
9.	Getcha	Nr. M. Teferi	97.0	1437	17.00
10.	Geba	Nr. Sopi	1894.0	1459	7.10
11.	Gumero	Nr. Gori	106.0	1746	28.37

Having filtered some inconsistencies accordingly, the collection of data for the watersheds under consideration was carried out, and made ready for further use in the model work. Some of the major parameters obtained are shown in Table 4.1 for all the watersheds selected.

4.2 Hydro-Meteorological Data Analysis

4.2.1 General

Hydrological modeling to a large extent depends on hydro-meteorological (precipitation, temperature, relative humidity and sunshine hours) and hydrological (stream flow) data. Reliability of the collected raw hydro-meteorological and hydrological data significantly affects quality of the model input data and, as a result, the model simulation. This chapter sequentially presents, rough data screening of raw hydro-meteorological and hydrological data, completion of identified missing data, estimation of areal rainfall for the study area. Figure 4.2 and 4.3 shows metrological and hydrological Gauging stations in Itang and Abebo areas respectively.

Figure 4.2 Itang metrological station.

Figure 4.3 Alwero River Stream gauging station.

4.2.2 Data Screening

- **Rainfall Data Screening**

Rough rainfall data screening of the eleven metrological stations in the study area was first done by visual inspection of monthly rainfall data. Because of long braking in rainfall records of some stations and absence of lengthy overlapping period of record this inspection was done in the record of the hydrologic years of 1987 to 2008.

Graphical comparison of the rainfall data done by crating time series plotting of monthly rainfall data (see figure 4.5) showed that the eleven stations show similar periodic pattern of records. A summary of the rainfall stations with years of record used in the thesis is given in Table 4.3. The rainfall data used in the model is given in Appendix D for the stations.

Figure 4.4 Average Monthly Sub-Basin Rainfall Data (mm/day) series for years 1989 to 2008.

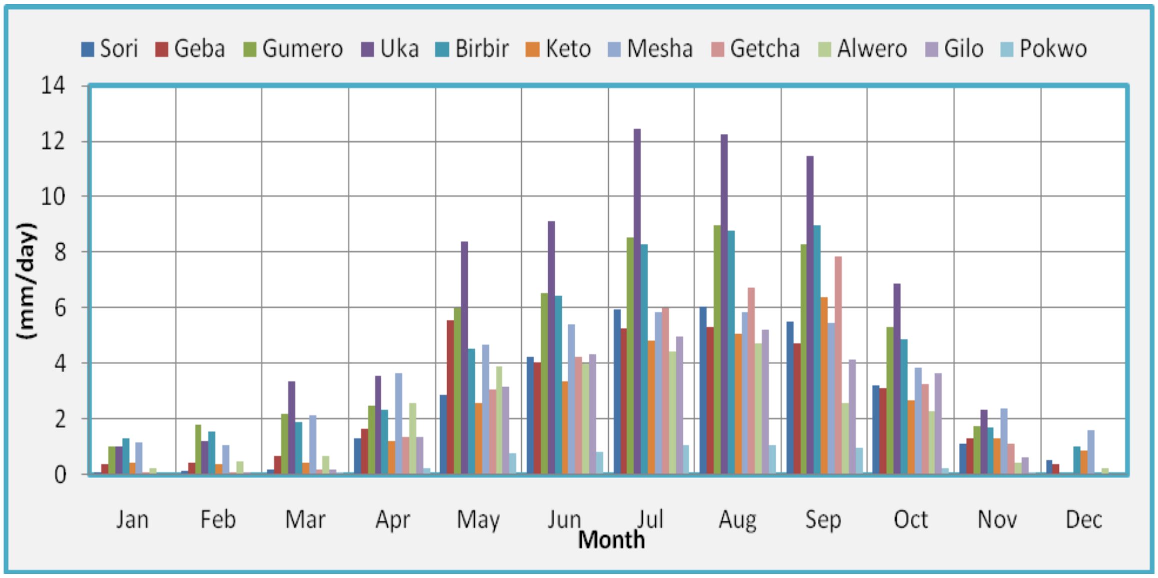


Figure 4.5 Average Monthly Rainfall Data (mm/day) series for years 1989 to 2008.

- **Stream flow Data Screening**

The initial step taken during the stream flow data screening as suggested by Gordon et al. (1992) was quick visual scan of the data time series to detect gross errors such as erroneous peak flow, missed recordings, and flow of constant rate. It helps to detect the year with magnitude change in the data, long period of missing records, and short-term missing data.

4.2.3 Missing Data Completion

Missing data is a common problem in hydrology. To perform hydrological analysis and simulation using data of long time series, filling in missing data is very important. The missing data can be completed using metrological and/or hydrological stations located in the nearby, provided that the stations are located in hydrological homogenous region.

- **Filling in Missing Stream flow Data**

A number of stations in the basin have incomplete records. Such gaps in the record are filled by developing correlations between the station with missing data and any of the adjacent stations with the same hydrological features and common data periods.

- **Filling in Missing Rainfall Data**

A number of methods have been proposed for estimate missing rainfall data (Richard H.McCuen (1989). the station average method is the simplest method. The normal-ratio and quadrant methods provide a weighted mean, with the former basing the weights on the mean annual rainfall at each gauge and the latter having weights that depend on the distance between the gauges where recorded data are available and the point where a value is required. The station average method for filling missing data is conceptually the same as the station average method for estimating a mean precipitation. This method may not be accurate when the total annual rainfall at any of the n region gauges differs from the annual rainfall at the point of interest by more than 10%.

The normal-ratio method is conceptually simple; it differs from the station-average method of that the average annual rainfall is used in deriving weights. If the total annual rainfall at any of the n region gauges differs from the annual rainfall at the point of interest by more than 10%, the normal-ratio method is preferable. Because the normal-ratio method is more advanced than station average method and simple; this thesis uses this method for filling the missing rainfall data. The general formula for computing P is:

$$P_m = \frac{1}{n}\left[\sum_{i=1}^{n}\left(\frac{N_m}{N_i}\right)P_i\right] \tag{4.1}$$

Where,

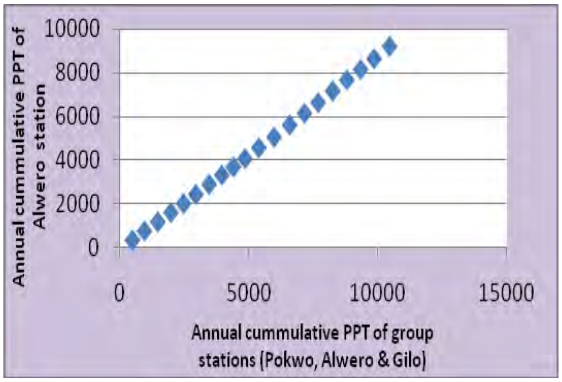
N_m = Average annual rain at rain gauge for which data are missing,

N_i = Average annual rain at gauge i.

4.2.4 Consistency of recording stations

If the conditions relevant to the recording of a rain gauge station have undergone a significant change during the period of record, inconsistency would arise in the rainfall data of that station. This inconsistency would be felt from the time the significant change took place. The checking for inconsistency of a record is done by double mass curve technique (Subramanya.K, 1998).

The accumulated total of the individual gauge is compared with the corresponding totals for a representative group of nearby gauge. If a decided change in the regime of the curve is observed it should be corrected. However, as all the selected stations in this study were consistent, there is no need of further correction.


Annual cummulative PPT of Alwero station
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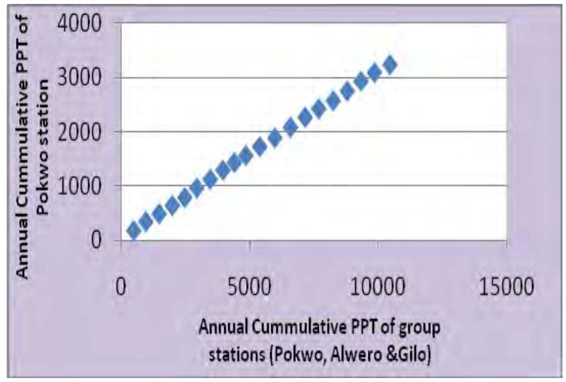
15000
Annual cummulative PPT of group stations (Pokwo, Alwero & Gilo)


Annual Cummulative PPT of Pokwo station
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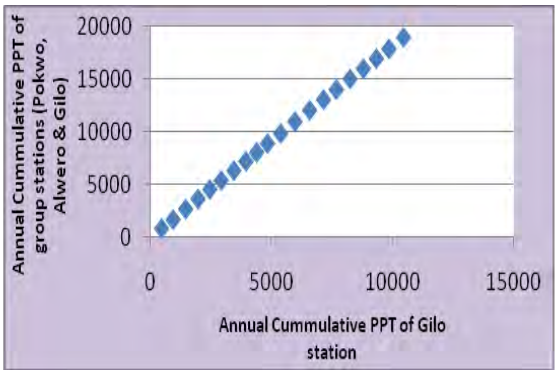
Annual Cummulative PPT of group stations (Pokwo, Alwero &Gilo)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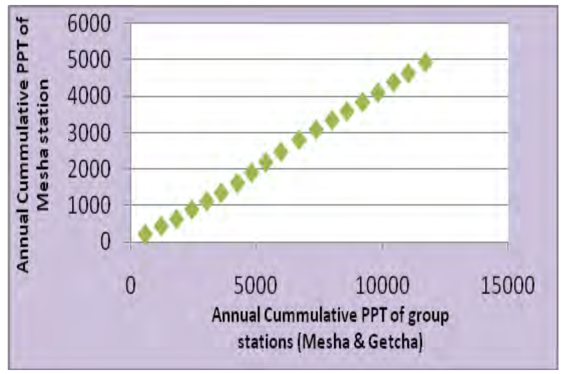
Annual Cummulative PPT of Gilo station


Annual Cummulative PPT of Mesha station
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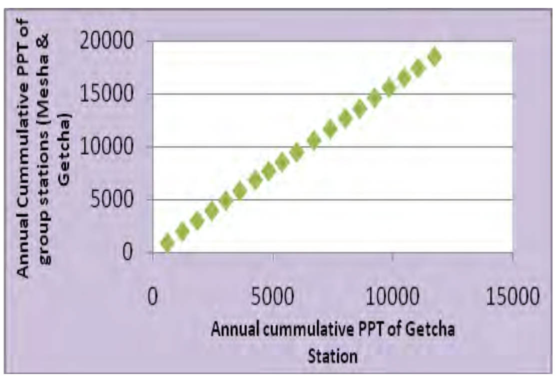
Annual Cummulative PPT of group stations (Mesha & Getcha)


Annual Cummulative PPT of group stations (Mesha & Getcha)
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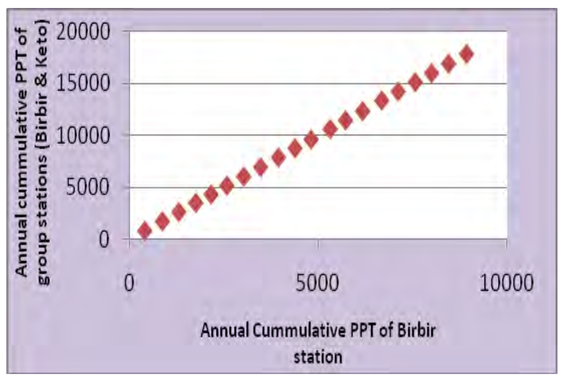
Annual cummulative PPT of Getcha Station


Annual cummulative PPT of group stations (Birbir & Keto)
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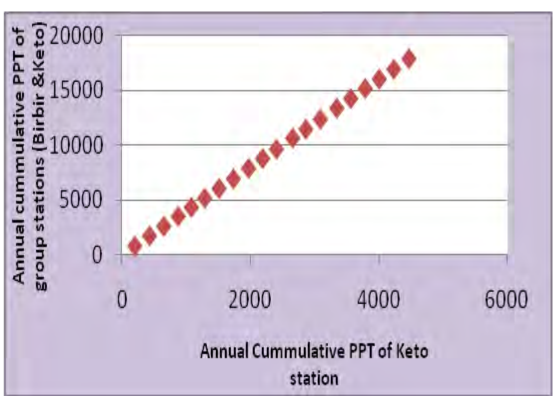
Annual Cummulative PPT of Birbir station


Annual cummulative PPT of group stations (Birbir &Keto)
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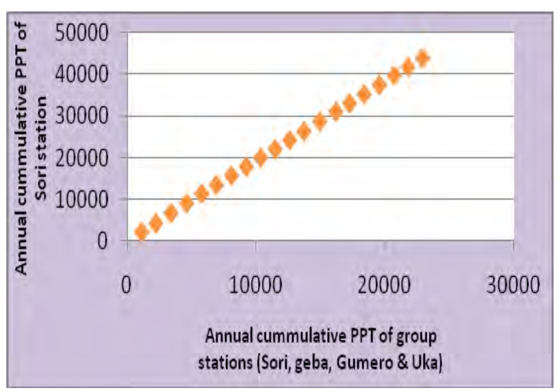
Annual Cummulative PPT of Keto station


Annual cummulative PPT of Sori station
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Annual cummulative PPT of group stations (Sori, geba, Gumero & Uka)

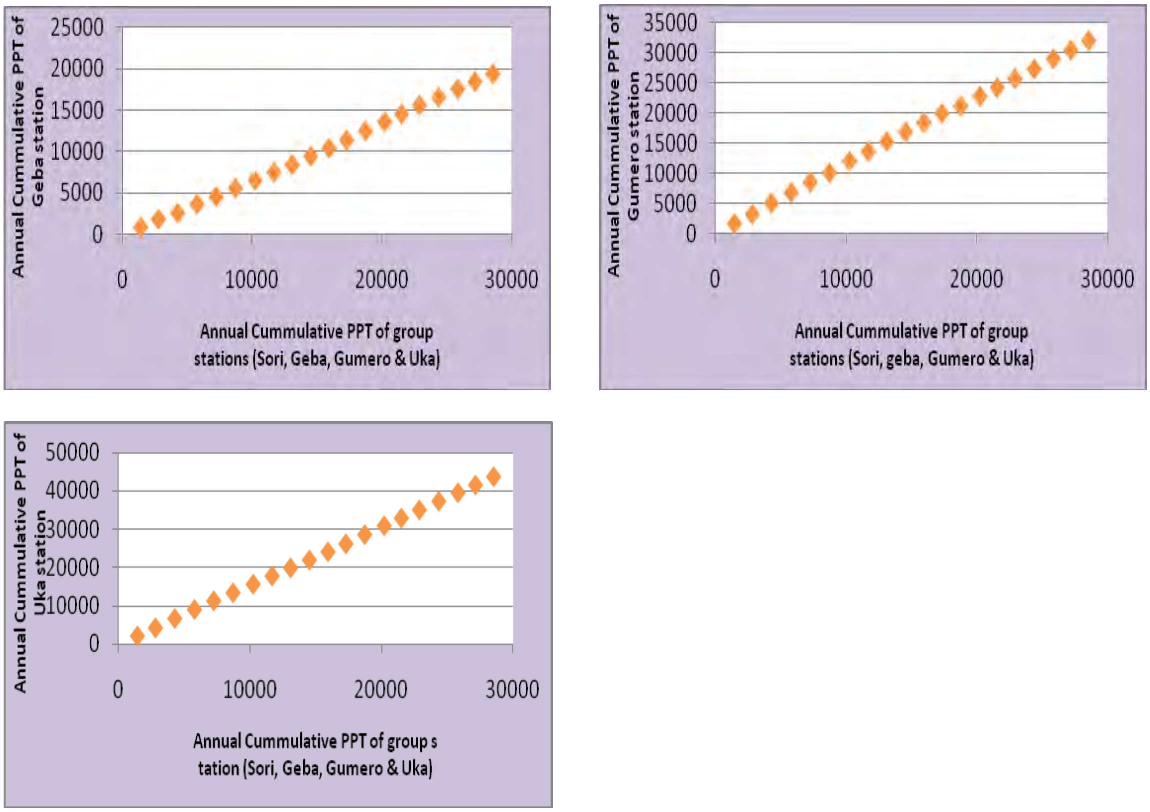


Figure 4.6 Consistency test graph for all the stations

The above graphs showed all points set on or form almost the straight lines, which was plotted for checking of consistency of rainfall, all stations were consistence and have more or less acceptable homogeneity. Therefore, the stations did not need further adjustment.

4.2.5 Estimation of Areal Model input Data

The areal input data for WatBal model are rainfall, air temperature, relative humidity and duration of sunshine hours. This section presents the steps followed to calculate these areal data sets taking the rainfall data as an example and also summarizes the result obtained.

The computation of average areal model input data may be done by the following methods:

- Arithmetic average method:-When the rainfall is uniformly distributed over the area, the average rainfall may be taken as the arithmetic average of the recorded rainfall. For Baro-Pokwo sub-catchment the Arithmetic average method is applied to determine the average precipitation using Poko and two nearby rainfall gauging stations of Gambella and Itang.

- Thiessen polygon method: - Rainfall varies in intensity and duration from place to place. Hence the rainfall recorded by each rain gauge station should be weighted according to the area it is assumed to represent. In this thesis paper; except for Baro-Pokwo, Thiessen polygon method is used to determine the average areal precipitation over sub-catchments from rain gauge measurements.
- Isohytal method: - isohyets are a line joining places of equal rainfall intensities on a rainfall map of the basin. An Isohytal map represents an accurate picture of the rainfall distribution over the basin. If the net work rainfall stations within the storm area are sufficiently dense, the Isohytal map will give a reasonably accurate indication of the rainfall distribution zones.

The sub-catchments in the basin considered for the thesis work have rainfall-gauging stations up to three within or in the vicinity of the boundary of their watershed. For catchments having rainfall gauges more than one, Thiessen polygon method has been used to compute the areal rainfall. The method weighs each gauge in direct proportion to the area it represents of the total basin. The area of influence of each gauge is obtained by constructing polygons determined by drawing perpendicular bisectors to lines connecting the gauges by using Arc view GIS soft ware.

The temporal variation of rainfall for the watershed is adapted in such a way that the pattern is representative for the entire watershed. If only one recording gauge is available, then it is assumed that the temporal distribution of the total storm rainfall at recording gauge is proportional to basin average rainfall. In the case that there are more than one recording gauges, it is often better to use the recording gauge that is close to the center of mass of the sub catchments as temporal distribution, (USACE, 1994). Thus, similar approach has been used for the modeling work to obtain the temporal variation for each event at each station.

Thiessen gauge weights shown in Table 4.4 are determined for sub-catchments with more than one rainfall gauging stations. For the thesis work, areal rainfall based on monthly total has been computed. The Theissen gauge weights developed for sub-catchments with more than one rainfall gauging stations are presented in Table 4.4 and Figure 4.7 while the rest are attached in appendix A.

Table 4.4 Thiessen gauge weights for Sore & Geba sub-catchment.

ID	Station Name	Area Weight (km2)	Thiessen weight (%)
1.	Uka Gore	2789	34.71
2.	Sori (Bedelle)	2637	32.81
3.	Geba Lalo	2610	32.48

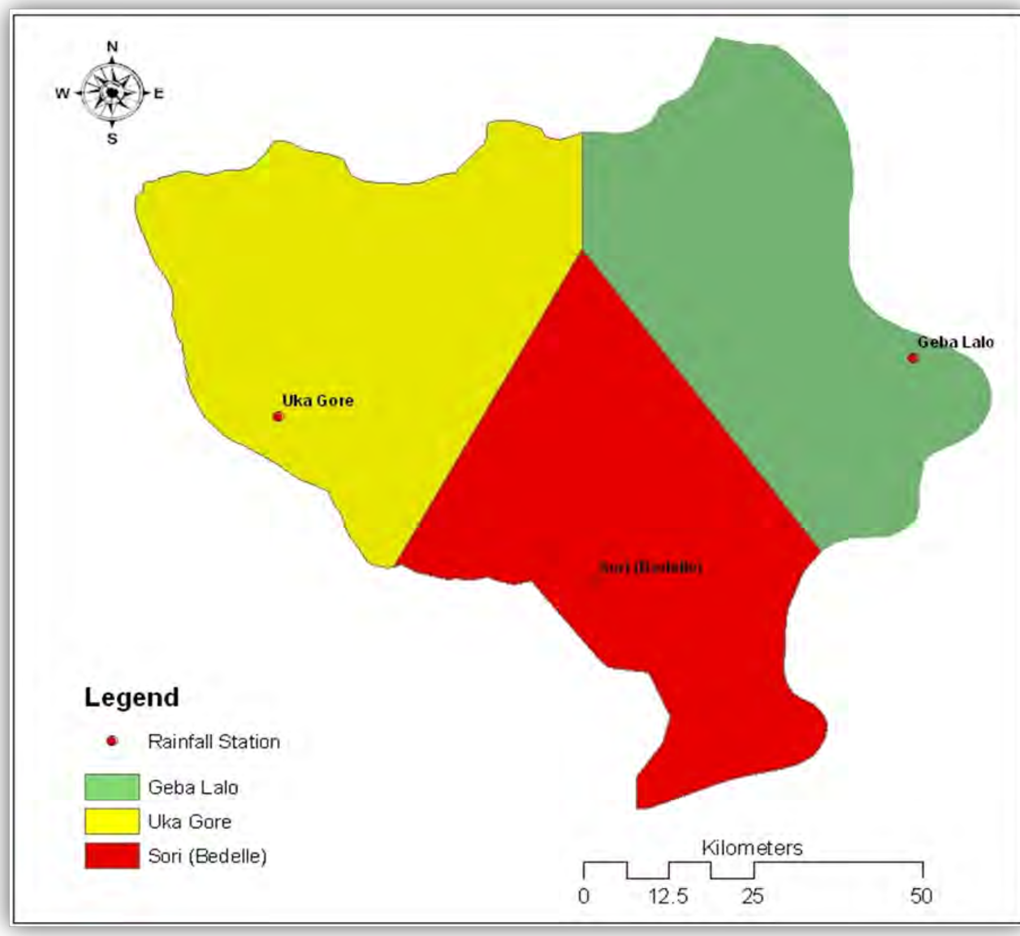


Figure 4.7 Thiessen polygon developed for gauged Sore & Geba sub-catchment.

CHAPTER FIVE

5 Methodology

5.1 Introduction

So far the study has considered estimation of monthly flows of ungauged catchments. This is relevant for most water resources planning and management problems. A general approach for estimating time series of flows at ungauged sites is the extrapolation of flow records from gauged sites. Catchments for which flow time series are to be estimated may not have comparable gauged catchments hence prohibiting extrapolation. For such cases the use of a rainfall-runoff model with regionalized parameters may be a feasible option.

Rainfall-runoff models fall into 2 main classes; a) lumped conceptual models, and b) distributed physically based. Lumped conceptual models describe mathematically processes within a hydrological system such as interception, surface runoff, and groundwater. Spatial variations of these processes are not accounted for, but rather spatially averaged values are used. Physically based models use continuum equations to describe temporal and spatial variations of hydrological processes. Estimation of parameter values of physically based models for ungauged catchments should theoretically be feasible because these parameters are supposedly measurable. There has been limited success in the use of these models on ungauged catchments, because the data required for estimating model parameter values are not available at both spatial and temporal scales to enable a truly physically based modeling. Pilgrim (1983) noted that hydrological processes are highly irregular in both space and time, and thus derivation of measurable model parameters is problematic.

This study is directed towards regionalization of lumped conceptual models. Regionalization of lumped conceptual models has been done by either extrapolating parameters from gauged sites, or by relating model parameters to catchment characteristics. WATBAL model is suitable for predicting model parameter values from gauging site. This study derived the WatBal model parameter of the selected sub catchment and predicts the model parameter value from gauged location. The reason of selecting this model is simple to use and takes advantage of mean monthly hydrologic data base (Leemans & Cramer, 1991).The aim of this chapter is to investigate the possibility of predicting model parameter values using WATBAL model.

5.2 Selection of Rainfall-Runoff Models

Several lumped models exist and the selection of models for use in this study is guided by the following points:

- The model addresses the problem, i.e. simulation of monthly flows. (Klemes, 1986; Simmers, 1984; Hendriks, 1990.
- Applicability of the model to the hydro climatic region of the study area.
- Using the simplest model if possible. Perrin et al. (2001) noted that simple conceptual rainfall-runoff models had fewer problems arising from parameter uncertainty than complex models. Uncertainty in the values of model parameters will limit the potential for regionalizing model parameters.

Lumped conceptual models selected for use in this study is WATBAL. This model is very simple and has six parameters. The uniqueness of the lumped water balance model is in its use of continuous functions of relative storage to represent hydrological processes in the form of a differential equation (Kaczmarek 1993; Yates 1996). Water enters the soil moisture store through precipitation and is removed either by evapotranspiration or direct runoff, surface runoff, subsurface runoff or base flow. The water balance component of the model comprises six parameters related to i) direct runoff (β), ii) surface runoff (ε), iii) sub-surface runoff (α and γ), iv) maximum catchment water-holding capacity (Smax) and v) baseflow (Rb).

5.2.1 Model Calibration

Calibration of model parameters is done in this study by combining manual trial-and-error and automatic optimization methods. The use of these two approaches is meant to minimize their limitations. Manual calibration of model parameters has the advantage that values can result hydrologically meaningful parameters. But this method does not always result in optimal parameter values. Automatic optimization will be used to fine tune parameter values. If automatic optimization is used only without manual calibration, values of parameters may not have any physically relevance. In addition, optimization routines do not always identify the global optimum, and parameters values may be based on local optima. Problems with the model structure and data errors can be more important than locating the global optimum. Equifinality of model parameters which means that different sets of model parameter values produce similar simulations on the same catchment is also a major constraint when attempting to identify optimal parameters values. This affects the feasibility of relating model parameters to catchment characteristics. Those sets of model parameter values that result in some of the state variables assuming values that are hydrologically not meaningful will be eliminated.

This study considers a simulation to be acceptable if simulated monthly flows satisfy the following conditions:

A. Coefficient of efficiency = $R^2 > 0.70$

The coefficient of efficiency, R^2, was defined by Nash and Sutcliffe (1970) as:

$$\mathbf{R^2 = \frac{F_o^2 - F^2}{F_o^2} = 1 - \frac{F^2}{F_o^2}} \tag{5.1}$$

Where,

$$F^2 = \sum_{I=1}^{n_s} \left(Q_{ob,s} - Q_{sim,\,s}\right)^2 \tag{5.2}$$

$$F_o^2 = \sum_{I=1}^{n_s} \left(Q_{ob,s} - Q_t\right)^2 \tag{5.3}$$

Where,

Qobs,t = observed or measured monthly flow

Qsim,t = simulated monthly flow

Qt = average of observed monthly flows

t = month interval

ns = total number of months simulated.

Values of coefficient of efficiency; R^2, ranging from zero (poor model) to 1.0 (perfect model). If R^2 is close to 1, indicate close agreement between observed and simulated flows.

B. The correlation coefficient (coefficient of determination), i.e., r^2, describes the proportion of the total variance in the observed data that can be explained by the model. It ranges from 0.0 (poor model) to 1.0 (perfect model) and is given by:

$$r^2 = \frac{Cov\ (Q_s, Q_o)}{\sigma_s\ \sigma_o} \qquad (5.4)$$

Where,

Cov (Qs,Qo) = the covariance of the observed and simulated(modeled) monthly flow.

σs = the standard deviations of simulated(modeled) monthly flow.

σo = the standard deviations of the observed monthly flow.

C. The average monthly error between the predicted and observed flow not exceed ± 10. If the average monthly error between the observed and simulated runoff, (E), values equal to zero were considered perfect. E is defined numerically as follow:

$$E = \frac{\sum_{I=1}^{n} Abs\ (Q_s - Q_o)}{n} \qquad (5.5)$$

Where,

E = average monthly error between the predicted and observed flow (mm/day)

Qs = the simulated (predicted) monthly flow

Qo = the observed monthly flow

n = total number of months simulated.

D. An acceptable agreement between the flow duration curves of observed and simulated flows based on visual inspection.

5.2.2 Model Validation

Calibrated model parameters can result in simulations that satisfy goodness-of fit criteria, but parameter values may not have any hydrological meaning. Values of model parameters will be a result of curve fitting. This is also reflected in having different sets of parameter values producing simulations which satisfy these criteria. It is necessary to test if parameter values reflect the underlying hydrological processes, and are not a result of curve fitting. Therefore; to conduct appropriate model validation results, it is necessary to carry out split sample test. The split-sample test involves splitting the available time series into two parts. One part is used to calibrate the model, and the second part is used for testing (validating) if calibrated parameters can produce simulations which satisfy goodness-of-fit tests. The spilt sample test is suitable for catchments with long time series, and it is applied in this study to catchments with over 20 years of data. For such catchments the available record is split into two equal parts.

5.3 Structure of WATBAL Models

- **Introduction**

David Yates of the Stockholm Environment Institute (SEI) in the USA developed the WATBAL model. It is a model that simulates changes in soil moisture and runoff. It is essentially an accounting scheme based on a conceptualized, one-dimensional bucket that lumps both the root and upper soil layer. The model comprises two elements. The first is a water balance component that describes water movement into and out of a conceptualized basin. The second is the calculation of potential evapo-transpiration, for which there are three possible alternatives, depending on data availability. The simplified representation of soil moisture dynamics has been shown to adequately represent runoff changes due to climate fluctuations (Yates and Strzepek, 1994; Yates, 1997).

- **Theory**

The uniqueness of the lumped water balance model is in its use of continuous functions of relative storage to represent hydrological processes in the form of a differential equation

(Kaczmarek 1993; Yates 1996). Water enters the soil moisture store through precipitation and is removed either by evapotranspiration or direct runoff, surface runoff, subsurface runoff or base flow (Figure 5.1). The water balance component of the model comprises six parameters related to i) direct runoff (β), ii) surface runoff (ε), iii) sub-surface runoff (α and γ), iv) maximum catchment water-holding capacity (Smax) and v) base flow (Rb).

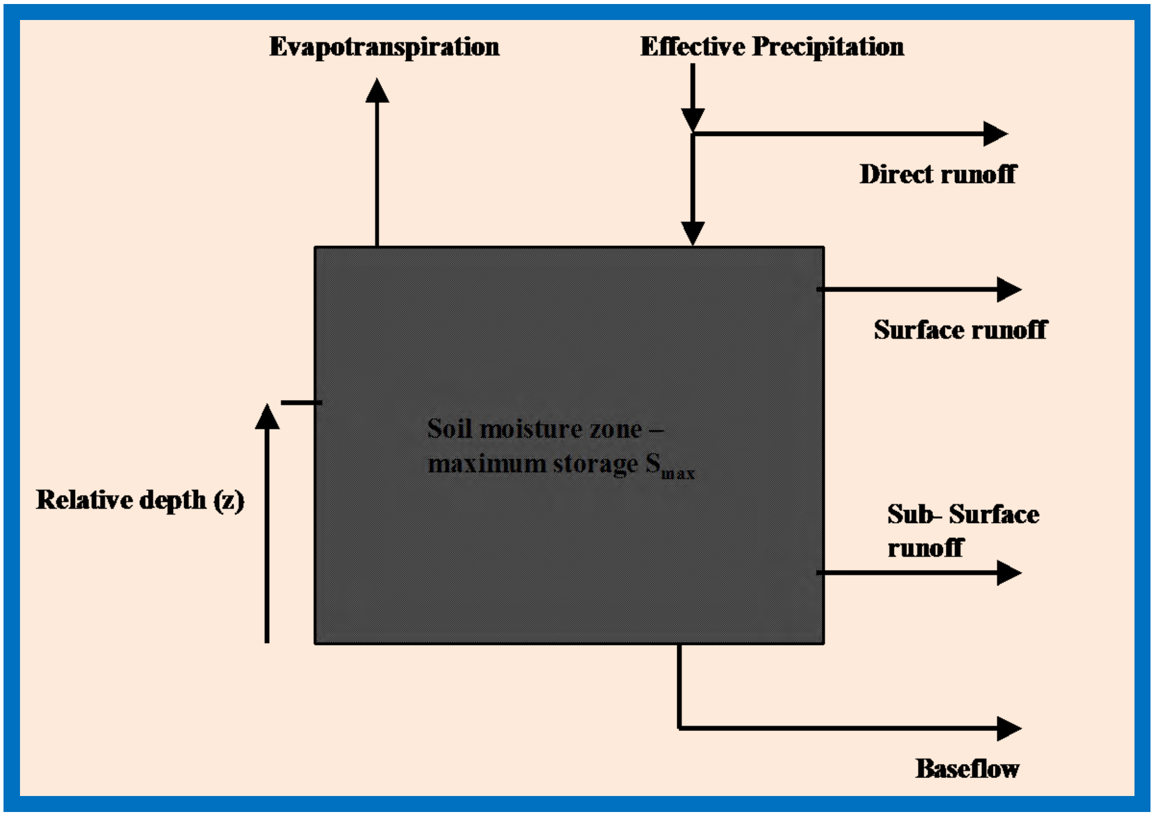


Figure 5.1 Conceptualization of the water balance of the WATBAL model.

The monthly soil moisture balance is written as:

$$S_{\max}\frac{dz}{dt} = P_{eff}(t)(1-\beta) - R_s(z,t) - R_{ss}(z,t) - E_v(Pet,z,t) - R_b \qquad (5.6)$$

Where:	P_{eff}	=	effective precipitation (mm/day)
	R_s	=	surface runoff (mm/day)
	R_{ss}	=	sub-surface runoff (mm/day)
	Ev	=	evapotransipiration (mm/day)
	Pet	=	potential evapotranspiration (mm/day)

R_b	=	base flow (mm/day)
S_{max}	=	maximum storage capacity (mm)
z	=	relative storage ($0 \leq z \leq 1$)

Smax, the maximum water holding capacity of a catchment reflects the relative importance of water storage on the hydrological regime of a catchment. It is dependent primarily on the nature of catchment geology and soils. The storage variable, z, is given as the relative storage state and is a value between 0 and 1. Consequently, when Smax is multiplied by z, it gives the volume of water stored in the catchment at any given time.

Surface runoff R_s, is described in terms of the storage state, z, and the effective precipitation, Peff, ε, a calibration parameter, and allows for surface runoff to vary both linearly and nonlinearly with storage (Yates 1996).

$$E_v(z, Pet, t) = Pet\left(\frac{5z - 2z^2}{3}\right) \qquad \textbf{(5.7)}$$

Sub-Surface runoff Rss, is a function of the relative storage state, multiplied by a coefficient α. In most cases the value of γ is 2, but for some basins may be different.

$$R_{ss} = \alpha \; z^{\gamma} \qquad \textbf{(5.8)}$$

Direct runoff (Rd) is a function of the effective precipitation. β is the proportion of effective precipitation that becomes direct runoff.

$$R_d = \beta P_{eff} \qquad \textbf{(5.9)}$$

The base flow (Rb) must be entered into the model as a constant value, determined by the user.

Total runoff for each time step is the sum of the four runoff components:

$$R_{total} = R_s + R_{ss} + R_b + R_d \quad \textbf{(5.10)}$$

In certain parts of the World, snowmelt represents a major portion of freshwater runoff and within WATBAL a temperature based snowmelt model can be used to adjust effective precipitation (Peff) to allow for snowmelt. However, in most places in Africa this is not a consideration, so description of this part of the model is not provided in these notes. However, details of the snowmelt model are given in Yates (1996).

Potential evapotranspiration is computed using one of three methods: i) Penman-Monteith (Penman, 1948; Monteith, 1965); ii) Priestley Taylor (Priestley and Taylor, 1972) or iii) Thornwaite (Thornwaite, 1984). The version of WATBAL available in 1996, only had one option, the Priestley Taylor method. Consequently, details of the Prietley Taylor method are given in Yates (1996), but no information on the other methods

- **Calibration and Validation of WATBAL Model Parameters**

In WATBAL, hydrological processes are simulated, as described above, on the basis of a conceptual approximation. Consequently it is necessary to adjust or optimize parameters until the model output is an acceptable estimate of the observed runoff regime. In order to do this it is necessary to have observed runoff data against which to calibrate parameter values.

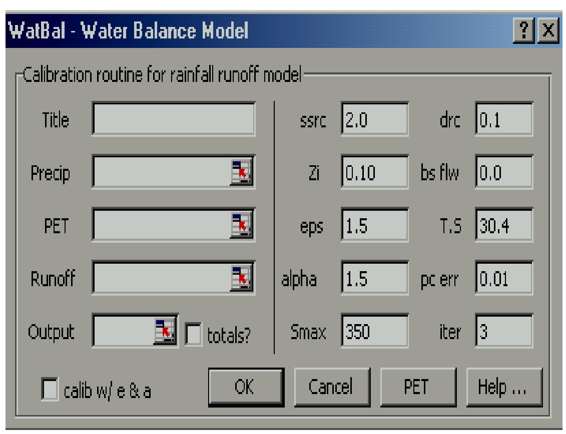


Figure 5.2 The WATBAL Dialog box accessed via the Calib/Valid option of the Runoff menu, showing an empty data sheet.

Ideally a split sample test should be performed. In this test the observed runoff record is split into two segments: one is used for calibration and the other for validation. If the statistical values derived from the calibration and validation procedure are similar, then the fitted model parameters are deemed acceptable.

Thus model parameters are found through empirical analysis of monthly and annual runoff. Key model parameters are alpha, epsilon and Smax. Within the model an automatic optimizing routine can be utilized to calibrate these three parameters. This uses a statistical relationship to reduce the error between the observed and simulated runoff. Optimal model parameters are rarely found on the first attempt of automatic calibration. Consequently, even when using such a method it is best to combine it, with an element of manual adjustment of parameters. The other model parameters can be calibrated, but this has to be done manually.

Smax has units of mm. Regions with higher runoff coefficients (i.e. average annual rainfall (mm)/average annual runoff (mm)) generally have larger Smax and vice-versa.

Alpha (α) has units of mm/day and is directly related to soil water storage. Regions with higher runoff coefficients generally have higher values of alpha (i.e. boreal forests and tropical rain forests) while regions with lower runoff coefficients generally have lower values for alpha (i.e. deserts and dry forests).

Epsilon (ε) is unit less and defines the functional form of surface runoff, which depends on the magnitude of the precipitation event and the relative storage. Smaller values of epsilon represent an increase in the contribution of surface runoff; therefore, smaller epsilons are generally associated with smaller soil moisture capacities and greater surface runoff (e.g. tundra and chaparral). Regions with larger base flows and flatter runoff hydrographs generally have a higher contribution of runoff from sub-surface flow. Higher values of epsilon tend to reduce the contribution from surface runoff.

- **Model Environment and Use**

WATBAL consists of two Dialog boxes (along with two help screens) within an Excel95 worksheet. The model is written in Visual Basic programming language. When WATBAL is loaded it is run from a button (runoff) on the Excel toolbar. This button gives access to both Dialog boxes.

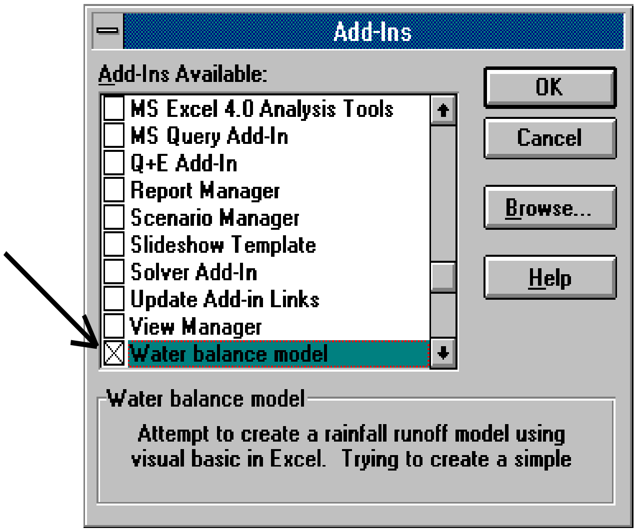


Figure 5.3 Add in selection box from Tools/Add-Ins on the Menu Bar of Excel 5.0.

The water balance component of WATBAL has the capability to run on any time step (seasonal, monthly, daily, hourly), however the potential evapotranspiration model has been developed to work only on a monthly time-step. If other time scales other than monthly are required, then a separate potential evapotranspiration model should be developed. If run in daily mode, it is recommended to not use more than 5 years of data at a time (approximately 1850 rows in an Excel worksheet). Five years of daily data should be adequate for calibration, so if there are more than five years of data available, this series should be broken into five-year increments. There should be no limitation on the number of years when performing analysis on a monthly time scale or longer.

CHAPTER SIX

6. Climate Impact Assessment on River Basin Runoff

6. 1 General

This chapter assesses the climate impacts on selected river basins before determination of rainfall-runoff model parameters for the construction of regional equations (Chapter Seven). A water balance model combined with the Priestley-Taylor method for computing potential evapotranspiration has been developed as an integrated tool for modeling the response of river basins to potential climate change. A number of modeling approaches have been developed and previous models have been modified for studying the impact of a potentially altered climate on river basin runoff (Nemec & Shaake, 1982; Gleick, 1987; Lettenmaier & Gan, 1990; Mimikou & Kouvopoulos, 1991; McCabe & Wolock, 1992; Nash & Gleick, 1993; Kaczmarek 1993; Riebsame et al., 1995; Skiles & Hanson, 1994; Yates & Strzepek, 1994). These methods have used different models and assumptions to derive the potential impact of a changed climate on river basin discharge.

Generally there is no accepted method or approach for proper assessment, and often simply using different models, assumptions and methods can lead to different conclusions regarding the impact of climate change on water resources. Proper evaluation of the water balance and evapotranspiration is important components of the hydrologic cycle, as evapotranspiration can be considered a key `link‘ between the atmosphere and the soil matrix within the hydrologic cycle. The importance of this link has been observed by Dooge (1992) who states that any estimate of climate change impacts on water resources depends on the ability to relate changes in actual evapotranspiration to predicted changes in precipitation and potential evapotranspiration (Ep). To predict proper changes in evapotranspiration it is obviously important to begin with good estimates of the mechanisms of that change, which are the water balance and potential evapotranspiration.

This motivates the need to arrive at a consistent and sound method for assessing the impact of climate change on a river basin. The model described here is an attempt to use simple yet widely accepted assumptions regarding the water balance and sound physical approaches to estimating potential evapotranspiration. Kaczmarek (1993) developed a DOS-based meso-scale water balance model, known as CLIRUN, for studying the impact of climate change on river basin discharge. The CLIRUN model takes as input effective precipitation, potential evapotranspiration and historic discharge and produces the runoff response of a river basin as well as changes in other variables such as storage and evapotranspiration. Because the model requires effective precipitation and potential evapotranspiration as inputs, it is difficult to find a consistent method for the proper assessment of climate impact on river basins with this model. Simply choosing a different set of criteria for determining effective precipitation or choosing an empirical method over a physically based method for the determination of potential evapotranspiration will likely produce significantly different impact results (Yates & Strzepek, 1994).

This model could be viewed as simply another slightly modified approach in a long line of hydrologic models. However Kundzewicz & SomlyoÂdy (1993) have observed a recent trend toward simpler, classical modeling approaches, especially with the new challenges which climate change brings. More sophisticated rainfall-runoff models have been developed over the past 30 years, but they are usually aimed at short-term flood forecasting on time-scales of days or even hours. These distributed models have been used for analyzing climate impacts (Lettenmaier & Gan, 1990; Nash & Gleick, 1993).

Franchini & Pacciani (1991) comment on event scale models such as the STANFORD IV and SACRAMENTO models. They state that the interaction of the various phases of rainfall-runoff transformation within the soil is not advantageous for computational purposes, resulting in over parameterization which leads to difficulty in the calibration procedure. Beven (1989) state‘s that three to five parameters should be sufficient to reproduce most of the information in a hydrological record.

With these issues in mind, this model makes use of a small number of parameters and incorporates a physically sound and widely accepted method for computing potential evapotranspiration in an attempt to draw attention to simple approaches using physically sound assumptions which are appropriate for climate impact assessment of river basin runoff.

6.2 Modeling Elements within WatBal

There are essentially two main modeling components within the WatBal model. The first being the water balance component which uses continuous functions to describe water movement into and out of a conceptualized basin. The second component is the calculation of potential evapotranspiration using the well known Priestley± Taylor radiation approach.

The common link in most water balance approaches is the computation of a mass balance within the soil moisture zone. There are many ways of representing the infiltration, discharge and storage behavior of the soil moisture zone (Eagleson, 1978; Chow et al., 1988; Todini, 1988). WatBal accounts for changes in the soil moisture by taking into account precipitation, runoff and actual evapotranspiration (Ev), while using potential evapotranspiration (PET) to drive the extraction of water from the soil moisture. A model of PET is included with the modeling system, creating an integrated tool for climate change impact assessment on river basins. Potential evapotranspiration modeled using the Priestley± Taylor method was chosen because of its simplicity and the evidence supporting such an empirical relationship on a regional basis, which is the case for river basin modeling (Shuttleworth, 1993).

The Priestley± Taylor method is a radiation-based approach to modeling PET, where the net radiation is taken from observed data (in equivalent water depth, mm/day) or is computed based on analytical methods. The albedo, a measure of surface reflectivity incorporated into the computation of net radiation, can be given as monthly mean values, or can be computed based on the soil moisture content of the soil as well as the predominant surface cover (grass or forest, and fraction of bare ground).

This thesis uses WatBal model for computing PET where the net radiation is taken in equivalent water depth, and albedo computed based on the soil moisture content of the soil in addition to surface cover, and computes them all within the model internally. Nevertheless, interpretation and computation of the Priestley± Taylor for PET based on analytical method of the net radiation and albedo given as monthly mean values are explained in the next article.

6.3 Priestley-Taylor Method for Potential Evapotranspiration

Penman (1948) was one of the first to describe evaporation in terms of the two main micrometeorological components: energy for the conversion of water to a vapor phase and aerodynamic processes for the removal of saturated air away from the surface. The Penman equation is the most widely known combined method of estimating evaporation:

$$E = \frac{\Delta}{\Delta + \gamma} Er + \frac{\gamma}{\Delta + \gamma} Ea \qquad (6.1)$$

Where,

E = combined evaporation estimate (mm/day)

Ea = evaporation estimate which assumes an unlimited availability of energy.

E r =evaporation estimate which assumes the ability of the system to remove moist air is not limiting.

Δ = slope of the saturated vapor pressure curve

γ = psychometric constant $=C_p$ p Kh/ (0.6221 Kw)

Where, Cp =specific heat at constant temperature

Kh, Kw =diffusivities $[L^2/t]$

Priestley & Taylor (1972) found that for very large areas, the second term of the Penman equation is approximately 30% that of the first. Thus an approximation to the Penman equation which gives an estimate of reference crop evapotranspiration may be written as:

$$E_{rc} = \alpha \frac{\Delta}{\Delta + \gamma} (R_n\text{-}G) \qquad (6.2)$$

where α has been given the value of 1.26 in humid climates (relative humidity greater than 60% in the month with the maximum evaporation) and 1.74 for arid climates (relative humidity less than 60% in the month with the maximum evaporation). G is the soil heat flux which for regional estimates can be assumed to be zero; all other terms have been defined. This is a reference crop evapotranspiration estimate (referred to in this paper as potential evapotranspiration), which should show lower values than similar estimates which give free surface or potential evapotranspiration.

Radiation

Because net radiation data are often scarce, an equation to derive values for net radiation was used. Aside from temperature, the equation uses two additional climate variables; relative humidity and bright sunshine hours per day. The value for net radiation can be calculated with the following equation (Shuttle worth, 1993).

$$Rn = \left((1\text{-}alb)(0.25+0.5\ n/N)\ Ra\right) - (f)\left(0.34\text{-}0.14ed^{1/2}\right)\left(T+272.2\right)^4 \qquad (6.3)$$

Where,

n = bright sunshine hours per day (h)

N = total day length (h)

Ra = extraterrestrial radiation (MJ/m^2day)

S = Stefan-Boltzman n constant ($4.903*10^9 MJ/m^2K^4day$)

T = mean air temperature (°C)

ed = vapor pressure (KPa)

Rn = net radiation (MJ/m2day)

Alb = albedo (short-wave radiation reaction coefficient)

f = cloudiness factor, given by

$$f = \left(a_c\ (b_c/(a_s+b_s)\right)n/N + \left(b_c+(a_s/(a_s+b_s))a_c\right) \qquad (6.4)$$

Where,

a_s =0.25 and b_s =0.50

a_c =1.35 and b_c = -0.35 (arid climates)

a_c =1.0 and b_c =0.0 (humid climates)

If it is assumed that the density of water is constant (1000 kg/m3), then Rn (equation 6.3) can be converted from MJ/m2 day to mm/day by dividing Rn by the latent heat of vaporization (in MJ/kg). Actual vapor pressures are estimated using mean monthly relative humidity values and are estimated by multiplying the saturated vapor pressure by the relative humidity data. To compute the extraterrestrial radiation and total day length the following equations were used (Shuttle worth, 1993).

$$R_A = 15.392 d_r \left(w_s \sin f \sin d + \cos f \cos d \sin w_s\right) \quad (6.5)$$

Where,

RA =extra-terrestrial radiation (mm/day)

N =maximum possible daylight hours (equation 6.6)

d_r =relative earth-sun distance (equation 6.7)

Table 6.1 Albedo values for different land cover types included within WatBal

Land cover class	Albedo value
Forest	0.11± 0.16
Grass and pasture	0.20± 0.26
Bare soil	0.10 (wet)± 0.35 (dry)

w_s =sunset hour angle [radians] (equation 6.8)

f =latitude of site [radians]

d =solar declination [radians] (equation 6.9)

J = Julian day

And

$$N = (24/\pi)\, w_s \quad (6.6)$$

$$d_r = 1+0.033\cos(2pJ/365) \quad (6.7)$$

$$ws = \arccos(-\tan f \tan d) \quad (6.8)$$

$$d = 0.4093 \sin(2pJ/365-1.405) \quad (6.9)$$

<u>Albedo</u>

Albedo is a measure of the surface's capacity to react incoming solar radiation. Albedo can be given exogenously as monthly mean values, or it can be computed based on land cover conditions and the soil moisture state. Two broad land cover classes have been used within WatBal, where one is tall forest and the other is grass and pasture. Shuttle worth (1993) suggested the coefficients for radiation reaction (albedo) given in Table 6.1; these have been used within WatBal to compute albedo based on equation 6.10.

$$Alb = \left(1-GC\right)\left(a_1-(Z*a_2)\right)+GC\left(a_d-((Z*a_w)\right) \quad (6.10)$$

Where, for each month,

GC =ground cover index (0.0 ≤ GC ≤ 1.0; GC = 0.0 completely covered, GC = 1.0 completely bare)

z = relative soil moisture; (0.0 ≤ zi ≤ 1.0)

a_1, a_2 = albedo bounds based on land cover type (grass/pasture or forest)

a_d, a_w = albedo bounds for bare soil (dry and wet)

Scenario development for climate change impact assessment is usually performed in one of four ways (Niemann et al., 1994):

(1) GCM based scenarios: GCM derived adjustments to base climates.

(2) Hypothetical scenarios: usually put in the framework of sensitivity analysis by applying an ensemble of potential climates.

(3) Historical scenarios: data from historic periods that `mimic‘ a changed climate (if available).

(4) Analogue scenarios: The changed climate in one location could be potentially similar to the current climate in another location.

Since the focus is assessing the applicability of WatBal as a water balance model for climate impact assessment on a river basin, the third method up to the base year is chosen for its compatibility and simplicity. In this approach, scenarios are cast as a set of descriptive climates. These scenarios will enable the generation of a family of tables that will give insight into the sensitivity of the basins and the model to climate variations. The scenarios chosen give uniform, annual changes in temperature (ΔT) and precipitation (%P) in the combinations given in Table 6.2, with the expectation for the climatological record years that they cover the range of credible climates.

Table 6.2 Uniform climate scenarios used (base*)

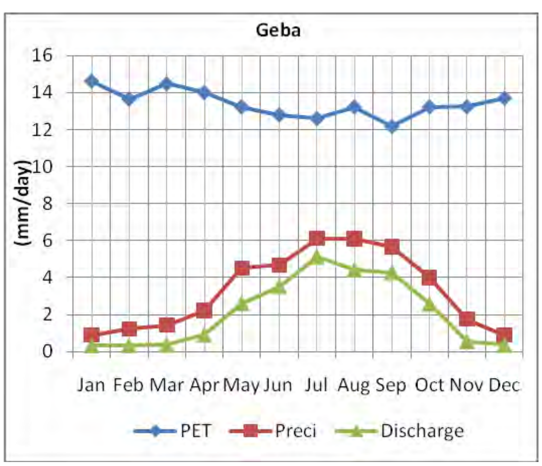
T+0P+0*	T+0P-10	T+0P-20
T+2P+0	T+2P-10	T+2P-20
T+4P+0	T+4P-10	T+4P-20

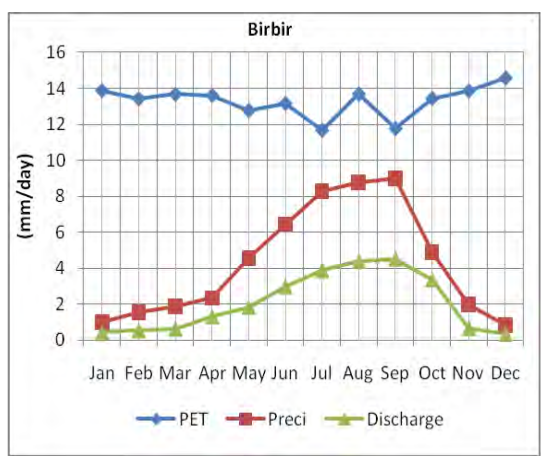
6.4 River Basin climate Assessment

To analyze the applicability of water balance model for climate impact assessment on a river basin the following representative rivers from each sub basins are selected for testing. And these are Geba, Birbir, Alwero, Getcha and Mesha rivers. They are intended to show the range of the model's applicability by describing a basin in a humid climate that is dominated by winter rainfall and warm summers and a basin in a colder and semi- arid temperature regions.

The Geba river Basin is situated at lat. 8°N, long. 35°E. It has a moderately temperate climate, with a mean annual air temperature of approximately 20°C. The Birbir river Basin is situated at lat. 9°N, long. 36°E. It has a mean annual air temperature of approximately 19°C. The region is characterized by dense ground cover. Alwero river basin is located from lat. 7°N, long. 35°E; with topography of the watersheds for these river is having flat to undulating landscape with elevations ranging from 400m-500m a.s.l. Getcha and Mesha rivers are located from at lat. 7°N, long. 36°E. The climate of these basins produces an interesting runoff characteristic that can be observed in Figure 6.1. In addition, it shows the mean monthly and annual values over the past 20-year record, respectively, for observed discharge, precipitation and potential evapotranspiration. Except for Mesha sub-catchment resulting with a wrong verification to the correlations of observed discharge, precipitation and potential evapotranspiration, all the remaining result shows periodic well-built precipitation response to reasonable changes in runoff and potential evapotranspiration.

During model calibration and validation period of the Mesha sub-catchment, the river has 0.25 model efficiency. This is much less than 0.7 for this catchment indicating inaccurate simulation of seasonal flows. This poor efficiency could be due to inaccuracy of data collection and/or recording errors.





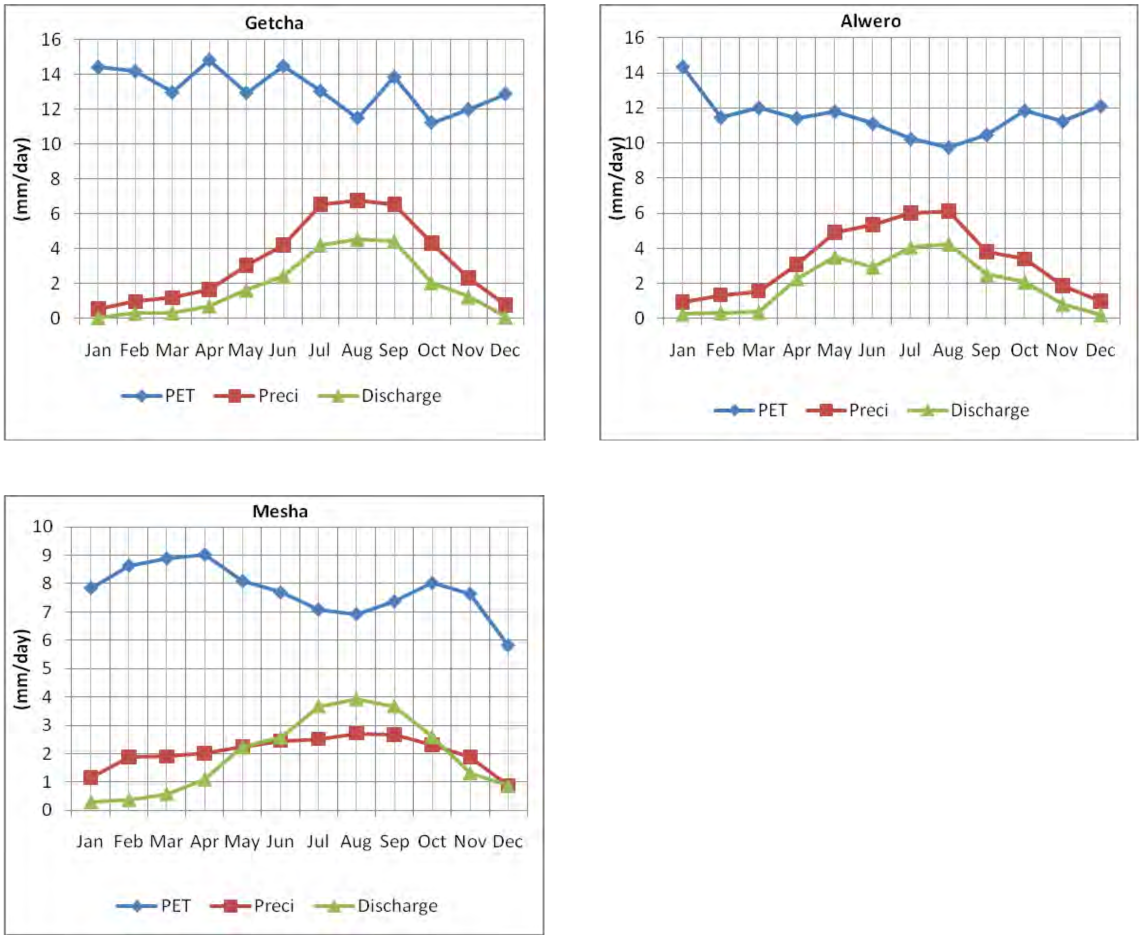
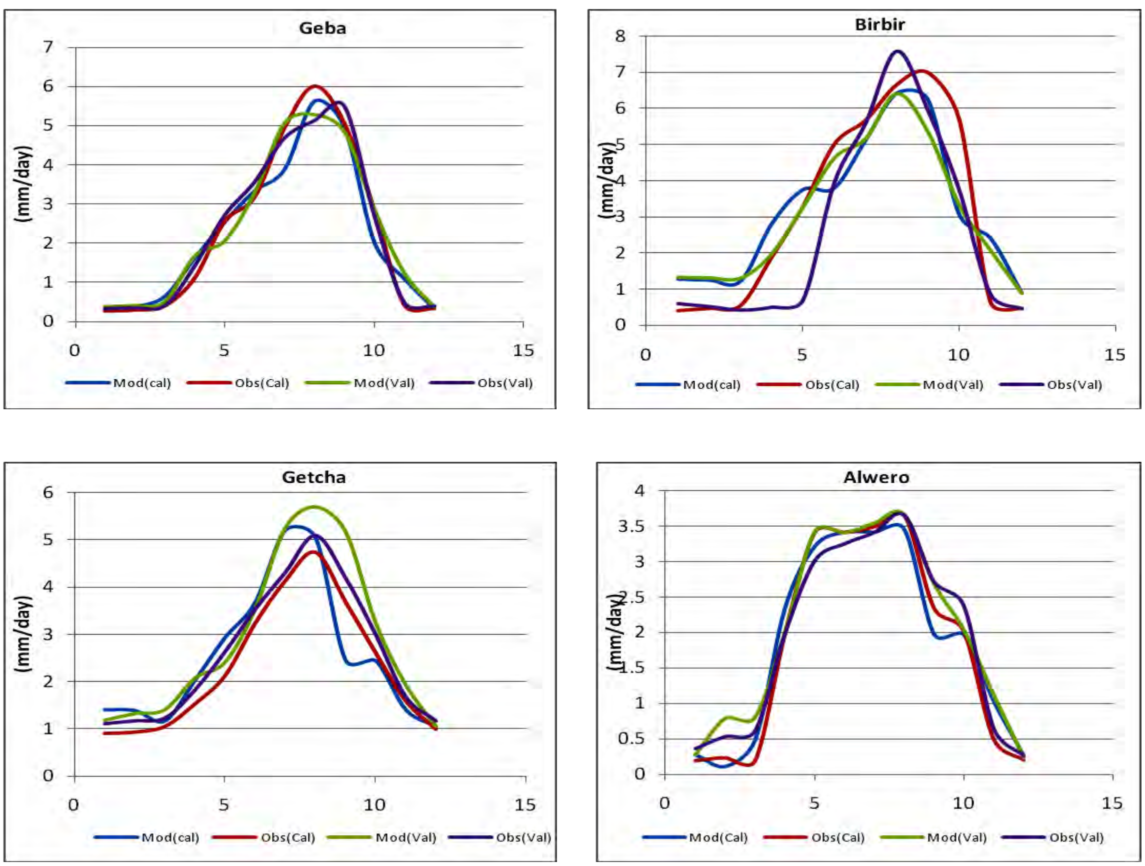


Figure 6.1 Mean monthly values of precipitation, runoff and potential evapotranspiration by Priestley-Taylor.

6.4.1 Calibration and validation Responses

The climatological record used for the Rivers spans the years 1989-2008. The catchments show strong runoff response to relative changes in precipitation (Figure 6.1). Temperature is negatively correlated to runoff, while precipitation, not surprisingly, is positively correlated. The annual precipitation, and discharge record seems to indicate that the basin is less sensitive to the existing temperature variations, though the driest portions in the record are also the warmest. One portion of the record (Mesha River) has a large increase and decrease in basin discharge relative to precipitation, without a substantial increase or decrease in temperature, which the data failed to show the genuine relationship. Figure 6.2 is a plot of the mean monthly observed and modeled discharge for the calibration and validation period for Geba, Birbir, Getcha, Alwero and Mesha Rivers respectively. The model appears to under predict consistently the winter runoff and tends to underestimate the transition period when the flow diminishes greatly from December to January. This kind of result might point to the strength of using seasonal model parameters. Calibration and validation values used in the WatBal model for the rivers include the following:

- sub-surface runoff exponent, γ
- sub-surface runoff coefficient, α
- surface runoff exponent, ε
- maximum storage, Smax
- initial storage, Zi
- direct runoff coefficient, DRC
- latitude
- temperature
- Priestley± Taylor coefficient, P.T.
- Ground cover index, G.C.
- Base flow



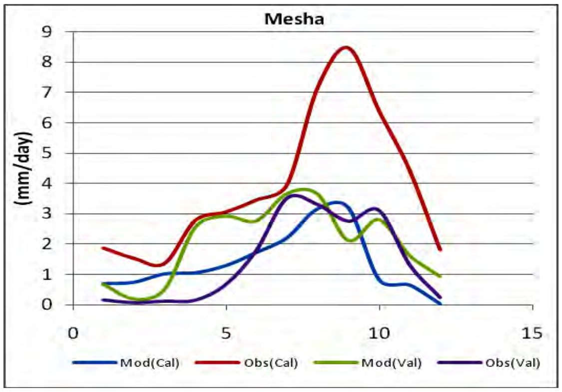


Figure 6.2 Mean monthly discharge: Observed discharge vs. model prediction for calibration and validation series.

6.4.2 Climate Change Scenarios

The discharge under the different climate change scenarios is given in Table 6.3. They reveal the sensitivity levels of the basin due to precipitation change, for example if Geba sub catchment is taken as an example, a 20% increase or decrease in precipitation leads to nearly a 20-30% increase or decrease in discharge. An approximate 0.59% (0.11°C) decrease in temperature is observed for 0.09mm/day flow increases. Except for Mesha showing irrelevant result, the other sub catchments show similar scenarios (Table 6.3).

Table 6.3 Annual and Seasonal flow changes (%) under various scenarios

River	Δ((T-20)-(T-20)), (T-20)	Δ((T-10)-(T-20)), (T-10) ⇨Δ Obs dis.	Δ((T0)-(T-20)), (T0)⇨Δ Obs dis.
Geba	0%, (19.77°C)	-0.59%, (19.66°C) ⇨ +0.09 mm/day	-1.09%, (19.56°C) ⇨ +0.04 mm/day
Birbir	0%, (19.90°C)	-2.64%, (19.38°C) ⇨ +0.14 mm/day	-3.27%, (19.26°C) ⇨ +0.08 mm/day
Getcha	0%, (20.02°C)	+3.29%, (20.68°C) ⇨ -0.16 mm/day	+0.32%, (20.08°C) ⇨ -0.01 mm/day
Alwero	0%, (29.79°C)	+0.04%, (29.80°C) ⇨ -0.08 mm/day	+2.33%, (30.49°C) ⇨ -0.06 mm/day
Mesha	0%, (16.39°C)	+2.52%, (16.80°C) ⇨ -0.55 mm/day	+2.84%, (16.85°C) ⇨ -0.18 mm/day

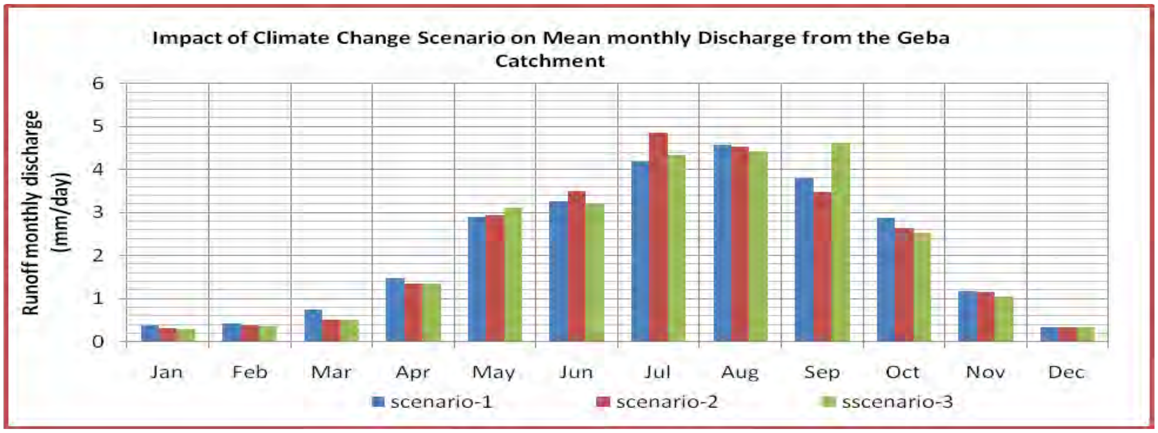
6.4.2.1 Climate Change Impact on Monthly Flow

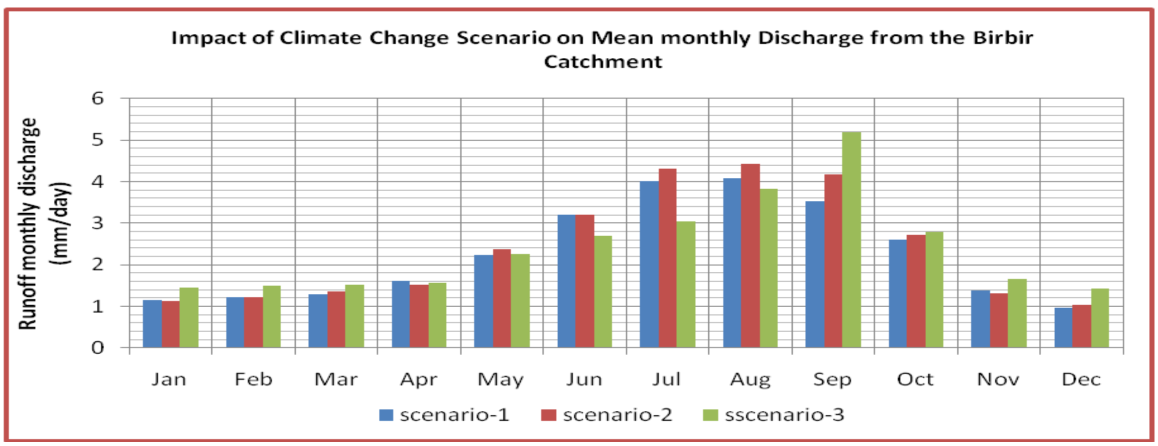
Climate change impact on monthly flow was analyzed by comparing continuous monthly river flow for the scenarios. Except Mesha, Increase or decrease in monthly flow for all the other sub catchments will be resulted, due to respective increase or decrease in monthly precipitation; and the monthly variation of change in precipitation is between 5% and 62%.

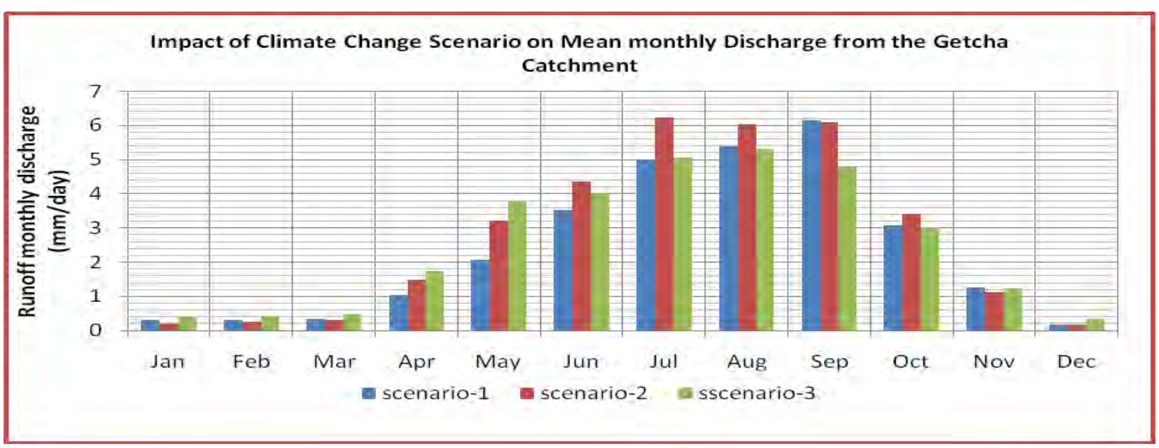
6.4.2.2 Climate Change Impact on Seasonal and Annual Flow

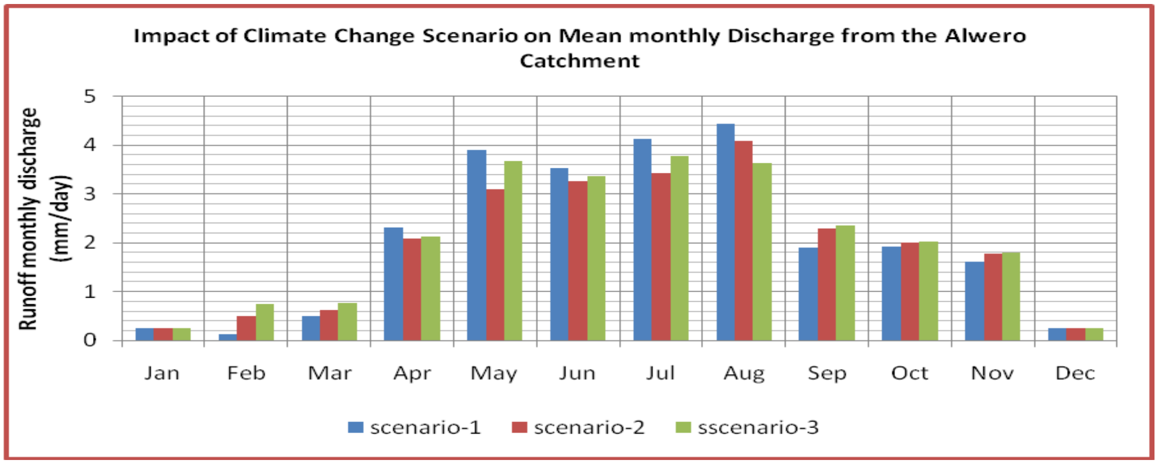
The impacts of climate change on the seasonal and annual flow can be seen on the basis of the four seasons: Kiremt (June to August), Belg (March to May), Tsedey (September to

November) and Bega (December to February). There exists increase in flow volume from 20% up to 41% in the Kiremt season; this increasing is shown in all scenarios. In Belg seasons the flow volume increase from twice to three times that of the kiremt season for the scenarios. In Tsedey season the flow decreases by 30%; while in Bega flow remains constant with the lowest discharge. Figure 6.3 below shows that Annual and Seasonal percentage change of flow under various scenarios.









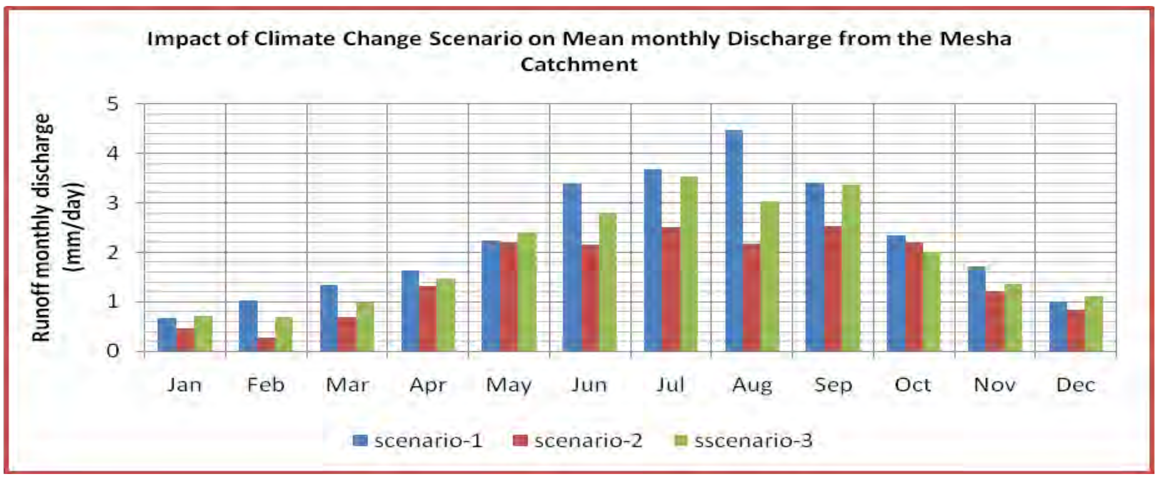


Figure 6.3 Annual and Seasonal percentage change of flow under various scenarios.

6.5 Sensitivity of Evapotranspiration to Climate Change

Evapotranspiration rates are controlled by several variables including the available water and energy. A temperature increase leads to higher energy available for evapotranspiration. Although a warmer atmosphere can hold more water, the actual changes in evapotranspiration will depend on the humidity levels and the wind patterns. Annual estimates of potential evapotranspiration are predicted to increase with increase in temperature, but the simulations for all catchments suggest that annual estimates of potential evapotranspiration almost remain the same with insignificant variation in temperature. The projected on average annual increase in potential evapotranspiration is 1-1.6 % throughout the three scenarios and temperature variations for the base year (T0) and year (T-20), are -0.21ºC, -0.64ºC, +0.06ºC, +0.3ºC and +0.36ºC for Geba, Birbir, Getcha, Alwero and Mesha respectively; where climate change results did not differ greatly between simulations indicating that there is less sensitive climate changes on all sub-catchments. Generally, a 1ºC increase in temperature reduces flow by 6% and increases potential evapotranspiration from 10 to16 %. A shift of 1ºC or 2ºC in temperature drastically shifts the runoff and requires recalibration to match the discharge record.

6.6 Conclusions

WatBal was designed to be a simple-to-use water balance model for assessing the impact of climate change on a river basin. The catchment studies show that:

- The model reveals the insensitivity of the basin to the existing precipitation changes, where precipitation was almost fairly uniform on all scenarios.
- Climate change results did not vary greatly between simulations showing that there are less sensitive climate changes on all sub-catchments.
- The model tends to underestimate the transition period flows. This kind of result might point to the strength of using seasonal model parameters.

The strong seasonal variation in runoff in all the basins points to a possible need for seasonal parameters within WatBal. However, Yates & Strzepek (1994) point out that empirically based potential evapotranspiration models that have been regionally developed and calibrated (Thornthwaite) can give superior results over a model such as Priestley± Taylor, which might eliminate the need for additional model parameters. Caution is required, though, because empirically based methods of PET can be very misleading when performing climate change studies in river basins (Yates & Strzepek, 1994).

CHAPTER SEVEN

7 Results and Discussion

7.1 Comparison of Modeled and Observed Monthly Flows

Since it is difficult to estimate values of model parameters from the field measurements, all the model ranging from parsimonious lumped to complex distributed physically based need to be calibrated. The WATBAL model was calibrated against the observed discharge and model parameters are found through analysis of monthly runoff for the eleven sub-catchments that fulfilled the criteria for the purposes of rainfall-runoff modeling (Figure 7.1).

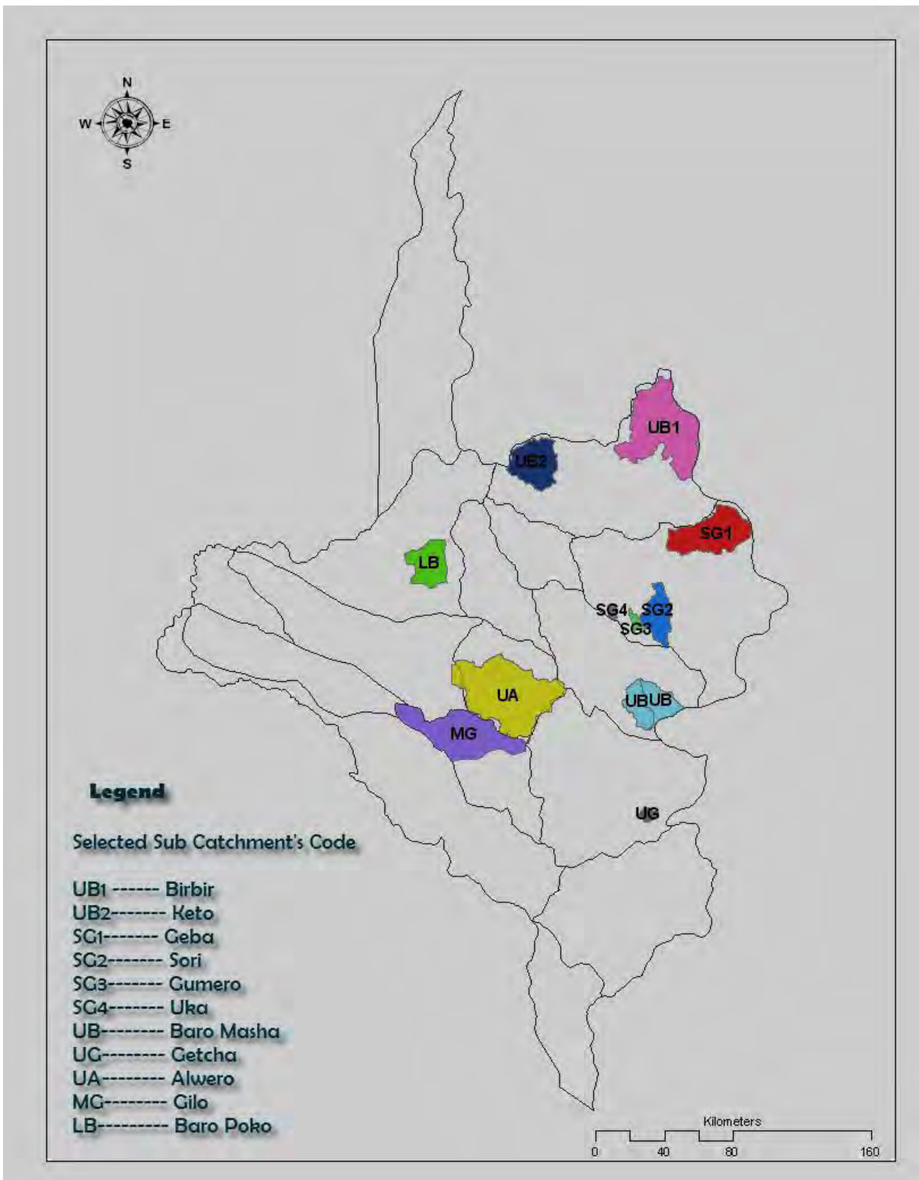
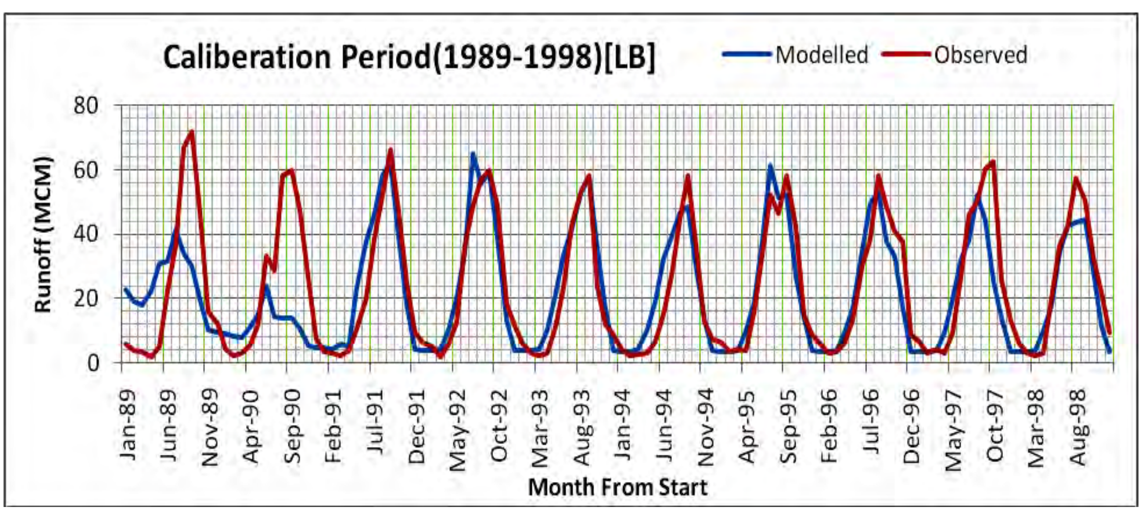
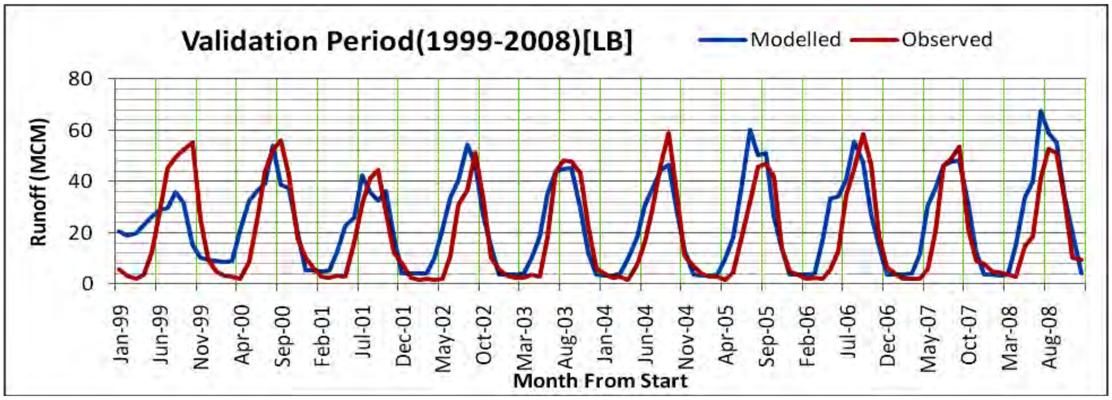


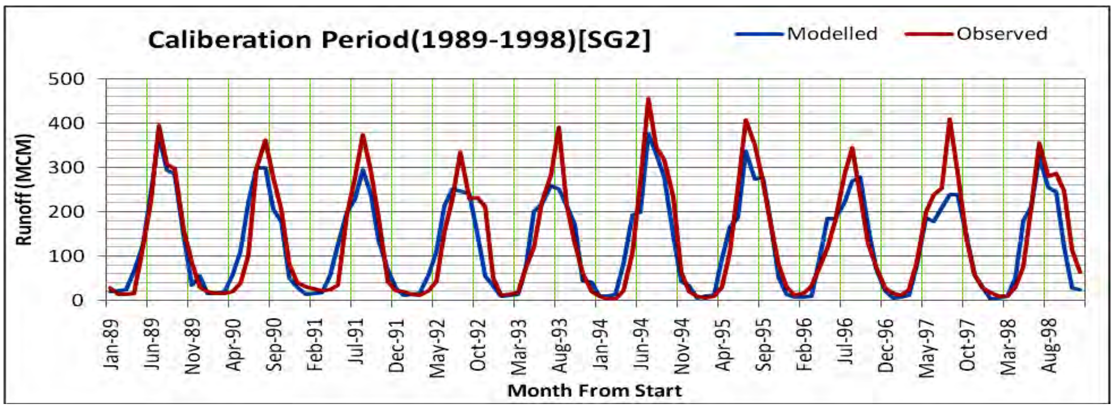
Figure 7.1 Sub-catchments selected for Rainfall-Runoff modeling.

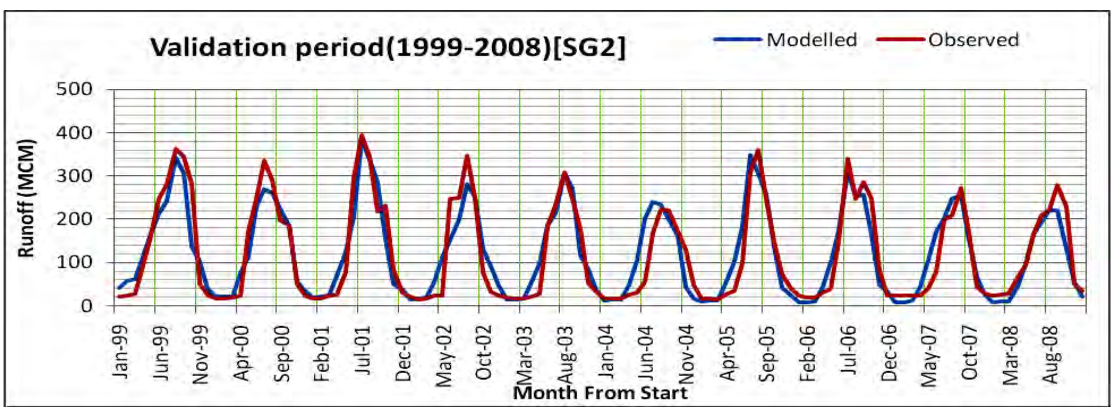
The WATBAL model preserved the seasonal and inter-annual variation of flows. There are some peak flows that are not correctly simulated for some years by WATBAL model. This may cause of thunderstorms, the total monthly rainfall can be due to a few storms within a month that are not captured by spare rain gauge networks. Hence peak flows are not always correctly due to inaccurate estimation of catchment rainfall. The model simulated accurately relatively high season flows (see figure 7.2 below).

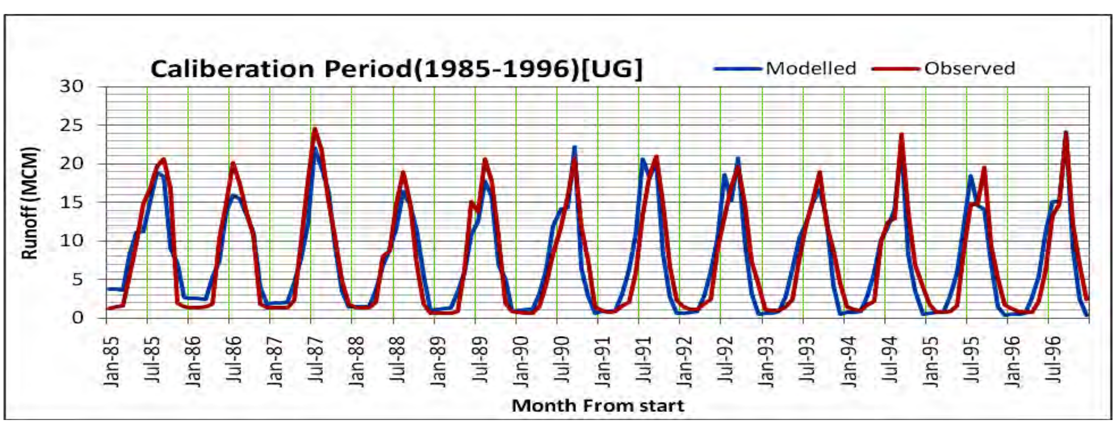
Figure 7.2 shows the model performance during calibration and validation period (close agreement between the goodness-of-fit criteria of the simulated and observed flow). Nash and Sutcliffe (1970) coefficient of efficiency, R^2, which is best if R^2>0.7. More than 80% of the selected catchment satisfies these criteria. Sub- catchments Baro-Mesha, and Baro-Poko generate poor results. The coefficients of efficiency, which are shown in table 7.1, are much less than 0.7 for these catchments indicating inaccurate simulation of seasonal flows. This result occurs may be due to inaccuracy of data collection. The values of the remaining goodness-of-fit criteria that are coefficient of determination, r^2, and average error, E, are given in Table 7.1.b. Table 7.1.a demonstrates the models output during calibration of the selected sub-catchment. By taking four sub catchments, Figure 7.2 shows value outputs of modeled (simulated) and observed monthly flow during calibration-validation period, and Appendix E will show the remaining model performance and comparison during calibration and validation period.




Validation Period(1999-2008)[LB]
Modelled
Observed
Runoff (MCM)
0
20
40
60
80
Jan-99
Jun-99
Nov-99
Apr-00
Sep-00
Feb-01
Jul-01
Dec-01
May-02
Oct-02
Mar-03
Aug-03
Jan-04
Jun-04
Nov-04
Apr-05
Sep-05
Feb-06
Jul-06
Dec-06
May-07
Oct-07
Mar-08
Aug-08
Month From Start


Caliberation Period(1989-1998)[SG2]
Modelled
Observed
Runoff (MCM)
0
100
200
300
400
500
Jan-89
Jun-89
Nov-89
Apr-90
Sep-90
Feb-91
Jul-91
Dec-91
May-92
Oct-92
Mar-93
Aug-93
Jan-94
Jun-94
Nov-94
Apr-95
Sep-95
Feb-96
Jul-96
Dec-96
May-97
Oct-97
Mar-98
Aug-98
Month From Start


Validation period(1999-2008)[SG2]
Modelled
Observed
Runoff (MCM)
0
100
200
300
400
500
Jan-99
Jun-99
Nov-99
Apr-00
Sep-00
Feb-01
Jul-01
Dec-01
May-02
Oct-02
Mar-03
Aug-03
Jan-04
Jun-04
Nov-04
Apr-05
Sep-05
Feb-06
Jul-06
Dec-06
May-07
Oct-07
Mar-08
Aug-08
Month From Start


Caliberation Period(1985-1996)[UG]
Modelled
Observed
Runoff (MCM)
0
5
10
15
20
25
30
Jan-85
Jul-85
Jan-86
Jul-86
Jan-87
Jul-87
Jan-88
Jul-88
Jan-89
Jul-89
Jan-90
Jul-90
Jan-91
Jul-91
Jan-92
Jul-92
Jan-93
Jul-93
Jan-94
Jul-94
Jan-95
Jul-95
Jan-96
Jul-96
Month From start

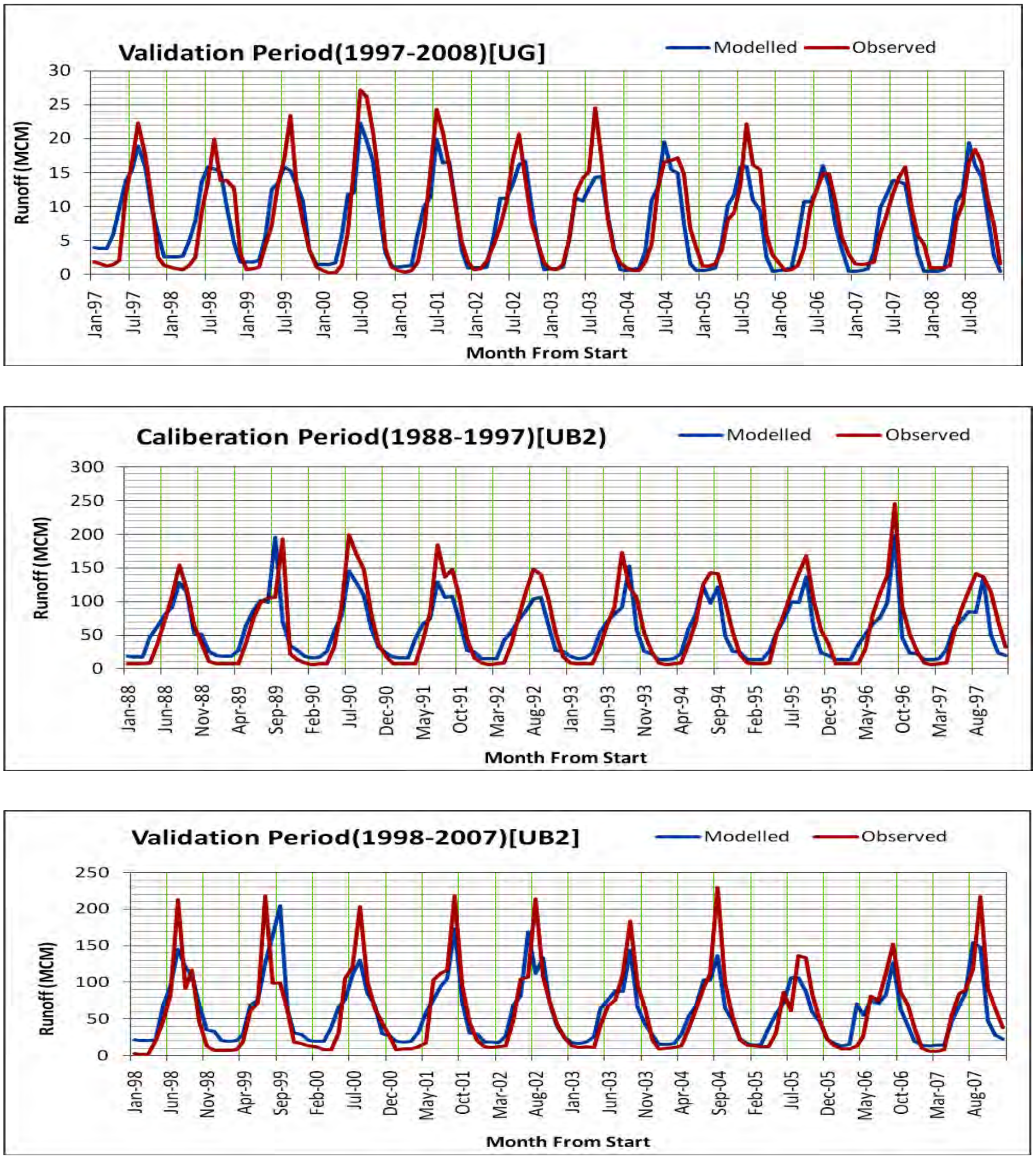
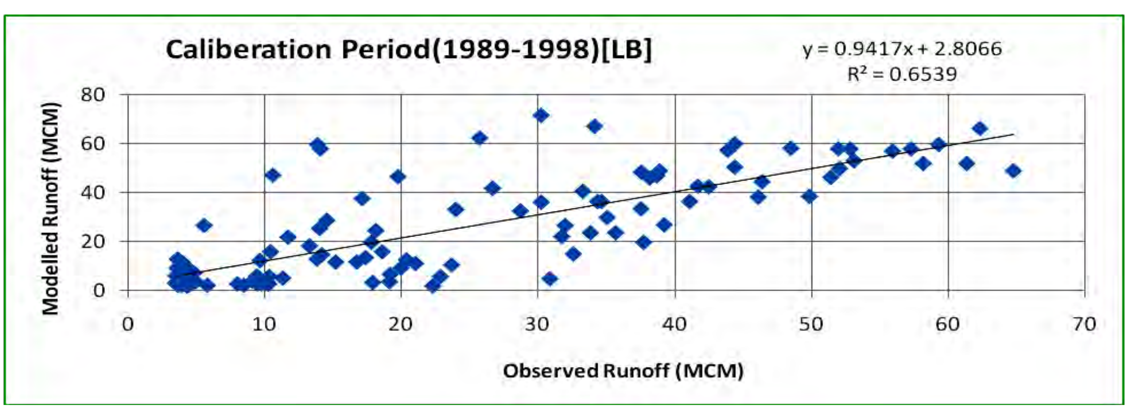
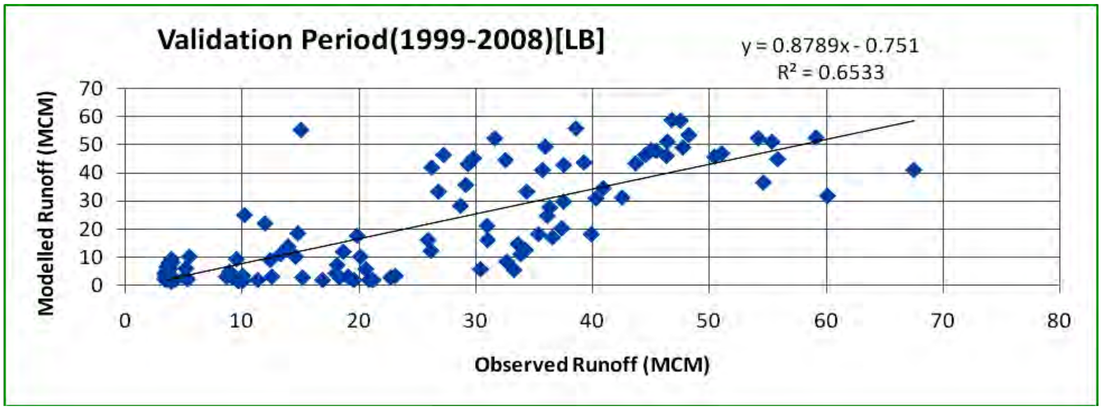
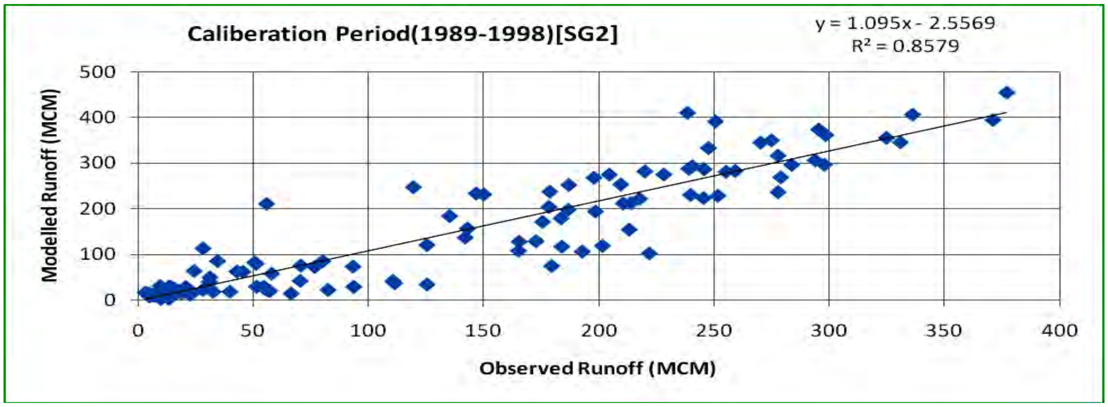
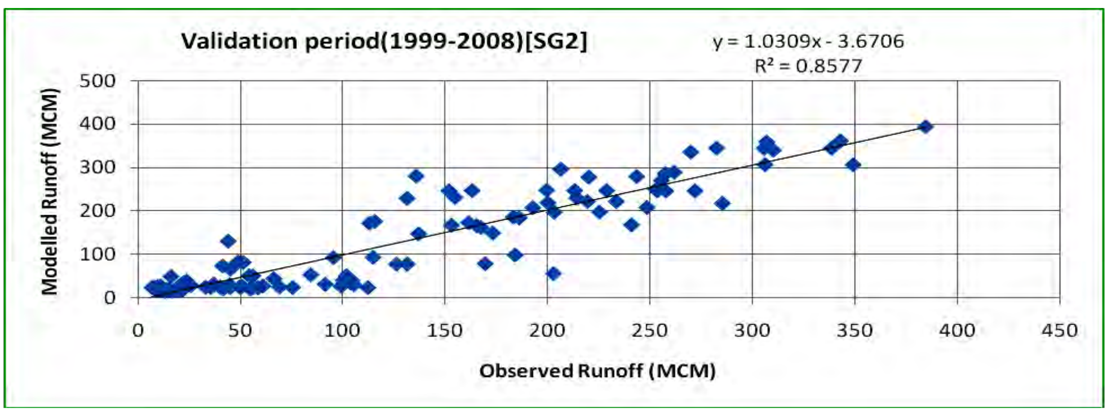


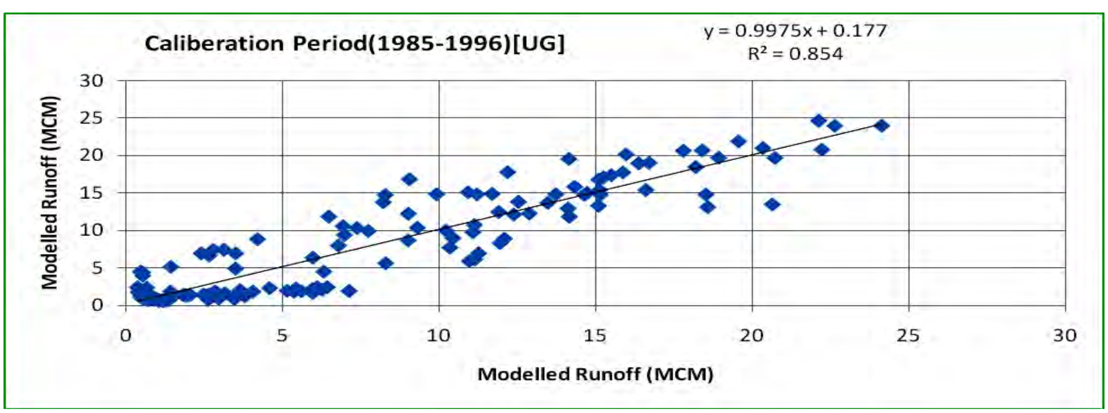
Figure 7.2 Comparison of Observed and Modeled Monthly flow.




Validation Period(1999-2008)[LB]
y = 0.8789x - 0.751
R² = 0.6533
Modelled Runoff (MCM)
Observed Runoff (MCM)
0
10
20
30
40
50
60
70
80


Caliberation Period(1989-1998)[SG2]
y = 1.095x - 2.5569
R² = 0.8579
Modelled Runoff (MCM)
Observed Runoff (MCM)
0
50
100
150
200
250
300
350
400
500


Validation period(1999-2008)[SG2]
y = 1.0309x - 3.6706
R² = 0.8577
Modelled Runoff (MCM)
Observed Runoff (MCM)
0
50
100
150
200
250
300
350
400
450
500


Caliberation Period(1985-1996)[UG]
y = 0.9975x + 0.177
R² = 0.854
Modelled Runoff (MCM)
Modelled Runoff (MCM)
0
5
10
15
20
25
30

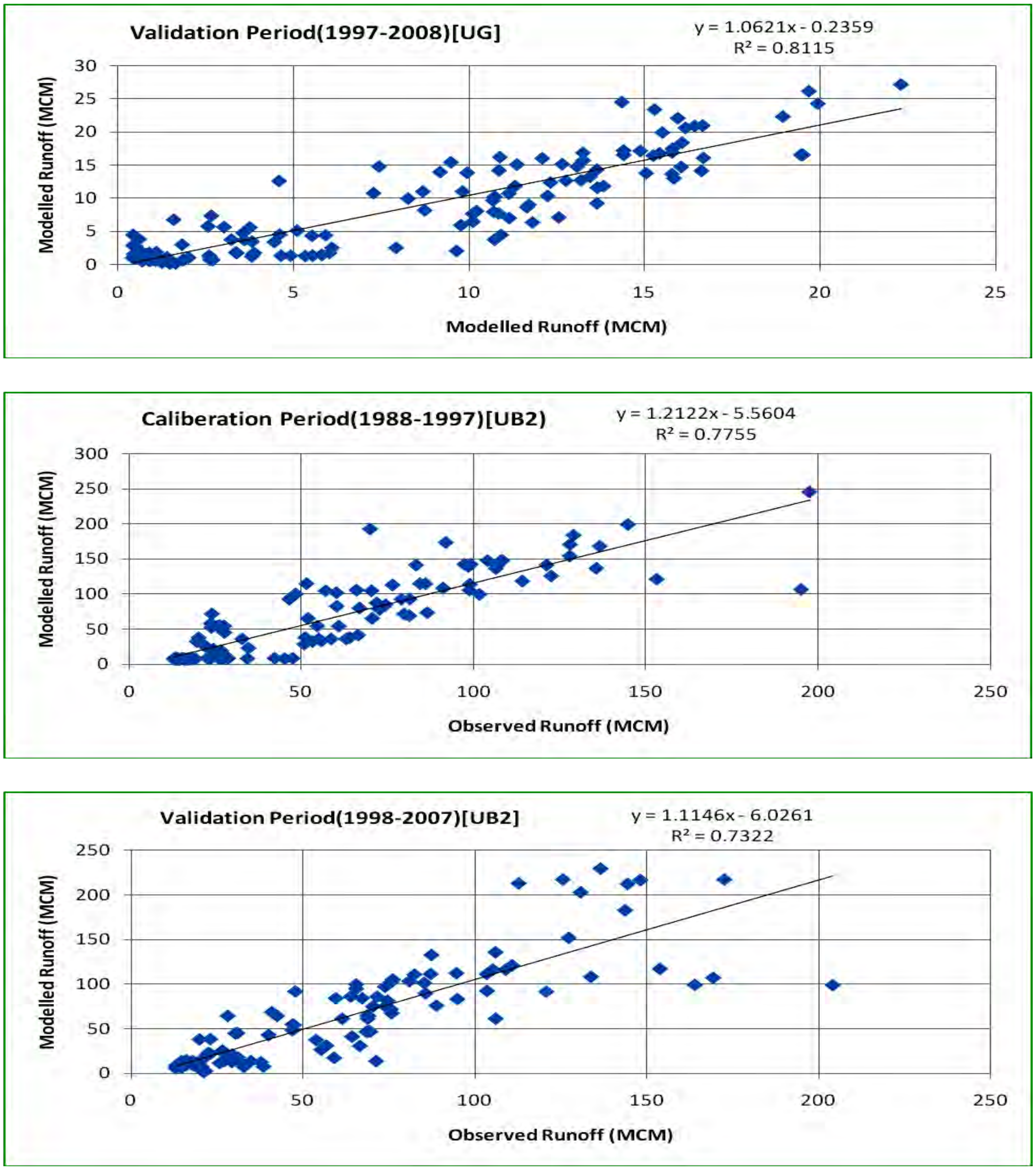


Figure 7.3 Comparison goodness-of-fit criteria of the simulated and observed flow.

7.2 Prediction of WATBAL Model Parameters

Model parameters are found through analysis of monthly runoff. Within the model an automatic optimizing routine can be utilized to calibrate these three parameters. The models use a statistical relationship to reduce the error between the observed and simulated (modeled) runoff. If sunshine hours and relative humidity are available in addition to temperature and the PM box is checked (X) then the model will use Priestly Taylor and these methods calculate average monthly potential evapotranspiration in mm/day and so require monthly input data. This component of the model cannot be run with daily data. Data from outside the model are entered from a worksheet via the PET space in the Dialog box. This functionality is made available by pressing the ―PET" button at the bottom of the initial Caliber/Valid Dialog box. Figure 7.4 shows the additional Dialog box that opens when the PET button is pressed.

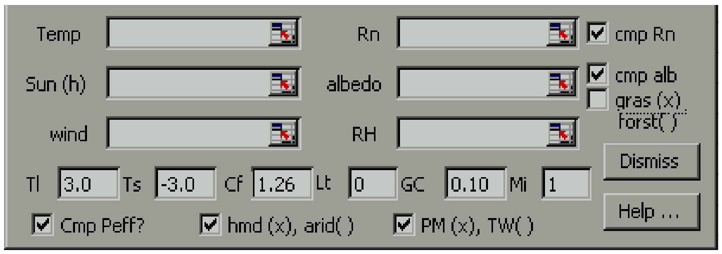


Figure 7.4 The PET component of the WATBAL Caliber/Valid Dialog box.

7.3 The View Output Option

This component is only utilized once the model has been run and results are available. It allows the user to select a wider range of outputs rather than just the observed and simulated runoff that can be output directly from the calibre/valid Dialog box. The user is required to identify which variables to display and the location on the spreadsheet where the output will begin to be printed.

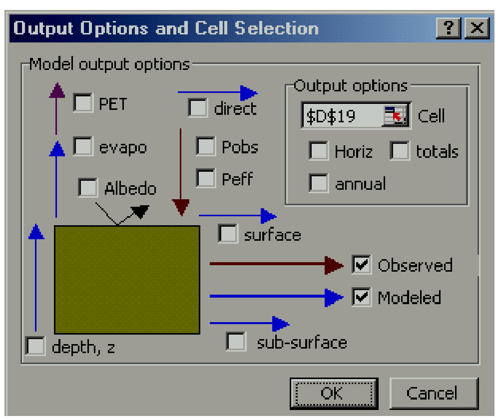


Figure 7.5 The Outputs Dialog box accessed via the View Results option of the Runoff menu.

7.4 Sensitivity of model parameters

To get a clear understanding of the model behavior with respect to the model outcome (i.e. model hydrograph) a sensitivity analysis is performed. Each of the six model parameters contribute to conceptualizing the rainfall-runoff processes which all together result in simulating the hydrograph. But every parameter does not contribute equal amount of change to the hydrograph. When trying to establish relationships between model parameters and

Physical catchment characteristics, it is most effective to investigate the most sensitive model parameters. Furthermore, it is useful to understand the influence of change in model parameter values on the hydrograph when evaluating the relationships. These parameters are analyzed on a model run of the output value.

It is generally obvious in WatBal model process that Smax is the most sensitive model parameter and it varies non-linearly with respect to the coefficient of efficiency, R^2; Relative Volume Error and Coefficient of Determination, r^2.The second sensitive parameter is epsilon which also varies non-linearly. Alpha varies linearly and is the third sensitive parameter while the rest model parameters are less sensitive. In the regionalization process the first three most sensitive parameters are selected for this study.

By considering the final third iterations of the sub-catchments for the time step (T.S.) equal 1, and taking Predictor corrector error tolerance (pc err) as 0.01, and the Sub-surface runoff coefficient (ssrc), γ is normally set at a value of 2; it is possible to analyze the sensitivity of model parameters. Hence, followings are tables with their respective figures (Figure 7.6) for model runs of the randomly selected Gilo, Geba and Getcha sub-catchments, and all illustrate the sensitivities of the model parameters.

Gilo	Smax	Epsilon	Alpha	Zi	Base flow	DRC
Input	870	0.88	0.01	0.10	0.06	0.05
Output	4967	0.08	13.46	0.10	0.06	0.05

Geba	Smax	Epsilon	Alpha	Zi	Base flow	DRC
Input	1000	4.00	0.14	0.85	0.01	0.75
Output	1641	2.91	0.04	0.85	0.01	0.75

Getcha	Smax	Epsilon	Alpha	Zi	Base flow	DRC
Input	400	0.08	0.8	0.25	0.03	0.67
Output	591	0.26	20.49	0.25	0.03	0.67

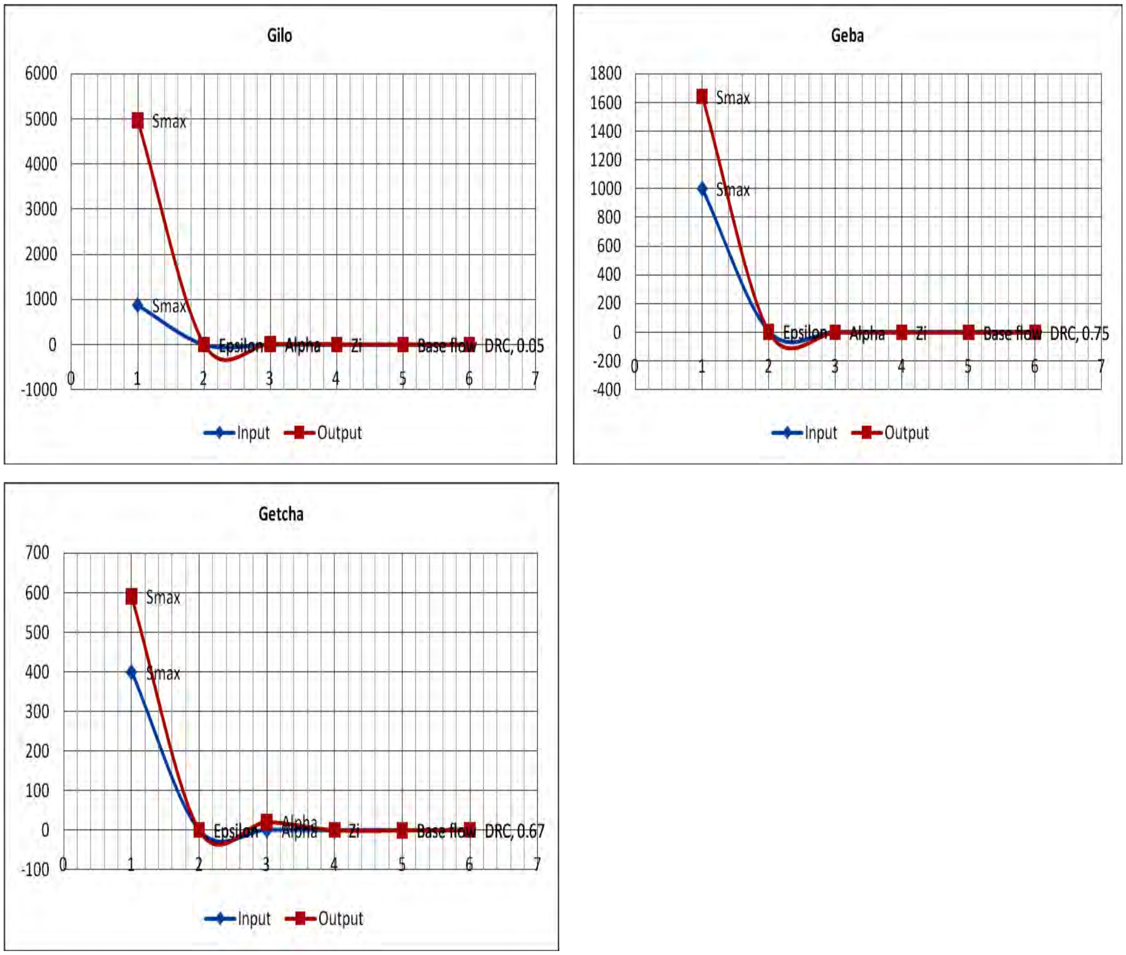


Figure 7.6 Sensitivity analyses for model parameters of Gilo, Geba and Getcha sub-catchments.

Table showing WATBAL Model parameters fixed for all model runs.

TS =30.4 day/month	Hmd checked
Lt. = 8 N (positive)	gras checked
Mi = 1	cmp alb checked
GC =0.2	cmp Rn checked
Cf = 1.74	Cmp peff not checked
Cf = 1.26 for Gilo, Alwero and Masha	PM checked

Table 7.1.a: Calibrated model parameter values.

Parameter	Getcha	Gilo	Birbir	Gumero	Keto	Geba	Sori	Uka	Alwero	Mesha	Pokwo
Area(km2)	97	2437	2563	106	1006	1894	1622	52.5	2800	1653	978
Smax (mm)	591	4967	203	1826	1554	1641	612	303	3025	1835	138
Alfa, α (mm/day)	20.50	13.46	0.92	1.65	1.35	0.04	0.49	5.08	0.55	0.004	0.71

Epsilon, ε	0.26	0.08	1.00	1.29	0.54	2.91	0.31	0.93	0.40	0.33	1.35
SSRC, Gamma., γ	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.99	2.00
Beta., β	0.67	0.05	0.10	0.001	0.01	0.75	0.50	0.10	0.83	0.26	0.10
Base flow (mm/day)	0.03	0.06	0.67	0.06	0.01	0.01	0.01	0.50	0.08	0.001	0.06
Zi	0.25	0.10	0.50	0.56	0.55	0.85	0.95	0.50	0.01	0.01	0.98
Latitude (deg, N)	7.02	7.62	8.95	8.15	8.30	7.02	8.35	8.17	7.76	7.63	8.24

Table7.1.b: Model efficiencies in calibration and validation periods.

Parameter	Period	Getcha	Gilo	Birbir	Gumero	Keto	Geba	Sori	Uka	Alwero	Mesha	Pokwo
R^2	Calibration	0.85	0.81	0.85	0.73	0.74	0.91	0.85	0.75	0.87	0.27	0.65
r^2	Calibration	0.92	0.89	0.91	0.84	0.87	0.92	0.91	0.84	0.93	0.49	0.77
E	Calibration	0.84	0.71	0.37	0.72	0.71	0.38	0.69	0.94	0.38	1.10	0.27
R^2	Validation	0.81	0.88	0.81	0.74	0.72	0.91	0.86	0.80	0.88	0.55	0.65
r^2	Validation	0.89	0.92	0.91	0.78	0.98	0.95	0.92	0.86	0.94	0.85	0.80
E	Validation	0.98	0.60	0.44	0.68	0.67	0.38	0.61	0.82	0.34	0.74	0.29

R^2 = Coefficient of Efficiency, r^2 = Coefficient of Determination, E = Average error (mm/day).

7.5 Process of regionalization

All rainfall-runoff models currently in use merely are approximations of real world hydrological processes taking place at the catchment scale and none of them are able to completely describe these actual processes, which is also the case for the WATBAL model. However, in order to simulate the rainfall-runoff transformation processes, values for WATBAL model parameters have to be defined in some way. Since for the WATBAL model it is not possible to directly determine the model parameter values, these values are normally estimated through a model calibration process by trying to fit the model output with observed discharge data (Hundecha, 2004). However, not at every catchment well observed discharge data are available. Calibration of the model is therefore difficult and prediction of discharge regimes must be associated with some degree of uncertainty. Regionalization technique could be applied to reduce the parameter uncertainty in predicting discharge regimes in ungauged catchments. Several definitions of regionalization are used in the literature, but a generic definition as stated in Bloschl and Sivapalan (1995) is used most often. Regionalization is the process of transferring information from comparable catchments to the catchment of interest.

7.5.1 Approaches of regionalization

The choice of catchments from which information is transferred is usually based on some sort of similarity. A number of methods have been applied to modeling ungauged basins such as similarity of spatial proximity and similarity of catchment characteristics (Deckers D, 2006).

While catchments for which flow time series are to be estimated may not have comparable gauged catchments thus prohibiting extrapolation using similarity of spatial proximity. Hence, the approach of regionalization using similarity of catchment characteristics is applied to estimate the flow of ungauged catchments; earliest; the WATBAL model was calibrated against the observed discharge to determine well performing parameter sets of gauged catchments. Next, a relationship will be made between the model parameters and physical catchment characteristics to establish the regional model that serves to estimate model parameters for ungauged catchments. This will be done by developing regression equations, which is the most commonly used method, which predicts the model parameter values using one or a combination of physical catchment characteristics. Commonly for each model parameter a separate equation is derived. Then the WATBAL model will be used to simulate the discharges for ungauged catchments.

7.5.2 Developing the Regional Equation

A set of generalized equations can be developed from watershed characteristics and their rainfall-runoff models‘ parameters for the construction of regional equation. The equations relate three parameters of the rainfall- runoff to other measurable watershed and channel characteristics. The general form of the equations is;

$$S_{max} = aA^{b}P^{c}PET^{d}S^{e} \quad (7.11a)$$

$$\alpha = fA^{g}P^{h}PET^{i}S^{j} \quad (7.11b)$$

$$\varepsilon = kA^{l}P^{m}PET^{n}S^{o} \quad (7.11c)$$

Where,

Smax = maximum water holding capacity of a catchments (mm)

α = Sub-surface runoff coefficients (mm/day)

ε = surface runoff coefficients (unitless)

A = Watershed drainage area (km^2)

P = effective precipitation (mm)

PET = Potential evapotranspiration (mm)

S = slope (%)

And a, b, c, d… up to o are coefficients to be derived by regression techniques.

Finally, the set of available parameters upon which the multiple linear regressions is to be conducted is provided in Table 7.2.

Table 7.2 Parameters for multiple linear regressions.

river	Area (km2)	P (mm)	PET(mm)	Slope (%)	Smax(mm)	α(mm/day)	ε
Getcha	97	1131.55	1871.20	17.00	591	20.50	0.26
Gilo	2437	890.84	1515.98	8.70	4967	13.46	0.08
Birbir	2563	1513.98	1479.08	3.41	203	0.92	1.00
Gumero	106	1688.75	1583.82	28.37	1826	1.65	1.29
Keto	1006	878.38	1529.15	11.00	1554	1.35	0.54
Geba	1894	914.73	1542.60	7.10	1641	0.04	2.91
Sori	1622	968.97	1622.56	3.01	612	0.49	0.31
Uka	52.5	2198.52	1659.18	14.20	303	5.08	0.93
Alwero	2800	824.81	1357.07	6.80	3025	0.55	0.40
Mesha	1653	1242.69	941.39	6.00	1835	0.004	0.33
Pokwo	978	743.86	1547.46	5.10	138	0.71	1.35

From relations in equation 7.12 to 7.14 we observe that the numbers of independent parameters are four while the number of observations of the dependent variable in our case is fifteen. According to Haan (1977), the number of observations should be more than 3 to 4 times the number of independent parameters. Hence the data we have is well within this recommendation, and can proceed in the regression analyses.

The multiple linear regressions are carried out using available software in Microsoft EXEL, tool library use solver. The technique requires target cell which formula cell and the software solve the equation by changing the dependent variables of the data, read-in parameter and right run the program.

The set of regional equations developed using multiple linear regression technique is:

$$S_{max} = 0.218A^{0.777}P^{0.228}PET^{-0.001}S^{0.972}, R_2 = 0.7449 \quad (7.12)$$

$$\alpha = 3.39E\text{-}11A^{-0.057}P^{1.164}PET^{2.069}S^{1.274}, R_2 = 0.6969 \quad (7.13)$$

$$\varepsilon = 0.002A^{-0.009}P^{0.194}PET^{-0.04}S^{1.425}, R_2 = 0.7063 \quad (7.14)$$

These equations contain four Physical catchment characteristics and their exponents indicate that, Smax increases with increasing A, and S but decreases with increasing in P, and PET. Alpha increases with increasing in P, and PET, and decreases with increasing A. The last parameter epsilon increases with increasing in P, and S but decreases with increasing in A, and PET. These equations together with table 7.1.a, that is the model parameter, form regional rainfall runoff model of the upper Baro-Akobo Basin.

Appendix F shows data used for regional equation and the regression results answer. The observed and predicted values of each model parameters are also attached in this appendix.

7.6 Verification of regional model

Since the purpose of regionalization is to estimate model parameters of ungauged catchments the performance of the regional model should be assessed by comparing the predicted and observed responses from gauged catchments, (Deckers D, 2006). In this study validation of the regional model is done using a ten year validation period of simulated ungauged catchments.

The established regional model was used to estimate the model parameters of ungauged catchment using their Physical catchment characteristics, by taking one gauged catchment of the sub basin and considering the other as ungauged. Then the discharge was simulated based on the estimated parameter and the model performance with respect to R^2, E and r^2 was evaluated, (Bogale T. 2011). Table 7.3, shows the parameters derived from the regional model and the model performances and it indicates that the model performs reasonably with respect to E, R^2 and r^2.

Table 7.3 Validation of the regional model of ungauged catchments

Gauged Sub-Catchment	Ungauged Sub-Catchment	E(Relative Volume Error)	R^2 (Coefficient of Efficiency)	r^2 (Coefficient of determination)
Birbir	Keto	0.519	0.744	0.910
Keto	Birbir	0.965	0.463	0.854
Alwero	Gilo	0.582	0.859	0.825
Alwero	Poko	0.549	0.769	0.831
Gilo	Alwero	0.565	0.867	0.924
Sori	Geba	0.772	0.811	0.917
Sori	Gumero	0.841	0.781	0.915
Sori	Uka	0.635	0.854	0.917
Geba	Sori	0.924	0.998	0.992
Getcha	Mesha	1.071	0.759	0.862
Getcha	Getcha	0.989	0.807	0.893

Getcha: validated using the predicted Smax, α and ε obtained from the regression equation.

CHAPTER EIGHT

8 Conclusion and Recommendation

8.1 Conclusion

In this research, attempt has been made to determine model parameters required to estimate monthly flow for ungauged watersheds in Baro-Akobo basin. Besides, efforts are also made to develop regional model which would enable us to relate some of the parameters to basin characteristics using regression analysis.

Thus, based on the applied methodology and results obtained, the following conclusions are drawn:

- The WatBal model combined with the Priestly-Taylor for climate impact assessment on river basins reveals the insensitivity of the basin to the existing precipitation changes, where precipitation was almost fairly uniform, and it behaves fairly well given its simplicity.
- During model calibration and validation period of the sub-catchments, except for Baro-Mesha, and Baro-Poko rivers whose coefficient of efficiencies are 0.25 and 0.65 respectively, the model efficiencies are reliable for 80% of the total selected sub-catchment considered in the study
- The failure of some of the sub-catchments is expected to be due to quality of hydrometrological and physiographic data in addition to equifinality problem.
- The sensitivity analysis of the model parameters indicates that maximum water holding capacity (Smax), sub-surface runoff parameter (α) and surface runoff parameter (ϵ) are the most sensitive parameters.
- The developed regional equations with values of R2 equal to 0.74, 0.70, and 0.71 show the strength and overall significance of the regression equations.
- The validation of regional equation indicates the model performs reasonably with respect to E (Relative Volume error) and R^2 (Coefficient of Efficiency).

In conclusion, the WATBAL model is found to be satisfactory for estimation monthly flow of ungauged catchments.

8.2 Recommendation

The following recommendations are made on the basis of the foregoing conclusion and discussion:

- One must take close observation to the similarity of the watershed to those used in the research work. As this research has been conducted on watershed sizes ranging from 52.5km^2 to 2800km^2, it is also recommended that the model be used within this range.
- Proper care should be taken when selecting maximum water holding capacity (Smax), sub-surface runoff parameter (α) and surface runoff parameter (ϵ), as the sensitivity analysis of the model parameters indicates that these are the most sensitive parameters.
- In order to determine which aspect of the hydrograph the WATBAL model has difficulty with in appropriately simulating, it is recommended to calibrate the WATBAL model separately.
- The strong seasonal variation in runoff in all the basins points to a possible need for seasonal parameters within WatBal. In addition, empirically based methods of PET can be very misleading when performing climate change studies in river basins (Yates & Strzepek, 1994). Therefore, it is better to do the climate impact assessment using more advanced models.
- A study of more advanced automatic model calibration techniques could be useful.
- The results of this study can be used for the regional water allocation and planning purposes. As the derived parameters can be used to generate flow at ungauged catchments, it may also be used to assessment potential water development and planning of water projects at sub basin level.

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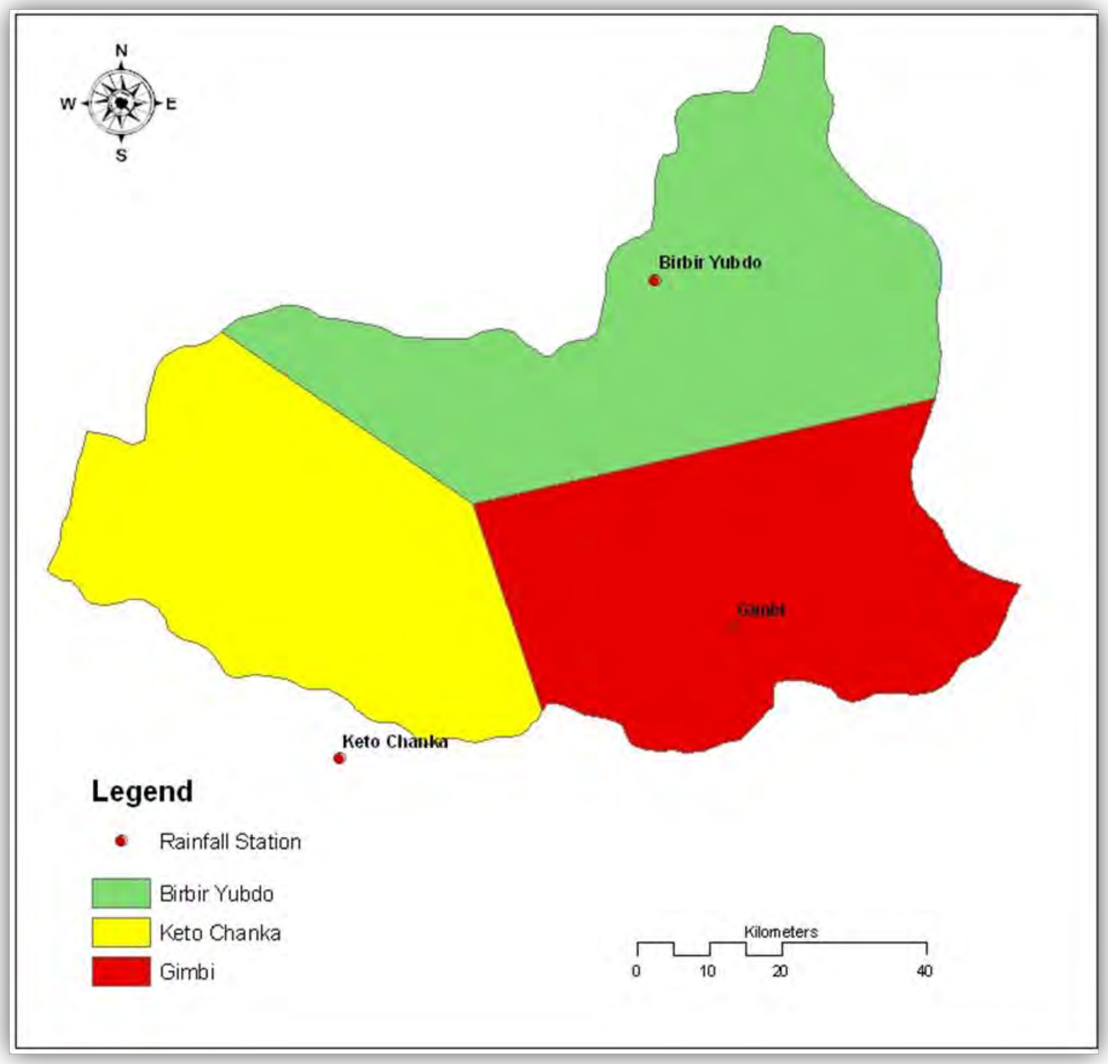
Appendices

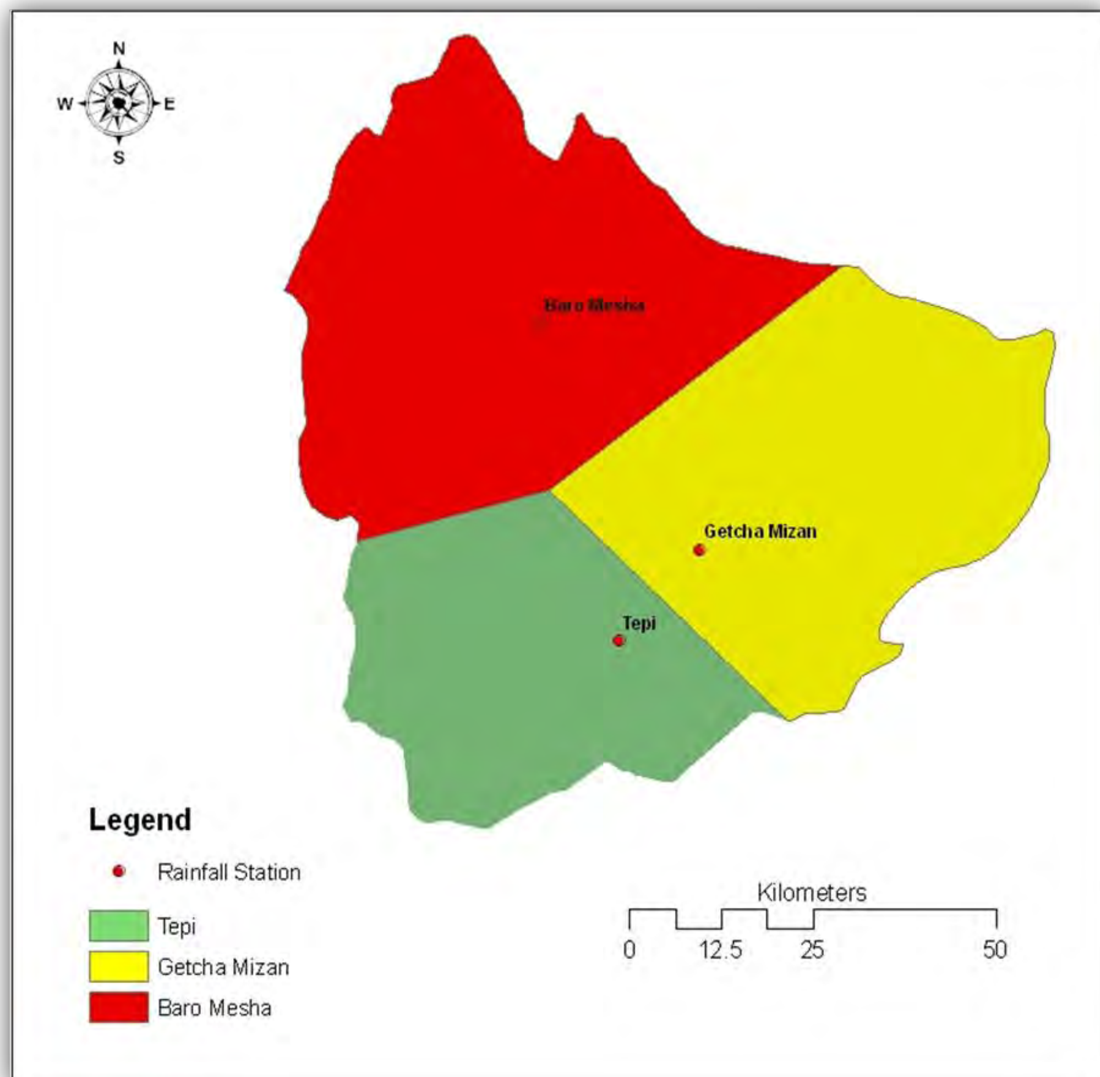
APPENDIX A

Thiessen Polygon Developed for Selected Sub-Catchments

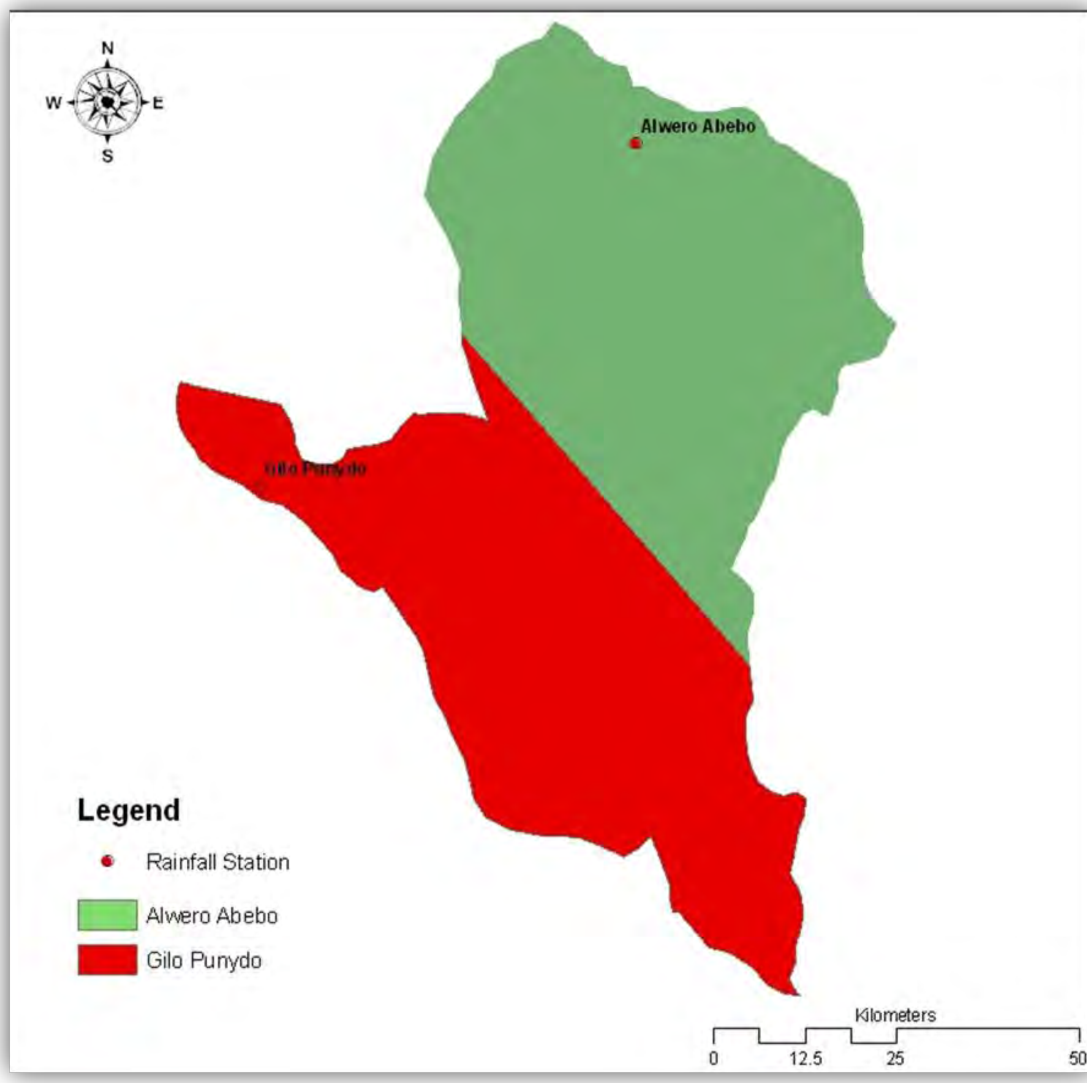
Upper Birbir Sub-Catchment			
ID	**Station Name**	**Area Weight (km2)**	**Thiessen weight (%)**
1.	Birbir Yubdo	2684	37.36
2.	Keto Chanka	2195	30.55
3.	Gimbi	2306	32.09



Upper Gilo Sub-Catchment			
ID	**Station Name**	**Area Weight (km2)**	**Thiessen weight (%)**
1.	Baro Mesha	2726	40.83
2.	Tepi	1675	24.76
3.	Getcha Mizan	2327	34.41

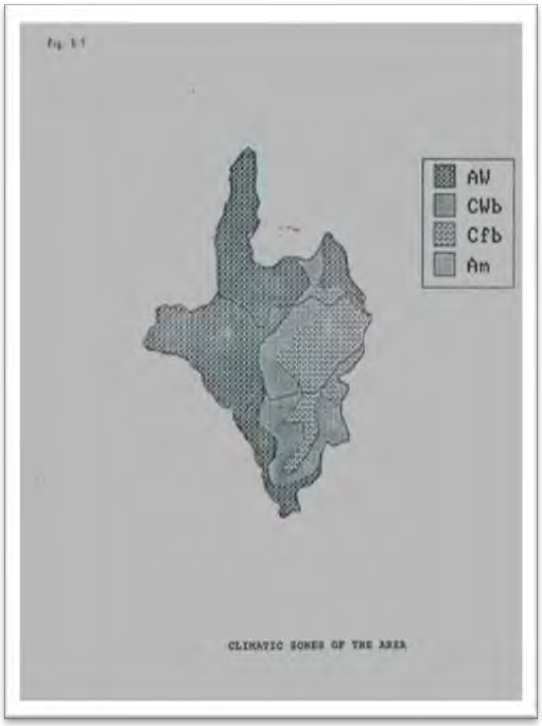


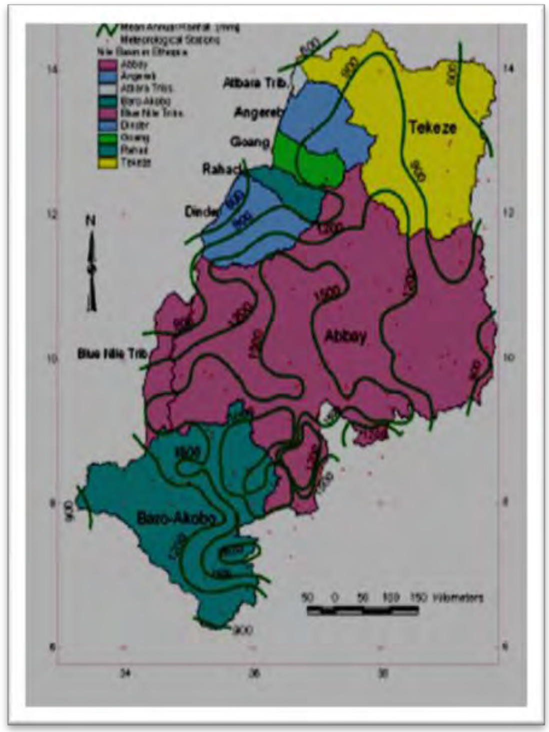
Upper Alewro & Middle Gilo Sub-Catchment			
ID	**Station Name**	**Area Weight (km2)**	**Thiessen weight (%)**
1.	Alwero Abebo	2893	50.22
2.	Gilo punydo	2868	49.78



APPENDIX B

Climatic Zones of the Baro-Akobo basin. With AW (Tropical savanna), AM (Tropical rainy climate), CwB(warm temperate rainy climate) and CfB(Rainy humid Temperature). (ARDCO-GEOSERV) and Rainfall Distributions of the Baro-Akobo Basin in relation to Abbay & Tekeze Basins (Source: The Nile Basin Development Forum [NBDF] 2006).





APPENDIX C

Selected Catchments with Data Availability Years

Code	St. Name	River	Lat. (°N)	Long. (°E)	Area (Km2)	Data Available (Yrs)
UB1	Birbir	Nr. Yubdo	8.95	35.48	2563.0	20
UB2	Keto	Nr. Chanka	8.78	35.05	1006.0	20
SG1	Geba	Nr. Sopi	8.48	35.65	1894.0	20
SG2	Sori	Nr. Metu	8.32	35.60	1622.0	20
SG3	Gumero	Nr. Gori	8.15	35.48	106.0	20
SG4	Uka	@ Uka	8.17	35.37	52.5	20
UB	Baro M.	Nr. Masha	7.63	35.56	1653.0	20
UG	Getcha	Nr. M. Teferi	7.02	35.55	97.0	24
UA	Alwero	Nr.Dumbong	7.76	34.67	2800.0	20
MG	Gilo	Nr.Pugndo	7.62	34.27	2437.0	20
Lb	Baro P.	Nr. Pokwo	8.24	34.43	978.0	20

APPENDIX D

Prepared Input Data for WATBAL model (Stream flow, Rainfall, Temperature, Sunshine Hrs and Relative Humidity)

RIVER SUB-BASIN: Upper Birbir

STATION NAME: Birbir R. Nr. Yubdo (BA1002)

Latitude: 8:57: 0 N   Longitude: 35: 48: 0 E   Elevation: 1543.0 m   Area: 1563.0 Km^2

RUNOFF (mm/day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1988	0.90	0.93	1.05	1.53	2.13	3.24	4.14	4.74	3.69	2.61	1.59	0.99
1989	0.96	0.99	1.05	1.26	2.43	3.51	3.93	4.05	4.08	3.03	2.13	1.08
1990	1.05	1.02	1.08	1.11	1.23	2.55	3.30	3.63	3.30	2.49	1.50	1.08
1991	1.05	1.26	1.29	1.44	2.43	3.27	5.80	4.53	3.69	2.61	1.65	1.05
1992	1.05	1.14	1.26	1.35	1.68	3.03	4.23	5.43	4.29	3.27	1.89	1.10
1993	1.08	1.20	1.23	1.35	1.83	2.61	3.18	3.69	4.08	3.42	2.28	1.10
1994	1.05	1.11	1.11	1.17	2.16	2.94	3.57	4.17	4.56	3.93	2.61	1.08
1995	1.07	0.96	0.98	1.25	1.41	2.55	3.75	4.89	4.17	3.63	0.99	1.21
1996	1.05	0.98	1.01	1.38	1.53	3.03	3.78	4.14	5.50	3.45	1.56	1.15
1997	1.06	0.99	1.02	1.26	1.32	2.79	3.90	4.86	3.93	3.75	2.19	1.68
1998	1.11	1.17	1.23	1.83	2.64	3.54	4.32	5.10	4.20	3.00	1.68	1.17
1999	1.23	1.32	1.50	1.32	1.74	3.36	3.39	3.90	4.89	3.21	1.65	1.14
2000	1.11	1.17	1.20	1.38	2.58	3.45	4.89	6.54	4.68	3.57	2.04	1.26
2001	1.14	1.17	1.23	1.32	1.65	3.06	5.19	3.33	4.23	3.87	2.37	1.38
2002	1.14	1.20	1.23	1.29	1.50	3.09	2.88	4.83	4.80	3.57	1.83	1.23
2003	1.14	1.17	1.20	1.23	1.89	2.61	3.45	4.11	4.47	3.51	1.56	1.20
2004	1.11	1.29	1.23	1.17	1.38	3.45	4.23	4.53	6.81	3.60	2.16	1.32
2005	1.17	1.14	1.20	1.29	2.22	3.03	3.84	4.89	5.73	3.84	2.40	1.35
2006	1.11	1.05	1.11	1.29	1.71	2.49	3.21	3.81	4.44	3.33	2.22	1.38
2007	1.14	1.08	1.08	1.14	1.29	2.22	2.79	3.03	4.98	3.75	2.64	0.93

PRECIPITATION (mm /day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1988	1.60	1.61	1.23	2.97	4.68	6.15	9.03	8.67	3.72	3.75	1.74	1.05
1989	1.57	1.58	1.76	2.13	4.62	6.63	7.23	8.04	8.61	5.52	1.74	1.11
1990	1.15	1.61	1.82	2.41	3.03	6.09	6.03	6.06	5.67	4.77	1.78	1.06
1991	1.17	1.57	2.11	2.85	4.35	6.21	11.28	8.55	5.67	4.05	2.22	1.03
1992	1.56	1.71	1.86	2.25	3.75	6.21	7.47	9.21	9.48	5.61	2.13	1.06
1993	1.68	1.62	2.05	2.49	3.45	6.15	7.23	8.25	8.28	4.89	2.45	1.05

1994	1.45	1.41	1.89	1.74	6.27	7.38	7.53	8.97	8.64	4.17	0.66	1.08
1995	1.65	2.07	2.64	2.43	5.91	6.81	9.30	9.36	6.30	5.46	1.29	1.07
1996	1.51	1.26	1.77	2.25	3.33	6.24	7.23	9.48	10.05	4.17	2.04	1.10
1997	0.93	1.47	1.68	2.52	5.46	5.97	10.05	8.19	6.63	5.55	1.47	1.02
1998	1.17	1.47	1.68	3.03	3.75	6.03	9.33	9.75	8.94	5.25	2.73	1.02
1999	1.05	1.44	1.92	2.07	5.01	7.59	7.77	8.19	7.29	5.73	1.44	1.05
2000	1.05	1.35	1.83	2.13	4.05	7.65	11.94	10.77	11.85	4.17	1.35	1.04
2001	0.99	1.53	2.04	2.19	3.63	5.97	12.03	8.97	9.69	6.45	1.92	0.21
2002	1.08	1.53	1.89	2.46	5.01	6.30	4.68	9.33	8.97	5.85	2.07	1.06
2003	1.47	1.59	1.95	2.37	3.03	6.00	7.17	8.43	8.31	4.83	1.47	1.05
2004	1.36	1.53	1.83	1.83	6.30	7.17	9.33	9.03	19.05	3.66	0.90	0.93
2005	1.02	1.29	1.92	2.16	6.03	6.90	8.94	9.66	13.83	5.43	1.32	1.17
2006	1.02	1.65	1.89	2.49	4.74	5.61	6.03	9.24	7.83	3.99	2.13	1.05
2007	1.05	1.83	2.13	2.22	4.68	5.64	6.33	7.65	11.01	4.47	1.38	1.05

TEMPERATURE (^{O}C)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1988	19.33	20.15	21.15	21.07	20.23	19.30	18.50	19.75	19.71	20.20	18.80	18.80
1989	18.79	20.45	21.33	20.90	20.05	20.21	19.25	19.40	19.18	18.89	19.07	19.03
1990	20.34	20.56	21.78	21.54	20.80	19.76	19.52	19.65	20.19	20.04	19.54	18.55
1991	21.20	19.57	21.53	21.80	21.25	19.57	19.34	19.56	19.69	20.32	19.94	18.75
1992	21.03	20.24	20.56	20.96	20.72	20.05	19.03	20.65	20.05	19.09	19.75	19.57
1993	21.03	19.57	19.58	20.07	17.27	21.01	18.84	20.62	19.27	19.52	18.74	19.92
1994	19.07	20.06	20.01	21.65	21.06	18.56	18.32	21.65	19.05	18.96	19.01	19.02
1995	19.88	19.94	21.05	19.87	20.45	19.00	19.16	18.56	18.77	19.22	19.23	18.78
1996	17.78	20.64	19.08	21.09	18.21	19.80	19.35	18.88	19.30	18.79	19.01	18.64
1997	18.68	20.08	20.56	20.06	18.72	18.67	19.53	19.06	19.02	17.57	18.65	17.02
1998	21.05	19.76	20.78	20.56	19.05	20.02	18.78	19.02	18.78	18.59	16.87	18.00
1999	20.01	20.04	19.67	21.19	19.67	19.51	19.63	20.23	17.89	19.35	19.47	18.56
2000	19.60	19.77	20.38	21.18	20.53	18.65	18.68	18.76	20.54	20.23	18.85	19.02
2001	19.05	19.90	20.46	20.80	20.95	19.40	19.01	18.85	18.56	18.79	19.78	17.47
2002	19.70	19.95	20.05	20.70	17.35	17.35	19.57	19.63	19.04	19.45	18.58	19.34
2003	17.95	19.35	19.65	20.65	19.20	18.20	18.47	20.01	17.75	18.88	17.48	18.76
2004	18.57	19.87	21.93	21.50	21.15	19.87	19.63	18.04	18.35	17.50	19.34	19.34
2005	19.00	19.35	20.75	21.85	20.60	20.03	18.85	19.20	19.80	18.80	18.55	18.55
2006	19.98	20.05	21.34	20.30	21.05	19.75	16.45	17.60	17.75	17.40	16.80	17.40

2007	19.87	20.56	22.32	21.80	20.70	19.65	17.30	17.15	17.16	17.95	19.20	19.20

RELATIVE HUMIDITY (%)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.42	0.6	0.48	0.38	0.61	0.73	0.71	0.72	0.73	0.73	0.65	0.74

SUNSHINE HOURS (Hrs)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	6.58	5.58	7.25	5.24	5.45	4.56	3.17	4.82	3.35	5.32	4.01	2.59

Station Name: Keto R. Nr. Chanka
Station Number: BA1005
RUNOFF (mm/day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1988	0.26	0.24	0.24	0.27	1.17	2.34	3.54	5.04	3.87	2.13	1.23	0.36
1889	0.24	0.23	0.23	0.25	1.23	2.40	3.25	3.45	3.48	6.30	0.75	0.45
1990	0.27	0.22	0.23	0.26	1.08	3.03	6.51	5.58	4.83	2.70	1.17	0.63
1991	0.24	0.23	0.23	0.25	1.35	2.76	6.01	4.46	4.83	3.42	1.47	0.54
1992	0.27	0.22	0.23	0.27	1.17	2.55	3.75	4.83	4.59	3.45	1.77	0.63
1993	0.29	0.23	0.24	0.26	1.05	2.13	3.03	5.67	3.96	3.42	1.77	0.84
1994	0.27	0.22	0.23	0.28	1.17	2.25	4.11	4.65	4.62	3.27	1.80	0.69
1995	0.28	0.24	0.24	0.27	1.77	2.70	3.72	4.65	5.50	3.33	1.89	1.23
1996	0.24	0.23	0.23	0.26	0.93	2.61	3.69	4.56	8.03	3.03	1.71	0.84
1997	0.27	0.22	0.23	0.27	1.77	2.85	3.75	4.62	4.47	3.75	2.34	1.05
1998	0.09	0.06	0.06	0.66	1.53	2.73	6.96	3.00	3.81	1.53	0.45	0.24
1999	0.24	0.24	0.27	0.62	2.01	2.35	7.12	3.25	3.24	2.01	0.59	0.55
2000	0.45	0.39	0.25	0.25	1.01	3.45	3.97	6.65	3.32	2.12	1.47	0.84
2001	0.27	0.30	0.30	0.41	0.57	3.36	3.68	3.81	7.12	3.18	1.48	0.69
2002	0.41	0.35	0.39	0.45	1.56	3.39	3.51	6.98	3.55	2.46	1.41	0.81
2003	0.45	0.36	0.41	0.38	1.35	2.21	2.49	3.65	5.99	3.11	2.11	0.69
2004	0.30	0.32	0.36	0.42	1.23	2.11	3.03	3.65	7.52	3.27	1.78	0.72
2005	0.48	0.45	0.41	0.41	1.02	2.82	2.01	4.45	4.35	2.76	1.59	0.75
2006	0.43	0.29	0.29	0.45	0.87	2.67	2.46	3.63	4.98	2.82	2.25	1.25
2007	0.33	0.19	0.21	0.25	1.80	2.76	2.94	3.84	7.10	3.01	2.11	1.26

PRECIPITATION (mm /day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1988	0.38	0.34	0.36	1.72	2.43	3.20	3.72	5.40	4.78	1.95	1.92	0.77

1889	0.47	0.42	0.43	0.86	2.56	3.61	4.32	4.19	8.67	2.86	1.22	0.89
1990	0.45	0.38	0.42	0.84	2.25	3.35	6.46	5.67	4.75	2.48	1.18	0.76
1991	0.43	0.40	0.41	1.80	2.83	3.22	5.85	4.77	4.85	3.04	0.98	0.88
1992	0.39	0.37	0.37	1.72	2.35	3.22	3.88	4.77	4.91	2.91	1.02	0.98
1993	0.56	0.41	0.46	0.85	2.33	3.20	3.75	4.28	7.35	2.54	0.96	0.79
1994	0.39	0.40	0.44	0.84	2.67	3.83	5.93	4.65	5.87	2.16	1.04	0.95
1995	0.38	0.42	0.42	1.06	2.53	3.54	4.83	4.85	6.79	2.83	0.94	0.76
1996	0.42	0.39	0.41	1.52	2.39	3.24	3.75	4.91	10.12	2.17	0.98	0.89
1997	0.46	0.44	0.50	1.26	2.98	3.57	4.25	4.19	6.99	2.49	1.02	0.79
1998	0.41	0.39	0.40	0.44	2.56	3.77	6.03	4.96	4.43	2.64	1.06	0.97
1999	0.40	0.39	0.41	0.84	2.67	2.99	5.32	7.11	8.98	2.35	0.94	0.87
2000	0.44	0.40	0.41	1.32	2.65	3.11	4.76	5.71	3.56	2.78	0.96	0.79
2001	0.45	0.39	0.48	1.06	2.38	3.19	4.11	4.63	7.89	3.12	1.04	0.98
2002	0.43	0.43	0.41	0.88	2.95	3.54	7.89	5.11	6.15	3.21	1.54	0.87
2003	0.45	0.38	0.52	0.86	2.79	3.37	4.03	3.95	6.79	2.87	1.72	0.98
2004	0.39	0.35	0.42	1.08	2.33	3.11	4.87	4.87	6.56	2.94	2.02	0.78
2005	0.43	0.36	0.39	1.56	2.55	3.32	5.11	5.11	4.15	2.71	2.06	0.79
2006	0.46	0.31	0.41	3.37	2.54	3.56	3.34	3.98	6.35	3.01	1.80	0.69
2007	0.41	0.33	0.42	0.44	2.16	3.25	4.24	7.89	7.58	2.21	1.16	0.89

TEMPERATURE (^{o}C)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1988	21.00	19.57	21.63	22.00	21.25	19.57	19.34	19.56	19.69	20.32	19.94	18.75
1889	21.03	20.14	20.56	20.96	20.72	20.05	19.03	21.65	20.05	19.09	19.75	19.57
1990	19.43	20.15	21.15	21.07	2023	19.30	18.50	18.75	19.71	20.20	18.80	18.80
1991	18.89	20.35	21.33	20.90	20.05	20.21	19.25	19.40	19.18	18.89	19.07	19.03
1992	20.54	20.56	21.78	21.54	20.80	19.76	19.52	19.65	20.10	20.04	19.64	18.55
1993	21.03	19.57	19.58	20.07	17.27	21.01	18.84	20.62	19.27	19.52	18.74	19.92
1994	19.07	20.06	20.01	21.65	21.06	18.56	18.32	21.65	19.05	18.96	19.01	19.02
1995	19.80	19.94	21.05	19.87	20.45	19.00	19.16	18.56	18.77	19.22	19.23	18.78
1996	17.78	20.64	19.08	21.09	18.21	19.80	19.35	18.88	19.30	18.79	19.01	18.64
1997	18.68	20.08	20.56	20.06	18.72	18.67	19.53	19.06	19.02	17.57	18.65	17.02
1998	21.05	19.76	20.78	20.56	19.05	20.02	18.78	19.02	18.78	18.59	16.87	18.00
1999	20.01	20.04	19.67	21.19	19.67	19.51	19.63	20.23	17.89	19.35	19.47	18.56
2000	19.60	19.77	20.38	21.18	20.53	18.65	18.68	18.76	20.54	20.23	18.85	19.02
2001	19.05	19.50	20.46	20.80	20.95	19.40	19.01	18.85	18.56	18.79	19.78	17.47

2002	19.70	19.95	20.05	20.70	17.35	17.35	19.57	19.63	19.04	19.45	18.58	19.34
2003	17.55	19.35	19.65	19.65	19.20	18.20	18.47	20.01	17.75	18.88	17.48	18.76
2004	18.57	19.87	21.53	21.50	21.15	19.87	19.63	18.04	18.35	17.50	19.34	19.34
2005	19.00	19.35	20.75	21.85	20.60	20.03	18.85	19.20	19.80	18.80	18.55	18.55
2006	19.98	20.05	21.34	20.30	21.05	19.75	16.45	17.60	17.75	17.40	16.80	17.40
2007	19.67	20.53	22.32	21.80	20.70	19.65	17.30	17.15	17.16	17.95	19.20	19.20

RELATIVE HUMIDITY (%)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.44	0.61	0.48	0.37	0.61	0.68	0.70	0.72	0.74	0.73	0.78	0.71

SUNSHINE HOURS (Hrs)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	6.98	5.70	8.05	6.20	5.55	4.96	3.18	2.72	3.26	5.22	5.12	6.18

RIVER SUB-BASIN: Upper Gilo
STATION NAME: Getcheb R. Nr. Mizan Teferi (BA2007)
Latitude: 7:02: 0 N Longitude: 35: 55: 0 E Elevation: 1387.0 m Area: 97.0 Km^2
RUNOFF (mm/day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.42	0.48	0.56	1.90	3.30	5.02	5.68	6.67	7.00	5.70	0.65	0.48
1986	0.45	0.45	0.48	0.62	3.50	5.02	6.82	5.88	4.63	3.63	0.62	0.47
1987	0.44	0.45	0.47	0.78	3.36	6.02	8.34	7.41	5.21	3.51	1.66	0.62
1988	0.45	0.44	0.44	0.69	2.70	2.94	5.04	6.42	5.08	2.35	0.64	0.21
1989	0.20	0.20	0.23	0.29	2.15	5.11	4.68	6.99	6.01	3.58	0.66	0.28
1990	0.25	0.22	0.23	0.51	1.52	2.81	4.01	5.36	7.04	4.01	2.51	0.50
1991	0.34	0.26	0.30	0.54	0.70	2.00	4.56	6.25	7.11	4.99	2.25	0.80
1992	0.50	0.38	0.38	0.62	0.82	3.04	4.44	5.78	6.66	5.02	2.51	1.50
1993	0.38	0.34	0.34	0.50	0.82	2.61	4.11	5.21	6.44	4.15	2.99	1.52
1994	0.48	0.36	0.34	0.58	0.74	3.38	4.22	4.38	8.11	4.66	2.35	1.34
1995	0.58	0.26	0.26	0.30	0.56	3.01	5.01	5.00	6.62	3.18	1.74	0.60
1996	0.40	0.30	0.26	0.26	0.76	2.08	4.50	5.00	8.12	4.14	2.35	0.82
1997	0.60	0.52	0.42	0.50	0.70	3.94	5.58	7.58	5.94	3.74	0.86	0.46
1998	0.38	0.26	0.24	0.46	0.86	3.14	4.64	6.76	4.68	4.70	4.28	1.02
1999	0.22	0.26	0.36	1.48	2.42	4.50	5.74	7.94	4.32	2.62	1.26	0.38
2000	0.20	0.06	0.06	0.46	2.16	5.44	9.22	8.88	7.12	4.74	1.28	0.38
2001	0.20	0.10	0.20	0.60	2.20	5.12	8.24	7.10	5.46	3.48	1.62	0.60

2002	0.22	0.30	0.64	1.50	2.38	3.64	5.72	7.00	4.80	2.60	1.54	0.56
2003	0.30	0.22	0.50	1.74	4.02	4.82	5.14	8.32	5.84	2.78	1.18	0.58
2004	0.34	0.18	0.20	0.60	1.52	4.30	5.62	5.70	5.82	5.02	2.30	1.30
2005	0.42	0.40	0.52	1.16	2.74	3.06	4.42	7.50	5.50	5.24	1.96	0.94
2006	0.58	0.20	0.22	0.44	1.28	3.28	4.20	5.00	5.02	3.66	1.90	0.98
2007	0.52	0.50	0.52	0.62	2.02	2.94	4.02	4.86	5.34	3.38	1.92	1.52
2008	0.34	0.32	0.32	0.46	2.70	3.52	5.62	6.24	5.62	3.74	2.50	0.54

PRECIPITATION (mm /day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.06	0.09	0.11	1.92	3.02	3.11	4.62	6.11	5.94	2.42	1.72	0.04
1986	0.04	0.06	0.08	1.22	2.02	4.48	5.36	5.20	4.44	3.56	0.86	0.00
1987	0.08	0.12	0.18	1.18	2.42	4.16	8.02	7.04	5.90	3.08	0.84	0.04
1988	0.06	0.10	0.14	0.98	2.22	3.10	4.16	6.00	5.36	4.01	1.80	0.00
1989	0.08	0.12	0.18	1.02	2.02	3.98	4.62	6.70	5.94	2.42	1.72	0.00
1990	0.12	0.14	0.18	0.96	2.24	4.48	5.36	5.43	8.56	2.31	0.85	0.00
1991	0.08	0.12	0.16	1.04	2.28	4.16	8.02	7.04	7.89	3.08	0.84	0.04
1992	0.04	0.08	0.14	0.94	2.26	4.00	7.26	5.92	8.11	3.78	1.06	0.00
1993	0.06	0.10	0.18	0.98	2.42	4.00	4.82	5.92	6.55	5.01	1.52	0.00
1994	0.12	0.14	0.18	1.02	2.26	3.98	4.66	5.55	8.98	3.16	1.26	0.06
1995	0.10	0.14	0.16	1.06	2.28	4.76	7.36	5.78	5.58	2.68	0.44	0.00
1996	0.04	0.08	0.14	0.94	2.08	4.40	6.00	6.02	9.65	3.52	0.84	0.00
1997	0.08	0.12	0.16	0.96	2.46	4.02	4.66	6.10	4.94	2.70	1.32	0.00
1998	0.06	0.10	0.16	1.04	2.22	4.44	5.28	5.20	5.04	3.10	1.06	0.00
1999	0.04	0.08	0.16	1.54	4.28	4.64	5.56	5.38	4.58	3.68	0.88	0.02
2000	0.06	0.10	0.18	1.72	4.18	4.30	8.30	7.28	6.10	3.18	0.86	0.04
2001	0.02	0.12	0.18	2.02	3.64	4.14	7.52	6.14	6.24	3.90	1.08	0.02
2002	0.06	0.08	0.14	2.06	4.14	4.14	4.98	6.14	6.32	3.74	1.56	0.02
2003	0.04	0.10	0.18	1.80	4.28	4.10	4.82	5.50	5.52	3.26	1.30	0.06
2004	0.02	0.06	0.16	1.16	4.18	4.92	7.62	5.98	5.76	2.78	0.44	0.04
2005	0.06	0.10	0.18	1.62	3.94	4.54	6.20	6.24	4.20	3.64	0.86	0.02
2006	0.04	0.12	0.20	2.00	4.18	4.16	4.82	6.32	5.12	2.78	1.36	0.00
2007	0.04	0.10	0.18	1.22	3.82	4.58	5.46	5.38	5.22	3.20	1.08	0.02
2008	0.02	0.06	0.14	1.76	4.22	4.84	7.76	6.38	5.70	3.38	0.94	0.04

TEMPERATURE (^{O}C)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	22.55	23.55	24.75	23.65	21.90	21.10	20.00	20.05	20.40	21.75	15.60	22.80
1986	22.35	22.95	22.85	21.60	21.15	20.50	19.30	18.90	19.70	20.80	22.05	21.40
1987	22.35	21.65	21.25	22.45	21.45	20.40	20.10	19.90	20.60	22.00	22.40	22.60
1988	22.45	22.65	23.35	21.95	21.95	19.00	20.35	19.67	20.02	20.34	19.67	21.68
1989	21.35	20.86	22.65	21.33	21.54	21.46	20.56	18.79	20.56	20.65	21.11	20.56
1990	20.89	19.99	21.75	19.78	20.35	20.34	21.34	19.98	21.45	21.34	20.97	22.45
1991	20.34	21.04	19.98	19.65	22.02	21.75	20.66	20.35	22.02	21.23	21.37	22.12
1992	21.01	22.01	21.67	20.02	21.65	20.77	21.36	20.38	20.89	20.87	21.63	20.69
1993	22.56	21.96	22.03	20.59	18.68	29.24	20.34	19.88	21.03	21.85	19.78	19.93
1994	22.01	20.87	20.54	21.04	21.00	20.56	19.89	16.89	20.67	22.01	21.65	20.67
1995	21.54	21.03	20.98	21.87	19.85	19.69	19.59	19.89	22.45	19.95	20.62	21.85
1996	20.03	19.78	19.76	21.08	20.45	20.16	19.96	21.14	22.25	20.96	19.98	20.65
1997	18.95	19.65	20.43	20.86	20.58	21.35	20.76	21.01	22.38	21.87	20.77	21.35
1998	19.78	20.02	19.67	19.98	19.98	20.02	20.34	20.96	21.45	22.03	21.67	22.25
1999	21.03	20.89	20.35	21.04	20.15	20.39	19.78	20.87	22.35	19.98	20.86	21.75
2000	20.89	21.04	21.04	21.68	21.02	21.03	18.56	21.33	20.89	19.35	18.87	19.89
2001	21.56	20.87	20.35	21.96	20.68	20.67	20.34	19.68	20.14	20.72	20.56	20.14
2002	22.05	21.08	21.02	20.87	21.85	21.45	17.78	20.65	21.67	21.39	21.87	21.61
2003	23.10	22.03	22.35	22.95	22.05	23.01	21.07	20.12	22.03	20.64	19.96	22.26
2004	18.45	19.15	19.20	17.75	17.65	16.45	17.20	16.60	23.11	21.77	20.87	23.01
2005	20.54	20.56	21.78	21.54	20.80	19.76	19.35	18.88	19.30	18.79	19.01	18.64
2006	21.03	19.57	19.58	20.07	17.27	21.01	19.53	19.06	19.02	17.57	18.65	17.02
2007	19.07	20.06	20.01	21.65	21.06	18.56	18.78	19.02	18.78	18.59	16.87	18.00
2008	19.80	19.94	21.05	19.87	20.45	19.00	19.63	20.23	17.89	19.35	19.47	18.56

RELATIVE HUMIDITY (%)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.61	0.57	0.71	0.68	0.76	0.83	0.79	0.85	0.77	0.82	0.79	0.72

SUNSHINE HOURS (Hrs)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	7.86	4.95	5.35	3.73	5.62	4.54	3.18	5.27	2.48	3.47	5.23	7.84

RIVER - BASIN: BARO
Station Number: BA1010

Station Name: BARO R. NR. MASHA
Latitude: 7:63:0 Latitude   35:56:0 Longitude   Elevation: 2175.0 m   Area: 1653 sq km
RUNOFF (mm/day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	1.88	1.54	1.37	2.78	3.06	3.46	3.96	7.15	8.46	6.40	4.44	1.82
1990	0.09	0.36	0.18	0.42	3.03	3.30	2.55	3.81	3.64	3.65	1.42	0.21
1991	0.14	1.53	2.25	2.26	1.87	3.23	4.27	3.42	2.81	1.94	1.26	0.40
1992	0.18	0.08	0.10	0.80	1.05	2.09	3.65	4.36	3.24	1.85	0.84	1.25
1993	0.24	0.02	0.03	0.15	3.00	2.18	2.68	4.15	2.68	3.01	1.21	0.64
1994	0.08	0.09	0.11	0.92	2.24	2.38	6.13	6.55	2.92	1.62	0.55	0.18
1995	0.09	0.11	0.19	0.80	1.28	2.36	3.52	4.09	4.60	2.64	0.36	0.72
1996	0.20	0.12	0.11	0.79	1.72	2.78	2.45	3.71	3.51	1.85	2.97	0.27
1997	0.18	0.05	0.41	0.42	0.63	2.20	3.44	2.98	3.54	3.77	0.71	0.36
1998	0.13	0.12	0.08	0.21	1.87	2.49	3.43	4.47	2.36	2.78	0.59	0.21
1999	0.09	0.02	0.00	0.14	0.66	1.79	3.52	3.31	2.76	3.12	1.32	0.23
2000	0.15	0.06	0.11	0.22	0.95	2.46	4.01	1.98	3.70	3.61	1.04	0.37
2001	0.47	0.15	0.23	3.50	4.67	1.80	2.58	3.28	2.99	1.83	1.17	0.42
2002	0.32	0.15	0.18	2.55	2.05	3.56	3.07	2.42	3.41	1.67	1.50	0.53
2003	0.34	0.24	2.01	0.22	0.69	0.59	7.42	3.64	4.15	2.75	1.20	0.62
2004	0.28	0.19	0.13	1.22	3.04	3.04	3.99	3.99	3.92	1.72	0.75	1.18
2005	0.19	0.31	2.19	0.98	1.98	3.16	3.48	3.79	4.89	2.87	0.26	0.87
2006	0.23	1.12	0.61	0.49	1.92	2.58	2.85	3.11	3.81	1.39	3.97	2.04
2007	0.54	1.32	1.30	3.01	5.34	3.21	3.43	3.92	3.15	2.48	0.54	3.80
2008	0.19	0.09	0.10	0.10	3.51	2.77	3.05	4.22	2.89	0.90	0.20	1.05

PRECIPITATION (mm /day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	1.64	1.74	2.36	2.42	2.94	3.88	4.90	6.90	6.88	1.80	1.40	0.08
1990	0.82	1.38	2.96	4.68	3.46	2.14	4.50	5.60	2.80	3.40	2.72	0.80
1991	1.52	0.44	2.02	2.00	3.34	3.94	2.76	6.10	3.22	2.82	2.52	2.22
1992	0.78	2.72	2.28	2.88	4.16	5.06	6.70	5.50	6.58	4.02	1.26	0.92
1993	1.20	0.24	0.76	2.34	7.10	7.08	5.30	3.30	4.32	2.38	1.14	2.24
1994	0.10	1.18	1.62	1.10	2.52	5.82	4.44	7.48	5.12	2.58	3.40	2.66
1995	2.64	1.02	3.22	4.36	4.96	3.72	4.20	4.80	7.38	2.36	4.56	0.72
1996	0.62	0.20	2.76	3.96	6.64	5.10	5.86	5.54	5.62	7.18	2.42	1.48
1997	0.94	0.12	4.56	2.60	3.28	6.34	6.80	5.76	6.76	7.62	0.84	0.94

1998	1.04	0.26	0.08	6.06	7.58	6.14	6.60	5.04	5.60	4.92	2.16	2.04
1999	1.60	0.48	1.20	5.82	6.54	6.10	7.92	7.76	4.48	5.86	3.40	1.96
2000	0.44	1.00	1.00	3.62	6.36	5.58	8.52	4.30	5.48	6.12	2.36	3.06
2001	1.96	0.16	2.84	5.52	3.42	7.20	4.42	7.18	3.80	3.28	1.44	1.32
2002	0.28	0.70	1.02	4.74	3.90	6.44	6.08	3.98	5.98	1.40	2.88	2.54
2003	1.48	0.32	1.94	2.78	3.88	3.96	7.74	6.24	4.40	2.80	3.60	1.74
2004	0.72	1.40	2.76	2.24	2.88	5.52	5.96	7.12	7.18	3.00	2.44	1.40
2005	1.16	1.36	1.82	1.24	6.04	6.58	8.12	5.48	7.46	4.42	2.38	1.86
2006	1.62	1.80	2.08	4.18	4.24	5.80	4.52	6.24	5.36	1.82	2.50	0.34
2007	2.30	2.30	1.98	4.54	6.42	5.56	6.16	6.04	5.48	4.14	2.06	2.14
2008	0.38	2.78	3.26	5.72	3.24	5.98	5.58	6.84	4.72	4.44	2.22	1.80

TEMPERATURE (°C)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1990	16.05	16.25	17.10	17.70	17.00	15.95	15.15	15.55	15.60	16.00	16.20	15.95
1991	16.45	17.35	17.40	16.95	17.10	16.00	14.70	15.25	15.95	15.90	15.55	15.55
1992	15.70	16.70	17.75	17.80	17.30	16.25	14.75	15.40	15.65	16.05	15.70	15.75
1993	15.35	16.05	17.25	17.09	16.60	15.60	15.35	15.90	16.30	16.10	16.40	15.80
1994	16.70	17.15	17.25	17.80	16.85	16.15	15.75	15.80	16.65	16.70	16.45	16.60
1995	16.70	17.15	17.65	18.35	17.50	16.80	15.60	16.00	16.60	16.90	16.85	16.85
1996	15.89	16.82	17.35	17.68	16.81	15.93	14.98	15.87	15.68	16.23	15.62	15.87
1997	16.65	17.03	17.43	18.21	17.95	16.56	15.54	16.02	16.21	16.87	16.75	16.56
1998	17.35	18.20	18.30	19.30	18.50	17.15	15.90	15.95	16.20	16.60	17.10	16.65
1999	16.85	18.65	18.80	18.25	16.85	16.66	15.30	15.55	16.35	16.34	16.67	16.32
2000	17.08	17.45	17.66	17.68	18.01	15.69	14.99	16.00	15.78	15.99	15.68	15.78
2001	16.95	18.05	18.34	17.96	17.76	16.76	15.56	15.87	16.26	16.78	17.57	16.69
2002	17.35	18.54	18.67	18.01	17.98	15.46	15.68	15.96	15.85	16.78	16.57	15.96
2003	17.50	18.45	18.75	18.10	18.25	16.25	15.55	16.01	16.30	16.95	16.70	16.30
2004	17.50	17.25	18.45	18.40	17.55	16.30	15.65	15.90	16.05	15.95	15.85	16.03
2005	16.79	18.01	18.25	18.65	17.55	16.77	16.00	16.10	16.50	16.45	16.60	16.25
2006	17.07	18.20	18.05	18.15	17.35	16.80	16.10	15.85	16.30	16.95	16.75	15.88
2007	16.55	17.75	18.20	17.90	17.25	16.25	15.80	15.80	16.35	16.85	16.45	16.45
2008	16.90	17.35	17.95	17.05	16.99	16.17	15.20	15.55	16.30	16.55	16.10	16.10
2009	19.20	17.20	17.70	17.35	16.75	16.75	15.95	15.70	16.65	16.65	16.35	16.35

RELATIVE HUMIDITY (%)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.42	0.39	0.46	0.53	0.64	0.72	0.81	0.76	0.68	0.76	0.56	0.62

SUNSHINE HOURS (Hrs)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	6.83	6.65	5.38	5.26	3.72	3.58	2.57	1.91	2.56	4.18	5.49	2.12

RIVER SUB-BASIN: Baro-Poko
STATION NAME: BARO R. Nr.Pokwo (BA1014)
Latitude: 8:24: 0 N Longitude: 34: 43: 0 E Elevation: 446.0 m Area: 4937 Km^2
RUNOFF (mm/day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	0.20	0.13	0.12	0.07	0.17	0.75	1.23	2.26	2.41	1.57	0.54	0.42
1990	0.14	0.08	0.10	0.18	0.40	1.12	0.97	1.95	2.01	1.59	0.90	0.25
1991	0.12	0.10	0.08	0.13	0.36	0.67	1.29	1.75	2.23	1.58	0.83	0.32
1992	0.21	0.17	0.07	0.20	0.43	1.23	1.65	1.92	2.01	1.65	0.62	0.39
1993	0.20	0.11	0.08	0.10	0.38	0.80	1.44	1.79	1.95	0.80	0.40	0.30
1994	0.14	0.08	0.09	0.10	0.23	0.51	0.91	1.50	1.96	1.22	0.44	0.26
1995	0.21	0.12	0.15	0.13	0.54	1.13	1.75	1.56	1.95	1.41	0.50	0.29
1996	0.20	0.11	0.12	0.21	0.46	1.01	1.30	1.95	1.63	1.37	1.27	0.30
1997	0.23	0.11	0.15	0.10	0.32	0.90	1.55	1.68	2.02	2.10	0.86	0.44
1998	0.21	0.11	0.08	0.10	0.67	1.23	1.43	1.93	1.70	1.10	0.74	0.32
1999	0.20	0.11	0.07	0.12	0.42	0.96	1.53	1.67	1.77	1.87	0.85	0.32
2000	0.17	0.11	0.10	0.07	0.29	0.84	1.48	1.77	1.89	1.45	0.60	0.35
2001	0.21	0.10	0.08	0.11	0.10	0.55	1.06	1.39	1.51	0.94	0.41	0.28
2002	0.08	0.05	0.07	0.06	0.07	0.38	1.05	1.24	1.73	1.13	0.35	0.20
2003	0.11	0.08	0.08	0.12	0.10	0.62	1.47	1.63	1.62	1.46	0.75	0.21
2004	0.14	0.08	0.10	0.06	0.25	0.55	1.01	1.57	1.99	1.21	0.38	0.23
2005	0.14	0.09	0.10	0.06	0.15	0.58	1.08	1.55	1.59	1.42	0.47	0.17
2006	0.12	0.07	0.08	0.07	0.19	0.43	1.17	1.52	1.98	1.57	0.63	0.22
2007	0.14	0.07	0.07	0.07	0.20	0.69	1.56	1.66	1.81	0.72	0.31	0.27
2008	0.16	0.15	0.13	0.10	0.50	0.62	1.39	1.78	1.73	1.13	0.35	0.32

PRECIPITATION (mm /day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	0.14	0.00	0.07	0.31	0.75	0.86	1.38	1.13	1.01	0.53	0.03	0.00

1990	0.03	0.03	0.07	0.35	0.69	1.42	0.73	0.74	0.77	0.53	0.10	0.03
1991	0.00	0.03	0.25	0.18	0.36	0.73	1.12	0.75	0.75	0.35	0.14	0.00
1992	0.03	0.07	0.14	0.05	0.76	0.76	0.98	0.99	0.83	0.10	0.07	0.03
1993	0.03	0.00	0.03	0.07	0.70	0.73	0.87	1.22	1.07	0.03	0.03	0.03
1994	0.03	0.03	0.10	0.05	0.72	0.74	1.29	1.25	0.95	0.39	0.07	0.00
1995	0.00	0.00	0.10	0.06	0.76	0.82	0.96	1.31	0.99	0.14	0.03	0.03
1996	0.03	0.03	0.00	0.05	0.70	1.25	1.30	1.06	1.01	0.07	0.03	0.03
1997	0.00	0.03	0.00	0.04	0.75	0.72	1.05	0.94	0.71	0.03	0.10	0.07
1998	0.11	0.00	0.03	0.05	0.67	0.75	0.71	0.86	0.99	0.03	0.07	0.03
1999	0.00	0.00	0.14	0.35	0.55	0.73	0.85	1.23	1.09	0.28	0.00	0.00
2000	0.07	0.03	0.07	0.27	0.76	0.82	0.99	0.96	0.81	0.35	0.03	0.03
2001	0.00	0.07	0.17	0.30	0.74	0.76	1.48	1.3	1.08	0.53	0.00	0.00
2002	0.12	0.00	0.03	0.36	0.65	0.73	1.34	1.09	1.11	0.53	0.03	0.00
2003	0.03	0.00	0.00	0.36	0.73	0.73	0.88	1.09	1.12	0.07	0.03	0.00
2004	0.03	0.00	0.03	0.32	0.76	0.73	0.86	0.98	0.98	0.10	0.03	0.03
2005	0.14	0.03	0.00	0.20	0.74	0.87	1.36	1.06	1.02	0.32	0.00	0.00
2006	0.00	0.00	0.07	0.28	1.38	0.81	1.10	1.11	0.75	0.34	0.03	0.07
2007	0.07	0.00	0.07	0.35	0.74	0.74	0.86	1.12	0.91	0.10	0.14	0.00
2008	0.00	0.00	0.07	0.21	0.68	0.81	0.97	0.96	0.93	0.03	0.07	0.03

TEMPERATURE (°C)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	29.16	31.11	30.69	30.70	30.51	29.39	29.70	27.11	27.53	29.51	28.79	29.80
1990	29.70	29.85	29.89	31.14	30.55	29.36	31.85	26.55	28.00	30.01	31.11	29.75
1991	30.31	31.28	31.54	30.26	29.48	29.27	30.53	27.44	27.75	29.33	29.87	29.65
1992	31.11	30.85	32.00	29.95	30.35	31.25	31.05	28.01	28.43	29.62	30.62	30.04
1993	30.20	29.93	29.96	31.00	29.75	29.15	31.90	27.98	30.01	31.01	30.28	29.63
1994	29.00	29.75	31.01	30.76	31.02	30.47	27.98	27.80	29.00	28.67	29.34	29.25
1995	32.08	31.63	29.76	31.02	29.69	31.63	30.11	26.75	27.03	29.32	28.74	29.05
1996	29.12	32.66	30.67	30.46	31.00	29.78	26.96	27.60	27.21	31.00	30.03	30.04
1997	29.16	29.91	32.05	31.04	29.73	29.85	30.55	26.75	28.28	29.55	29.25	29.45
1998	30.11	31.99	31.87	32.57	31.25	31.04	31.65	27.86	27.98	29.34	30.25	30.64
1999	29.56	32.00	31.45	33.24	30.87	29.86	27.56	26.56	27.02	31.00	29.77	29.55
2000	29.79	32.25	32.00	32.62	31.96	30.78	31.34	27.54	29.86	29.95	31.45	30.64
2001	30.20	32.50	32.35	33.25	32.10	32.56	32.90	27.98	30.45	32.65	29.76	29.63
2002	31.11	33.20	34.05	33.25	31.45	29.00	27.80	27.80	28.00	29.90	29.75	29.60

2003	31.18	33.28	33.20	31.55	30.01	29.85	30.13	26.75	28.20	29.45	29.25	29.75
2004	30.85	33.85	31.87	32.65	29.04	29.05	26.98	28.60	27.55	31.00	30.21	30.01
2005	30.71	32.45	31.60	32.75	28.85	27.80	27.45	27.20	27.45	28.55	28.30	29.86
2006	31.00	30.99	32.01	33.27	32.16	31.56	28.90	28.18	30.15	31.65	29.86	29.69
2007	29.14	29.90	32.05	31.05	29.70	32.64	29.00	27.99	28.67	30.58	30.24	29.94
2008	32.05	31.22	33.46	31.20	29.00	29.96	32.19	29.27	28.94	31.11	31.12	30.48

RELATIVE HUMIDITY (%)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.71	0.66	0.61	0.63	0.74	0.65	0.91	0.93	0.94	0.81	0.83	0.76

SUNSHINE HOURS (Hrs)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	7.79	7.45	8.36	6.81	6.12	5.08	4.36	5.04	4.57	6.75	6.79	7.72

RIVER SUB-BASIN: Lower Gilo
STATION NAME: Gilo R. Nr. Pugndo (BA2006)
Latitude: 7:62: 0 N Longitude: 34: 27: 0 E Elevation: 452.0 m Area: 2437 Km^2
RUNOFF (mm/day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	0.05	0.09	0.16	0.18	0.24	3.74	4.68	5.24	7.50	3.58	1.08	0.03
1990	0.07	0.08	0.17	3.00	4.00	4.21	3.42	5.36	6.04	2.76	0.98	0.04
1991	0.07	0.07	0.15	0.54	0.70	2.00	4.56	6.76	4.46	4.10	1.50	0.04
1992	0.05	0.07	0.16	0.62	0.82	3.04	4.44	5.78	5.66	5.02	1.68	0.05
1993	0.06	0.06	0.16	0.50	0.82	1.60	4.78	4.66	6.44	3.40	0.90	0.06
1994	0.03	0.08	0.17	0.58	0.74	3.38	4.22	5.96	4.28	4.66	1.04	0.06
1995	0.06	0.07	0.17	0.30	0.56	1.58	3.88	6.44	6.62	3.18	1.74	0.03
1996	0.03	0.06	0.16	0.26	0.76	2.08	6.02	7.34	5.58	4.14	1.68	0.04
1997	0.09	0.07	0.15	0.50	0.70	3.94	5.58	6.58	5.94	3.74	0.86	0.07
1998	0.04	0.06	0.15	0.46	0.86	3.14	4.64	6.76	4.68	2.70	1.65	0.05
1999	0.05	0.07	0.15	1.48	2.42	4.50	5.74	7.69	4.32	2.62	1.26	0.07
2000	0.06	0.06	0.17	0.46	2.16	5.44	7.71	5.88	4.12	4.74	1.28	0.04
2001	0.03	0.08	0.16	0.60	2.20	5.12	7.62	7.10	5.46	3.48	1.62	0.05
2002	0.04	0.07	0.17	1.50	2.38	3.64	5.72	6.00	4.80	2.60	1.54	0.02
2003	0.05	0.06	0.16	1.74	4.02	4.82	5.14	5.32	5.84	2.78	1.18	0.06
2004	0.02	0.08	0.17	0.60	1.52	4.30	5.62	5.70	4.82	3.02	2.30	0.04
2005	0.04	0.07	0.16	1.16	2.74	3.06	4.42	7.50	5.50	4.24	1.96	0.02

2006	0.06	0.08	0.19	0.44	1.28	3.28	4.20	5.00	4.02	2.96	1.90	0.06
2007	0.05	0.06	0.21	0.62	2.02	2.94	4.02	4.86	5.34	3.38	1.92	0.05
2008	0.03	0.07	0.14	0.46	2.70	3.52	5.62	6.24	5.62	3.74	2.50	0.04

PRECIPITATION (mm /day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	0.07	0.08	0.18	1.02	2.02	3.98	4.62	6.70	5.94	2.42	1.72	0.05
1990	0.08	0.09	0.18	0.96	2.24	4.48	5.36	5.20	4.44	3.56	0.86	0.06
1991	0.08	0.09	0.16	1.04	2.28	4.16	8.02	7.04	5.90	3.08	0.84	0.04
1992	0.04	0.08	0.14	0.94	2.26	4.00	7.26	5.92	6.02	3.78	1.06	0.03
1993	0.06	0.08	0.18	0.98	2.42	4.00	4.82	5.92	6.10	3.62	1.52	0.07
1994	0.04	0.07	0.18	1.02	2.26	3.98	4.66	5.32	5.34	3.16	1.26	0.06
1995	0.06	0.08	0.16	1.06	2.28	4.76	7.36	5.78	5.58	2.68	1.27	0.04
1996	0.04	0.08	0.14	0.94	2.08	4.40	6.00	6.02	4.06	3.52	1.65	0.03
1997	0.08	0.09	0.16	0.96	2.46	4.02	4.66	6.10	4.94	2.70	1.32	0.05
1998	0.06	0.08	0.16	1.04	2.22	4.44	5.28	5.20	5.04	3.10	1.06	0.06
1999	0.04	0.08	0.16	1.54	4.28	4.64	5.56	5.38	4.58	3.68	1.35	0.08
2000	0.06	0.08	0.18	1.72	4.18	4.30	8.30	7.28	6.10	3.18	1.71	0.04
2001	0.02	0.06	0.18	2.02	3.64	4.14	7.52	6.14	6.24	3.90	1.08	0.02
2002	0.06	0.08	0.14	2.06	4.14	4.14	4.98	6.14	6.32	3.74	1.56	0.05
2003	0.04	0.07	0.18	1.80	4.28	4.10	4.82	5.50	5.52	3.26	1.30	0.06
2004	0.02	0.06	0.16	1.16	4.18	4.92	7.62	5.98	5.76	2.78	0.98	0.04
2005	0.06	0.08	0.18	1.62	3.94	4.54	6.20	6.24	4.20	3.64	0.86	0.03
2006	0.04	0.09	0.20	2.00	4.18	4.16	4.82	6.32	5.12	2.78	1.36	0.06
2007	0.04	0.07	0.18	1.22	3.82	4.58	5.46	5.38	5.22	3.20	1.08	0.05
2008	0.02	0.06	0.14	1.76	4.22	4.84	7.76	6.38	5.70	3.38	1.85	0.04

TEMPERATURE (^{O}C)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	29.67	32.66	29.75	31.02	30.65	29.33	31.65	26.88	27.53	29.30	30.11	29.75
1990	30.22	32.53	29.55	31.56	29.78	29.25	30.23	26.85	27.28	29.95	29.85	29.65
1991	31.00	29.76	31.66	29.82	30.25	29.13	31.35	27.68	26.87	30.68	30.02	30.04
1992	29.17	31.00	30.87	30.65	30.48	29.40	29.61	27.02	27.45	29.43	28.98	29.73
1993	29.68	29.85	29.89	31.14	30.55	29.36	31.85	26.55	28.00	30.01	31.11	29.75
1994	30.95	33.85	31.87	32.65	29.04	29.05	26.98	28.60	27.55	31.00	30.21	30.01
1995	30.65	32.45	31.60	32.75	28.85	27.80	27.45	27.20	27.45	28.55	28.30	29.86

1996	31.01	30.99	32.01	33.27	32.16	31.56	28.90	28.18	30.15	31.65	29.86	29.69
1997	29.15	29.90	32.05	31.05	29.70	32.64	29.00	27.99	28.67	30.58	30.24	29.94
1998	32.10	31.32	33.65	31.15	29.10	29.85	32.02	29.33	28.88	31.01	31.05	30.65
1999	29.15	29.91	32.05	31.04	29.73	29.85	30.55	26.75	28.28	29.55	29.25	29.45
2000	30.00	31.99	31.87	32.57	31.25	31.04	31.65	27.86	27.98	29.34	30.25	30.64
2001	29.65	32.00	31.45	33.24	30.87	29.86	27.56	26.56	27.02	31.00	29.77	29.55
2002	29.98	32.25	32.00	32.62	31.96	30.78	31.34	27.54	29.86	29.95	31.45	30.64
2003	30.15	32.50	32.35	33.25	32.10	32.56	32.90	27.98	30.45	32.65	29.76	29.63
2004	31.00	33.20	34.05	33.25	31.45	29.00	27.80	27.80	28.00	29.90	29.75	29.60
2005	31.14	33.28	33.20	31.55	30.01	29.85	30.13	26.75	28.20	29.45	29.25	29.75
2006	30.68	32.30	32.20	33.21	29.68	29.00	27.61	27.20	27.65	31.64	29.88	29.73
2007	29.11	32.66	29.75	31.02	30.65	29.33	31.65	26.88	27.53	29.30	30.11	29.75
2008	30.21	32.53	29.55	31.56	29.78	29.25	30.23	26.85	27.28	29.95	29.85	29.65

RELATIVE HUMIDITY (%)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.80	0.75	0.58	0.69	0.75	0.68	0.89	0.97	0.96	0.79	0.82	0.75

SUNSHINE HOURS (Hrs)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	7.68	7.63	8.34	6.80	6.22	5.19	5.26	4.05	4.87	6.76	6.87	7.74

RIVER SUB-BASIN: Sore & Geba
STATION NAME: Sori R. Nr. Metu (BA1001)
Latitude: 8:32: 0 N Longitude: 35: 60: 0 E Elevation: 1987.0 m Area: 1622.0 Km^2
RUNOFF (mm/day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	0.58	0.26	0.26	0.30	2.45	4.54	8.00	6.21	6.01	3.18	1.74	0.60
1990	0.40	0.30	0.33	0.41	0.76	2.08	6.02	7.34	5.58	4.14	1.68	0.82
1991	0.60	0.52	0.42	0.50	0.70	3.94	5.58	7.58	5.94	3.74	0.86	0.46
1992	0.38	0.26	0.24	0.46	0.86	3.14	4.64	6.76	4.68	4.70	4.28	1.02
1993	0.22	0.26	0.36	1.48	2.42	4.50	5.74	7.94	4.32	2.62	1.26	0.38
1994	0.20	0.06	0.06	0.46	2.16	5.44	9.22	7.01	6.42	4.74	1.28	0.38
1995	0.20	0.10	0.20	0.60	2.20	5.12	8.24	7.10	5.46	3.48	1.62	0.60
1996	0.22	0.30	0.64	1.50	2.38	3.64	5.72	7.00	4.80	2.60	1.54	0.56
1997	0.30	0.22	0.50	1.74	4.02	4.82	5.14	8.32	5.84	2.78	1.18	0.58
1998	0.34	0.18	0.20	0.60	1.52	4.30	7.21	5.70	5.82	5.02	2.30	1.30
1999	0.42	0.48	0.56	1.90	3.30	5.02	5.68	7.35	7.00	5.70	1.04	0.51

2000	0.36	0.34	0.38	0.49	3.50	5.02	6.82	5.88	4.02	3.78	1.03	0.49
2001	0.36	0.35	0.50	0.51	1.58	6.02	8.01	7.00	4.42	4.70	1.66	0.62
2002	0.43	0.31	0.33	0.47	0.48	5.01	5.04	7.01	5.08	1.58	0.64	0.50
2003	0.37	0.34	0.35	0.41	0.55	3.74	4.68	6.24	5.01	3.58	1.08	0.64
2004	0.32	0.35	0.34	0.51	0.62	1.14	3.42	4.51	4.45	3.52	2.65	1.00
2005	0.34	0.34	0.30	0.54	0.70	2.00	6.23	7.30	5.00	3.00	1.50	0.80
2006	0.50	0.38	0.38	0.62	0.82	3.04	6.91	5.00	5.81	5.02	1.68	0.50
2007	0.48	0.49	0.50	0.50	0.82	1.60	4.01	4.23	5.50	3.40	0.90	0.58
2008	0.48	0.51	0.55	1.35	1.89	3.38	4.22	4.51	5.65	4.66	1.04	0.70

PRECIPITATION (mm /day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	0.10	0.14	0.16	1.06	2.28	4.76	7.36	5.78	5.58	2.68	0.44	0.86
1990	0.04	0.08	0.14	0.94	2.08	4.40	6.00	6.02	4.06	3.52	0.84	0.43
1991	0.08	0.12	0.16	0.96	2.46	4.02	4.66	6.10	4.94	2.70	1.32	0.42
1992	0.06	0.10	0.16	1.04	2.22	4.44	5.28	5.20	5.04	3.10	1.06	0.53
1993	0.04	0.08	0.16	1.54	4.28	4.64	5.56	5.38	4.58	3.68	0.88	0.76
1994	0.06	0.10	0.18	1.72	4.18	4.30	8.30	7.28	6.10	3.18	0.86	0.63
1995	0.02	0.12	0.18	2.02	3.64	4.14	7.52	6.14	6.24	3.90	1.08	0.22
1996	0.06	0.08	0.14	2.06	4.14	4.14	4.98	6.14	6.32	3.74	1.56	0.42
1997	0.04	0.10	0.18	1.80	4.28	4.10	4.82	5.50	5.52	3.26	1.30	0.66
1998	0.02	0.06	0.16	1.16	4.18	4.92	7.62	5.98	5.76	2.78	0.62	0.53
1999	0.38	0.74	0.80	1.92	3.02	3.98	4.62	6.70	5.94	2.42	1.72	0.44
2000	0.04	0.06	0.08	1.22	2.02	4.48	5.36	5.20	4.44	3.56	0.86	0.43
2001	0.08	0.12	0.18	1.18	2.42	4.16	8.02	7.04	5.90	3.08	0.84	0.54
2002	0.06	0.10	0.14	0.98	2.22	3.10	4.16	6.00	5.36	2.68	1.80	0.78
2003	0.08	0.12	0.18	1.02	2.02	3.98	4.62	6.70	5.94	2.42	1.72	0.65
2004	0.12	0.14	0.18	0.96	2.24	4.48	5.36	5.20	4.44	3.56	0.86	0.22
2005	0.08	0.12	0.16	1.04	2.28	4.16	8.02	7.04	5.90	3.08	0.84	0.43
2006	0.04	0.08	0.14	0.94	2.26	4.00	7.26	5.92	6.02	3.78	1.06	0.68
2007	0.06	0.10	0.18	0.98	2.42	4.00	4.82	5.92	6.10	3.62	1.52	0.54
2008	0.12	0.14	0.18	1.02	2.26	3.98	4.66	5.32	5.34	3.16	1.26	0.47

TEMPERATURE (^{O}C)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	21.05	19.65	21.05	20.85	20.30	19.35	18.30	21.85	19.15	19.15	18.75	18.90

1990	20.01	20.25	21.30	21.30	20.45	19.70	18.50	18.55	19.30	19.20	19.10	18.90
1991	19.30	20.70	22.30	21.90	21.20	19.95	19.55	19.60	19.30	18.90	19.00	18.35
1992	17.58	20.15	20.69	20.97	20.75	20.00	18.75	20.17	20.01	19.69	18.84	19.66
1993	18.57	19.87	21.53	21.50	21.15	19.87	19.34	19.56	19.69	20.32	19.94	18.75
1994	19.00	19.35	20.75	21.85	20.60	20.03	19.03	21.65	20.05	19.09	19.75	19.57
1995	18.98	20.05	21.34	20.30	21.05	19.75	18.50	18.75	19.71	20.20	18.80	18.80
1996	18.67	20.53	22.32	21.80	20.70	19.65	19.25	19.40	19.18	18.89	19.07	19.03
1997	21.00	19.57	21.63	22.00	21.25	19.57	19.52	19.65	20.10	20.04	19.64	18.55
1998	21.03	20.14	20.56	20.96	20.72	20.05	18.84	20.62	19.27	19.52	18.74	19.92
1999	19.43	20.15	21.15	21.07	20.23	19.30	18.32	21.65	19.05	18.96	19.01	19.02
2000	18.89	20.35	21.33	20.90	20.05	20.21	19.16	18.56	18.77	19.22	19.23	18.78
2001	20.54	20.56	21.78	21.54	20.80	19.76	19.35	18.88	19.30	18.79	19.01	18.64
2002	21.03	19.57	19.58	20.07	17.27	21.01	19.53	19.06	19.02	17.57	18.65	17.02
2003	19.07	20.06	20.01	21.65	21.06	18.56	18.78	19.02	18.78	18.59	16.87	18.00
2004	19.80	19.94	21.05	19.87	20.45	19.00	19.63	20.23	17.89	19.35	19.47	18.56
2005	17.78	20.64	19.08	21.09	18.21	19.80	18.68	18.76	20.54	20.23	18.85	19.02
2006	18.68	20.08	20.56	20.06	18.72	18.67	19.01	18.85	18.56	18.79	19.78	17.47
2007	21.05	19.76	20.78	20.56	19.05	20.02	19.57	19.63	19.04	19.45	18.58	19.34
2008	20.01	20.04	19.67	21.19	19.67	19.51	18.47	20.01	17.75	18.88	17.48	18.76

RELATIVE HUMIDITY (%)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.46	0.62	0.49	0.39	0.60	0.69	0.70	0.73	0.75	0.72	0.60	0.79

SUNSHINE HOURS (Hrs)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	7.00	5.71	8.06	5.19	5.56	4.98	2.19	2.73	3.25	5.23	6.13	7.19

Station Name: Alwero R. Nr. Dumbong

Station Number: BA2005

RUNOFF (mm/day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	0.19	0.14	0.17	2.34	2.56	2.34	5.08	5.04	3.01	1.79	0.54	0.19
1990	0.19	0.23	0.19	1.98	3.46	3.81	3.21	5.11	2.34	2.01	0.49	0.20
1991	0.17	0.13	0.27	2.28	3.35	3.03	5.87	4.01	2.01	2.15	0.75	0.21
1992	0.25	0.19	0.31	2.41	2.89	2.76	3.41	5.63	1.50	2.51	0.84	0.18
1993	0.19	0.17	0.25	2.71	4.93	2.55	4.11	3.78	1.65	1.70	0.89	0.19

1994	0.24	0.18	0.29	2.81	4.01	3.44	3.03	5.67	4.31	3.67	1.17	0.20
1995	0.35	0.13	0.15	2.11	2.85	2.25	4.11	5.11	2.79	1.59	0.87	0.21
1996	0.20	0.15	0.13	2.15	2.65	2.70	4.62	3.84	2.21	2.07	0.84	0.20
1997	0.30	0.26	0.25	2.01	3.51	2.61	3.69	5.32	2.55	2.35	0.43	0.21
1998	0.19	0.13	0.23	1.35	3.25	2.85	5.21	3.25	2.34	2.01	1.53	0.18
1999	0.29	0.58	0.85	2.87	3.01	2.73	5.45	3.16	1.85	1.85	0.75	0.33
2000	0.36	0.53	0.61	1.98	3.01	3.25	3.41	5.01	3.56	2.37	0.64	0.26
2001	0.28	0.58	0.64	3.01	4.86	3.45	3.46	3.01	2.73	1.74	0.81	0.25
2002	0.27	0.42	0.44	2.86	4.91	3.36	3.68	3.81	2.40	2.00	1.85	0.28
2003	0.25	0.56	0.59	2.57	3.11	3.63	5.01	3.25	2.92	2.28	0.59	0.25
2004	0.58	0.43	0.42	1.01	5.01	3.72	2.49	3.65	2.51	2.21	0.42	0.21
2005	0.21	0.47	0.58	2.21	4.43	2.11	3.03	3.65	2.07	1.95	0.98	0.27
2006	0.29	0.31	0.33	2.10	2.51	2.82	4.15	4.45	2.51	2.21	0.66	0.29
2007	0.31	0.84	0.56	1.93	2.76	2.67	3.61	4.71	2.18	1.69	0.96	0.25
2008	0.23	0.58	0.41	2.81	3.12	2.76	4.82	3.84	2.81	1.82	0.55	0.21

PRECIPITATION (mm /day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	0.18	0.04	0.38	2.67	3.78	3.98	5.10	4.89	2.97	2.15	2.11	0.23
1990	0.23	0.03	0.48	2.65	3.90	4.35	3.90	4.68	2.22	2.21	1.12	0.22
1991	0.18	0.08	0.52	2.38	4.32	4.12	6.54	4.23	2.95	2.09	2.41	0.21
1992	0.19	0.05	0.47	2.95	3.39	3.57	3.33	4.80	1.31	2.13	1.87	0.19
1993	0.21	0.06	0.49	2.79	4.89	3.87	4.83	4.47	1.61	2.21	1.43	0.18
1994	0.23	0.05	0.51	2.33	5.19	4.56	4.11	6.81	2.67	2.17	1.46	0.23
1995	0.18	0.04	0.53	2.55	2.88	3.51	4.53	5.73	2.79	2.20	2.01	0.22
1996	0.21	0.06	0.47	2.54	3.45	4.56	4.89	4.44	2.03	2.19	2.11	0.21
1997	0.19	0.04	0.48	2.16	4.23	3.84	3.81	4.98	2.47	2.32	2.21	0.22
1998	0.19	0.05	0.52	2.43	3.84	3.33	3.03	3.69	2.52	2.25	1.87	0.21
1999	0.23	1.06	0.77	2.56	3.21	3.75	4.74	4.08	2.29	2.17	1.97	0.17
2000	0.24	0.84	0.86	2.25	2.79	3.89	4.05	5.89	3.05	2.29	1.89	0.19
2001	0.23	1.03	1.01	2.83	4.14	4.18	3.63	3.69	3.12	2.45	2.01	0.22
2002	0.18	0.70	1.03	2.35	3.93	3.89	4.53	4.29	3.16	2.39	2.11	0.19
2003	0.18	0.95	0.90	2.33	3.30	4.21	5.43	4.08	2.76	2.56	2.43	0.21
2004	0.22	0.63	0.58	2.67	5.80	4.25	3.69	4.56	2.88	2.19	2.12	0.20
2005	0.25	0.88	0.81	2.53	4.23	3.42	4.17	4.17	2.10	2.18	1.65	0.18
2006	0.21	0.39	1.00	2.39	3.18	3.93	4.89	5.50	2.56	2.25	1.03	0.19

2007	0.22	1.13	0.61	2.98	3.57	3.63	4.14	4.76	2.61	2.36	1.49	0.21
2008	0.24	0.85	0.88	2.56	3.75	4.67	4.86	4.20	2.85	2.56	1.98	0.22

TEMPERATURE (°C)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	30.68	32.30	32.20	33.21	29.68	29.00	27.61	27.20	27.65	31.64	29.88	29.73
1990	29.11	32.66	29.75	31.02	30.65	29.33	31.65	26.88	27.53	29.30	30.11	29.75
1991	30.21	32.53	29.55	31.56	29.78	29.25	30.23	26.85	27.28	29.95	29.85	29.65
1992	31.00	29.76	31.66	29.82	30.25	29.13	31.35	27.68	26.87	30.68	30.02	30.04
1993	29.17	31.00	30.87	30.65	30.48	29.40	29.61	27.02	27.45	29.43	28.98	29.73
1994	29.68	29.85	29.89	31.14	30.55	29.36	31.85	26.55	28.00	30.01	31.11	29.75
1995	30.25	31.28	31.54	30.26	29.48	29.27	30.53	27.44	27.75	29.33	29.87	29.65
1996	31.00	30.85	32.00	29.95	30.35	31.25	31.05	28.01	28.43	29.62	30.62	30.04
1997	30.14	29.93	29.96	31.00	29.75	29.15	31.90	27.98	30.01	31.01	30.28	29.63
1998	29.13	29.75	31.01	30.76	31.02	30.47	27.98	27.80	29.00	28.67	29.34	29.25
1999	32.11	31.63	29.76	31.02	29.69	31.63	30.11	26.75	27.03	29.32	28.74	29.05
2000	29.01	32.66	30.67	30.46	31.00	29.78	26.96	27.60	27.21	31.00	30.03	30.04
2001	29.15	29.91	32.05	31.04	29.73	29.85	30.55	26.75	28.28	29.55	29.25	29.45
2002	30.00	31.99	31.87	32.57	31.25	31.04	31.65	27.86	27.98	29.34	30.25	30.64
2003	29.65	32.00	31.45	33.24	30.87	29.86	27.56	26.56	27.02	31.00	29.77	29.55
2004	29.98	32.25	32.00	32.62	31.96	30.78	31.34	27.54	29.86	29.95	31.45	30.64
2005	30.15	32.50	32.35	33.25	32.10	32.56	32.90	27.98	30.45	32.65	29.76	29.63
2006	31.00	33.20	34.05	33.25	31.45	29.00	27.80	27.80	28.00	29.90	29.75	29.60
2007	31.14	33.28	33.20	31.55	30.01	29.85	30.13	26.75	28.20	29.45	29.25	29.75
2008	30.95	33.85	31.87	32.65	29.04	29.05	26.98	28.60	27.55	31.00	30.21	30.01

RELATIVE HUMIDITY (%)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.51	0.64	0.57	0.49	0.63	0.69	0.72	0.74	0.78	0.74	0.65	0.81

SUNSHINE HOURS (Hrs)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	7.25	6.15	7.45	5.64	5.71	5.25	3.42	3.23	4.15	5.54	6.65	7.56

Station Name: Geba R. Nr. Sopi
Station Number: BA1003
RUNOFF (mm/day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	0.27	0.30	0.41	1.12	2.56	3.18	4.95	6.01	5.06	2.86	0.43	0.34
1990	0.32	0.32	0.35	1.33	2.38	3.78	5.46	4.85	3.67	2.27	0.41	0.34
1991	0.33	0.34	0.35	0.81	2.00	2.41	3.01	3.80	5.89	2.78	0.37	0.30
1992	0.30	0.38	0.39	0.86	3.08	3.70	5.82	4.73	3.94	2.72	0.35	0.33
1993	0.35	0.36	0.40	0.92	2.76	3.94	5.52	4.85	2.27	2.59	0.49	0.37
1994	0.32	0.36	0.34	0.72	2.45	3.28	3.01	3.47	5.68	2.35	0.68	0.40
1995	0.34	0.34	0.39	0.77	2.56	3.70	5.58	4.07	3.58	2.88	0.66	0.37
1996	0.35	0.35	0.41	0.95	3.01	3.26	4.71	3.80	3.53	2.36	0.51	0.38
1997	0.35	0.36	0.40	0.72	2.64	3.18	4.54	5.55	3.42	2.45	0.49	0.35
1998	0.33	0.41	0.39	1.13	2.67	3.86	6.45	4.22	3.42	2.12	0.64	0.55
1999	0.33	0.35	0.41	1.42	2.71	3.56	4.68	5.12	5.49	2.70	0.49	0.40
2000	0.40	0.40	0.45	0.79	2.61	3.80	4.07	4.10	4.40	2.89	0.63	0.35
2001	0.32	0.33	0.36	1.13	2.47	4.99	7.50	5.27	4.21	2.66	0.53	0.36
2002	0.34	0.35	0.37	0.79	2.48	3.21	7.23	4.73	4.43	2.67	0.79	0.41
2003	0.34	0.32	0.33	0.85	2.25	2.74	5.36	4.06	4.32	2.56	0.55	0.41
2004	0.40	0.38	0.41	0.86	2.64	3.18	4.17	3.34	6.31	2.47	0.66	0.36
2005	0.33	0.35	0.37	0.78	3.02	3.62	6.67	3.38	4.52	2.01	0.71	0.39
2006	0.37	0.35	0.39	0.87	2.69	3.33	5.19	4.26	3.80	2.95	0.65	0.33
2007	0.32	0.38	0.36	0.83	2.44	2.23	4.44	5.51	3.94	2.56	0.70	0.38
2008	0.32	0.34	0.46	0.81	2.78	5.68	4.35	3.26	3.85	2.78	0.66	0.37

PRECIPITATION (mm /day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	0.34	0.41	0.70	1.78	2.81	3.69	4.30	6.25	5.53	2.25	1.21	0.36
1990	0.56	0.45	0.69	1.39	3.85	4.18	5.00	4.84	4.12	3.31	1.25	0.39
1991	0.49	0.53	0.92	1.55	2.22	3.24	3.72	4.22	3.56	2.86	1.12	0.33
1992	0.40	0.50	0.88	1.82	3.28	3.73	6.77	5.53	3.90	3.94	1.65	0.38
1993	0.29	0.42	0.99	1.85	3.73	3.73	4.48	5.53	2.88	3.37	1.40	0.35
1994	0.40	0.51	0.79	1.62	3.85	3.69	4.34	4.95	5.98	3.96	1.32	0.40
1995	0.37	0.50	0.56	1.04	3.76	4.43	6.86	5.38	3.12	2.50	1.43	0.36
1996	0.30	0.50	0.65	1.46	3.55	4.09	5.58	5.62	3.78	3.28	1.46	0.36
1997	0.29	0.36	0.58	1.80	3.76	3.74	4.34	5.69	4.61	2.50	1.22	0.37
1998	0.38	0.39	0.61	1.94	3.36	4.46	7.62	4.91	3.56	3.87	1.20	0.39
1999	0.38	0.41	0.52	1.82	2.25	3.62	5.60	5.85	5.36	3.15	1.35	0.38

2000	0.35	0.42	0.60	1.48	4.19	4.55	4.66	4.91	4.37	3.44	1.46	0.37
2001	0.31	0.42	0.64	2.45	4.19	4.59	7.16	6.46	5.38	2.50	1.24	0.36
2002	0.32	0.40	0.58	1.76	3.46	3.58	7.22	5.38	5.81	3.87	1.15	0.37
2003	0.38	0.32	0.62	2.00	3.80	3.78	2.81	5.60	5.38	3.51	1.24	0.41
2004	0.35	0.44	0.58	1.57	3.91	3.60	4.30	5.06	7.28	2.90	1.19	0.40
2005	0.35	0.48	0.60	1.10	3.78	4.30	7.20	4.50	6.50	2.20	1.22	0.39
2006	0.32	0.47	0.60	1.40	3.62	4.14	5.36	5.80	3.62	3.26	1.30	0.35
2007	0.31	0.32	0.56	1.76	3.80	3.78	4.30	5.54	4.70	2.39	1.28	0.33
2008	0.31	0.36	0.61	1.06	3.60	5.42	3.80	4.59	4.63	2.68	1.19	0.37

TEMPERATURE (^{O}C)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	20.01	20.25	21.30	21.30	20.45	19.70	18.50	18.55	19.30	19.20	19.10	18.90
1990	10.30	20.70	22.30	21.90	21.20	19.95	19.55	19.60	19.30	18.90	19.00	18.35
1991	18.58	20.15	20.69	20.97	20.75	20.00	18.75	20.17	20.01	19.69	18.84	19.66
1992	18.57	19.87	21.53	21.50	21.15	19.87	19.34	19.56	19.69	20.32	19.94	18.75
1993	19.00	19.35	20.75	21.85	20.60	20.03	19.03	21.65	20.05	19.09	19.75	19.57
1994	20.18	20.05	21.34	20.30	21.05	19.75	18.50	18.75	19.71	20.20	18.80	18.80
1995	18.67	20.53	22.32	21.80	20.70	19.65	19.25	19.40	19.18	18.89	19.07	19.03
1996	20.50	19.57	21.63	22.00	21.25	19.57	19.52	19.65	20.10	20.04	19.64	18.55
1997	21.03	20.14	20.56	20.96	20.72	20.05	18.84	20.62	19.27	19.52	18.74	19.92
1998	19.43	20.15	21.15	21.07	20.23	19.30	18.32	21.65	19.05	18.96	19.01	19.02
1999	19.69	20.35	21.33	20.90	20.05	20.21	19.16	18.56	18.77	19.22	19.23	18.78
2000	20.54	20.56	21.78	21.54	20.80	19.76	19.35	18.88	19.30	18.79	19.01	18.64
2001	21.03	19.57	19.58	20.07	17.27	21.01	19.53	19.06	19.02	17.57	18.65	17.02
2002	20.07	20.06	20.01	21.65	21.06	18.56	18.78	19.02	18.78	18.59	16.87	18.00
2003	19.80	19.94	21.05	19.87	20.45	19.00	19.63	20.23	17.89	19.35	19.47	18.56
2004	18.78	20.64	19.08	21.09	18.21	19.80	18.68	18.76	20.54	20.23	18.85	19.02
2005	19.68	20.08	20.56	20.06	18.72	18.67	19.01	18.85	18.56	18.79	19.78	17.47
2006	20.05	19.76	20.78	20.56	19.05	20.02	19.57	19.63	19.04	19.45	18.58	19.34
2007	19.22	20.10	20.99	21.08	20.21	19.72	19.07	19.59	19.31	19.27	19.02	18.74
2008	20.03	20.13	21.57	20.67	20.79	20.10	18.94	20.82	19.37	19.57	18.74	19.92

RELATIVE HUMIDITY (%)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.33	0.36	0.43	0.63	0.60	0.73	0.75	0.75	0.69	0.73	0.75	0.75

SUNSHINE HOURS (Hrs)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	6.25	6.20	5.40	5.20	3.77	3.56	3.54	3.45	2.55	4.19	4.36	3.25

RIVER - BASIN: Sor and Geba
Station Number: BA1006
Station Name: Uka R. @. Uka
Latitude: 8:17:0Latitude 35:37:0Longitude Elevation: 2011.0 m Area: 1653 sq km
RUNOFF (mm/day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	1.200	1.750	1.500	1.458	2.125	3.600	6.541	8.100	7.650	5.916	3.291	1.980
1990	1.455	1.458	1.458	2.250	4.095	4.950	6.625	9.499	6.600	5.708	3.208	1.650
1991	1.455	1.470	1.515	1.950	3.750	4.800	7.350	9.450	7.375	5.541	3.165	1.665
1992	1.425	1.650	1.750	3.083	4.416	5.749	7.083	8.400	8.791	5.125	3.510	1.695
1993	1.470	1.485	2.250	2.700	3.150	4.950	7.999	9.150	10.25	4.958	2.833	2.250
1994	1.541	1.440	1.470	1.950	1.916	5.131	5.835	6.645	7.815	6.250	3.166	2.125
1995	1.425	1.426	1.455	1.470	3.165	2.708	7.500	13.20	9.583	6.666	4.200	1.875
1996	1.624	1.440	1.440	1.995	1.958	3.541	6.166	9.208	7.791	4.950	2.500	1.791
1997	1.375	1.351	1.353	2.302	3.000	5.416	6.416	7.916	9.416	4.791	2.166	1.500
1998	1.333	1.330	1.833	1.666	4.500	5.700	6.300	7.333	6.833	5.083	2.541	1.791
1999	0.833	1.083	1.166	1.500	1.999	3.250	6.583	10.50	10.00	6.750	3.416	1.455
2000	1.440	1.425	1.665	2.010	2.083	4.665	6.499	10.00	5.965	5.833	3.600	1.966
2001	1.432	1.425	1.429	1.467	2.250	4.950	8.550	9.300	8.083	5.916	2.250	1.443
2002	1.44	1.444	1.452	2.916	4.416	5.550	6.833	7.833	9.166	5.166	2.333	1.500
2003	1.249	1.216	1.276	2.100	2.500	5.583	6.416	4.493	7.050	5.850	4.050	1.500
2004	1.480	1.471	1.516	2.550	3.750	4.950	5.700	6.600	7.200	5.400	3.250	1.999
2005	1.348	1.349	1.875	1.950	3.750	5.550	7.650	7.800	8.100	5.916	3.666	1.916
2006	1.458	1.451	1.750	1.750	1.916	3.583	6.666	7.950	7.200	5.250	2.666	1.666
2007	1.350	1.650	1.350	1.396	4.166	5.083	6.000	7.083	8.166	4.416	2.583	1.455
2008	1.333	1.333	2.333	2.160	4.650	5.550	6.150	6.500	7.916	4.916	2.416	1.833

PRECIPITATION (mm /day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	0.791	1.541	1.708	4.125	6.499	8.541	9.958	14.458	12.791	5.208	3.666	0.041
1990	1.291	1.650	3.150	3.208	8.916	9.666	11.583	11.208	9.541	7.666	1.833	0.041
1991	1.185	1.485	3.165	3.583	8.708	8.958	17.291	15.166	12.708	6.625	1.791	0.083

1992	0.900	0.765	3.315	4.208	7.583	8.625	15.666	12.791	13.000	8.125	2.250	0.041
1993	1.050	0.930	3.450	4.291	8.625	8.625	10.375	12.791	13.166	7.791	3.250	0.041
1994	0.900	1.095	3.315	3.750	8.916	8.541	10.041	11.458	11.500	6.791	2.708	0.124
1995	0.750	1.215	3.195	2.416	8.708	10.25	15.875	12.458	12.00	5.791	0.916	0.083
1996	1.050	1.170	3.510	3.375	8.208	9.458	12.916	13.000	8.749	7.583	1.791	0.041
1997	1.200	1.290	3.315	4.166	8.708	8.666	10.041	13.166	10.666	5.791	2.833	0.000
1998	1.050	1.005	3.675	2.541	7.958	9.541	11.375	11.208	10.875	6.666	2.250	0.041
1999	1.050	0.930	3.345	4.249	6.750	8.333	10.000	14.083	13.000	5.083	3.250	0.041
2000	0.750	1.125	3.465	3.083	8.916	10.000	10.833	11.250	9.333	7.416	2.333	0.041
2001	0.750	1.048	3.255	3.583	8.749	9.166	16.583	14.916	12.416	6.750	1.833	0.083
2002	1.050	1.245	3.510	4.249	7.583	8.333	14.916	12.833	12.583	9.166	1.916	0.041
2003	0.900	1.185	3.645	4.083	8.583	8.500	10.416	4.333	13.000	7.583	3.000	0.041
2004	1.200	1.305	3.360	3.750	8.916	8.666	9.833	11.666	11.250	6.833	2.916	0.124
2005	1.050	1.275	3.810	2.416	9.166	10.166	15.750	11.916	12.583	5.833	0.916	0.083
2006	0.900	1.048	3.810	3.416	9.166	10.083	13.416	13.750	8.416	7.416	1.666	0.041
2007	0.900	1.281	3.510	4.166	8.416	8.500	9.916	11.500	10.250	5.916	2.583	0.008
2008	1.050	1.351	3.645	2.583	8.416	9.583	11.750	11.250	10.916	7.583	2.583	0.041

TEMPERATURE (°C)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	18.45	20.10	20.70	20.80	21.10	20.10	21.02	20.70	20.20	20.05	19.95	20.30
1990	20.40	21.20	20.65	20.85	20.50	19.65	19.80	20.05	20.30	20.10	20.05	19.95
1991	17.89	20.35	20.43	19.54	19.56	16.48	18.57	17.45	15.99	20.23	19.78	20.79
1992	20.23	21.03	21.65	20.56	18.87	15.89	20.03	15.78	19.78	19.76	20.68	18.89
1993	19.56	19.87	22.53	19.79	19.76	17.56	19.34	19.43	20.34	19.69	20.34	19.56
1994	19.00	18.98	21.67	21.56	21.32	27.65	17.66	20.03	18.98	20.45	18.98	20.10
1995	17.45	19.77	21.23	23.00	20.86	20.76	18.63	19.67	19.54	18.97	19.56	20.02
1996	18.97	20.56	20.57	20.56	19.64	21.02	19.77	15.75	17.67	19.78	19.78	17.79
1997	17.57	20.02	19.63	21.78	20.34	17.56	20.20	18.56	18.58	17.57	20.02	19.56
1998	19.03	21.05	21.34	22.67	20.25	20.43	17.67	20.03	20.43	20.04	17.56	20.23
1999	19.76	22.23	20.07	21.95	17.56	16.53	19.03	15.79	19.67	18.67	20.45	18.69
2000	20.23	22.01	21.52	19.89	21.43	19.43	17.89	19.54	17.45	19.87	18.67	19.76
2001	20.35	18.96	20.05	18.85	16.79	20.01	20.01	19.98	18.89	20.15	17.56	20.01
2002	18.35	16.90	19.10	17.10	16.65	15.85	15.90	15.37	16.21	16.40	17.10	17.85
2003	17.20	20.10	20.10	20.80	19.60	18.15	18.20	18.00	18.35	18.75	17.90	18.05
2004	18.23	21.58	20.57	21.78	21.05	19.05	18.97	19.76	20.02	17.45	19.67	18.98

2005	19.54	20.69	22.04	23.43	22.04	20.34	19.75	20.56	17.89	19.97	20.56	20.34
2006	20.39	21.20	21.76	22.54	21.89	19.67	20.54	19.79	19.99	17.45	20.67	20.45
2007	18.50	20.50	22.55	23.10	22.10	20.70	19.75	20.20	20.45	20.20	18.80	19.30
2008	21.20	22.20	22.10	22.90	21.90	20.50	19.85	20.05	20.25	20.80	20.35	20.02

RELATIVE HUMIDITY (%)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.47	0.65	0.50	0.42	0.65	0.75	0.73	0.79	0.76	0.74	0.62	0.69

SUNSHINE HOURS (Hrs)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	7.27	6.31	8.27	5.31	6.23	4.98	3.19	2.73	4.25	5.35	6.43	7.39

Station Name: Gumero R. Nr. Nr. Gori
Station Number: BA1010
RUNOFF (mm/day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	0.60	1.05	1.45	1.50	2.70	3.90	5.10	7.05	7.10	7.55	1.98	0.60
1990	0.55	0.65	1.10	1.65	2.80	3.95	5.05	6.20	4.60	3.10	1.85	0.60
1991	0.40	0.30	0.58	1.05	2.15	4.25	6.25	8.95	5.60	3.33	1.25	0.75
1992	0.50	0.54	1.05	0.90	2.05	3.45	5.50	5.27	5.28	3.08	1.38	0.60
1993	0.60	0.60	0.65	0.75	0.95	3.95	3.95	7.15	4.80	2.98	1.70	1.05
1994	0.65	0.75	1.20	1.20	1.98	2.75	3.53	4.30	5.08	3.55	2.60	1.65
1995	0.70	0.63	0.63	0.75	0.85	2.70	4.30	4.35	5.75	4.00	2.18	1.13
1996	0.90	0.90	0.85	0.95	1.55	2.55	3.55	4.05	3.40	2.23	1.25	0.90
1997	0.82	0.63	0.63	0.64	1.05	2.55	3.95	4.90	4.20	2.55	1.30	0.90
1998	0.70	0.70	0.75	0.80	2.25	2.80	3.25	3.75	4.40	3.10	1.93	1.10
1999	0.95	1.15	1.45	2.10	3.05	4.15	5.60	6.80	5.45	4.05	1.05	0.90
2000	0.80	0.75	0.85	1.05	1.25	3.05	5.05	4.71	4.55	2.70	1.60	0.80
2001	0.55	0.55	0.60	0.80	1.75	3.05	3.85	4.15	3.40	3.55	1.35	0.65
2002	0.65	0.70	0.80	0.95	2.40	3.70	4.90	5.50	4.30	3.08	1.85	0.65
2003	0.60	0.60	0.65	1.05	2.05	3.35	3.85	2.55	4.65	3.20	1.00	0.75
2004	0.70	0.65	0.65	0.70	0.90	1.90	3.05	3.90	4.05	3.10	2.25	1.35
2005	0.70	0.61	0.62	0.70	0.80	2.10	4.00	6.21	4.03	4.12	2.10	1.15
2006	0.88	0.90	1.05	1.05	1.15	2.15	3.65	5.35	3.01	2.82	1.60	0.90
2007	0.81	0.70	0.80	1.05	1.30	2.05	3.10	3.95	3.25	3.10	1.55	1.05

2008	0.80	0.80	0.75	0.80	1.00	1.95	2.90	5.88	4.78	4.65	2.25	1.10

PRECIPITATION (mm /day)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	1.86	2.52	3.78	2.97	4.68	6.15	7.17	10.41	9.21	3.75	2.64	0.03
1990	0.18	1.89	3.18	2.31	6.42	6.96	8.34	8.07	6.87	5.52	1.32	0.00
1991	0.09	0.78	2.52	2.58	6.27	6.45	9.42	16.02	9.15	4.77	2.10	0.06
1992	1.17	1.68	3.09	3.03	5.46	6.21	11.28	9.21	9.36	5.85	1.62	0.00
1993	0.48	2.37	2.10	3.09	6.21	6.21	7.47	14.10	9.48	2.70	2.34	0.03
1994	1.56	2.49	2.85	2.70	6.42	6.15	7.23	8.25	8.28	4.89	1.95	0.00
1995	0.21	1.41	1.89	1.74	6.27	7.38	11.43	8.97	8.64	14.28	0.66	0.06
1996	1.65	2.07	2.64	2.43	5.91	6.81	9.30	9.36	6.30	5.46	1.29	0.03
1997	0.48	1.74	1.17	3.00	6.27	6.24	7.23	9.48	11.58	4.17	2.04	0.00
1998	0.36	0.78	0.66	2.94	10.02	6.87	8.19	8.07	7.83	4.80	1.62	0.03
1999	1.62	1.86	2.10	3.06	5.16	6.00	7.20	10.14	9.36	3.66	2.34	0.03
2000	1.26	1.86	2.04	2.22	6.42	7.20	7.80	8.10	6.72	5.34	1.68	0.03
2001	1.20	1.20	1.38	1.50	5.16	6.06	6.78	3.90	6.24	4.86	1.32	0.06
2002	1.26	1.68	1.44	2.28	4.68	6.00	10.74	9.24	9.06	6.60	1.38	0.03
2003	1.32	1.80	1.56	2.22	4.86	6.12	7.50	3.12	9.36	5.46	2.16	0.03
2004	1.38	1.98	2.10	2.22	4.50	6.24	7.08	8.40	8.10	4.92	2.10	0.09
2005	0.24	2.10	1.80	1.74	6.60	7.32	11.34	8.58	9.06	4.20	0.66	0.06
2006	1.68	2.10	2.76	2.46	6.60	7.26	9.66	9.90	6.06	5.34	1.20	0.03
2007	0.60	1.80	1.20	3.00	6.06	6.12	7.14	8.28	7.38	4.26	1.86	0.01
2008	1.14	1.44	3.30	1.86	6.06	6.90	8.46	8.10	7.86	5.46	1.86	0.03

TEMPERATURE (°C)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1989	20.94	21.00	19.89	21.69	20.45	20.19	20.65	21.04	22.44	19.95	20.32	21.85
1990	20.03	19.69	20.03	21.08	20.58	21.31	19.59	21.01	21.38	20.96	19.89	20.45
1991	19.15	19.89	20.43	20.86	19.98	20.01	19.96	20.36	20.45	21.87	20.78	21.14
1992	19.48	20.11	19.67	19.67	19.85	20.02	20.76	20.83	21.35	22.03	21.76	22.03
1993	21.03	20.89	20.35	21.03	21.90	21.15	20.34	21.05	21.40	19.98	20.85	21.07
1994	21.55	22.78	23.56	23.43	21.15	20.51	19.78	18.92	19.70	20.28	15.63	22.03
1995	22.95	22.95	22.56	21.03	21.45	20.42	20.00	19.90	20.60	21.06	22.03	21.65
1996	22.15	21.65	21.37	22.44	21.95	20.04	19.30	19.67	20.02	22.00	19.68	22.02
1997	22.25	22.65	22.23	20.89	21.54	21.46	20.10	18.79	20.56	20.34	22.21	21.24

1998	21.48	20.86	22.65	21.24	21.02	21.03	20.35	21.33	20.89	20.65	21.11	20.55
1999	19.89	21.04	21.02	21.84	20.68	20.67	20.56	19.68	20.14	19.35	18.87	19.37
2000	21.56	20.87	20.35	21.69	21.85	21.45	18.56	20.65	21.07	20.72	20.56	20.14
2001	22.15	21.08	21.02	20.76	22.05	23.01	20.34	20.12	22.03	21.39	21.87	23.01
2002	22.10	22.03	22.35	21.89	20.65	18.45	17.78	16.60	20.11	20.64	19.96	22.03
2003	18.45	20.15	19.76	17.58	18.78	20.34	20.07	19.98	18.86	20.78	20.87	21.72
2004	20.89	20.25	22.11	21.54	21.02	21.75	17.20	16.89	21.02	21.34	20.97	22.45
2005	21.34	20.55	19.89	19.89	19.65	16.77	21.34	20.25	20.37	21.23	21.37	22.10
2006	20.80	22.01	21.75	20.03	20.68	20.24	20.66	19.88	20.22	20.87	21.63	20.69
2007	21.89	21.57	22.00	20.55	20.60	20.50	21.36	20.56	20.67	21.75	19.78	19.93
2008	21.81	21.21	20.67	19.87	20.18	19.89	20.34	16.89	22.01	22.11	21.65	20.67

RELATIVE HUMIDITY (%)

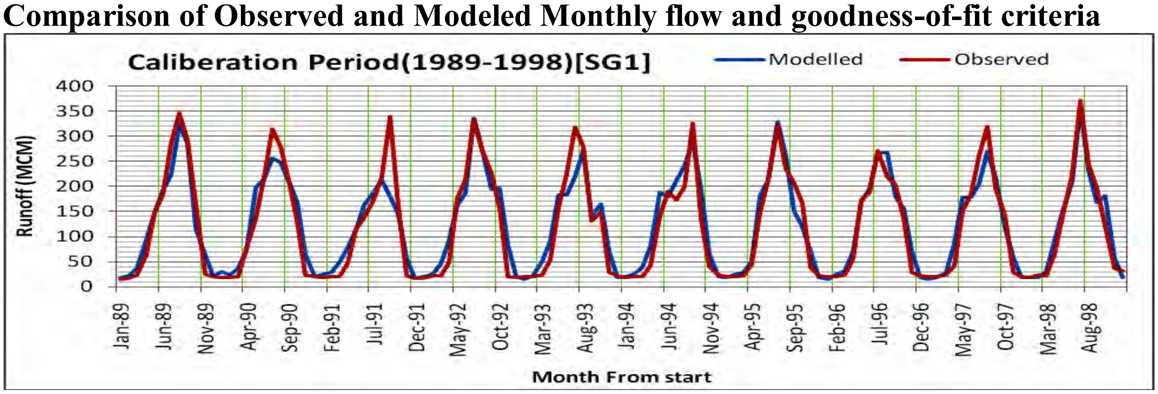
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.45	0.65	0.47	0.39	0.55	0.64	0.75	0.68	0.71	0.73	0.64	0.67

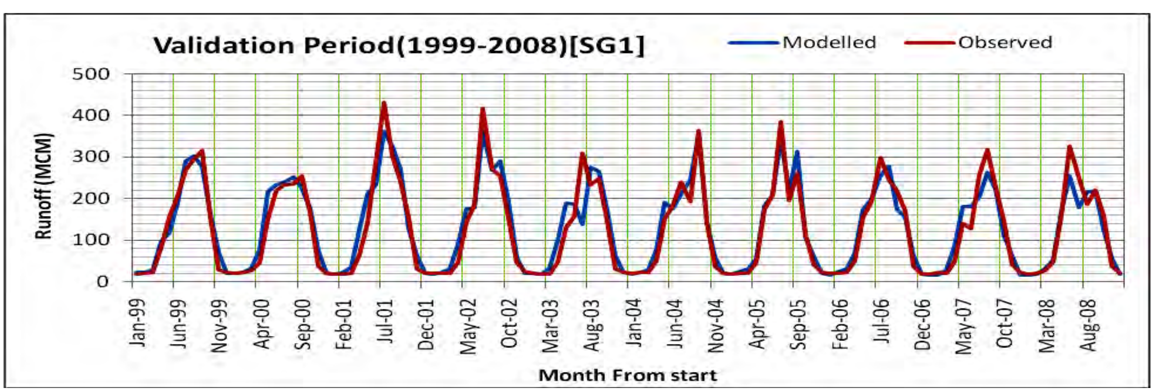
SUNSHINE HOURS (Hrs)

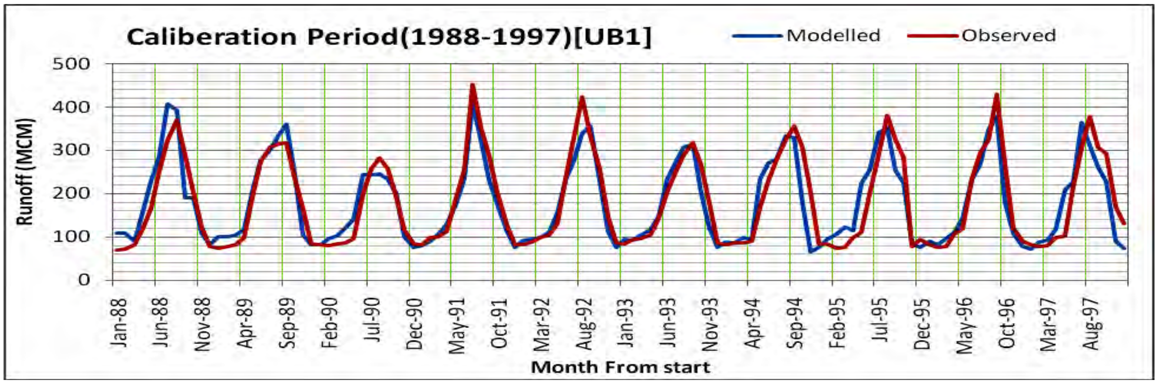
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	5.56	4.69	6.45	5.46	4.45	4.35	3.21	2.96	3.75	4.85	5.64	6.21

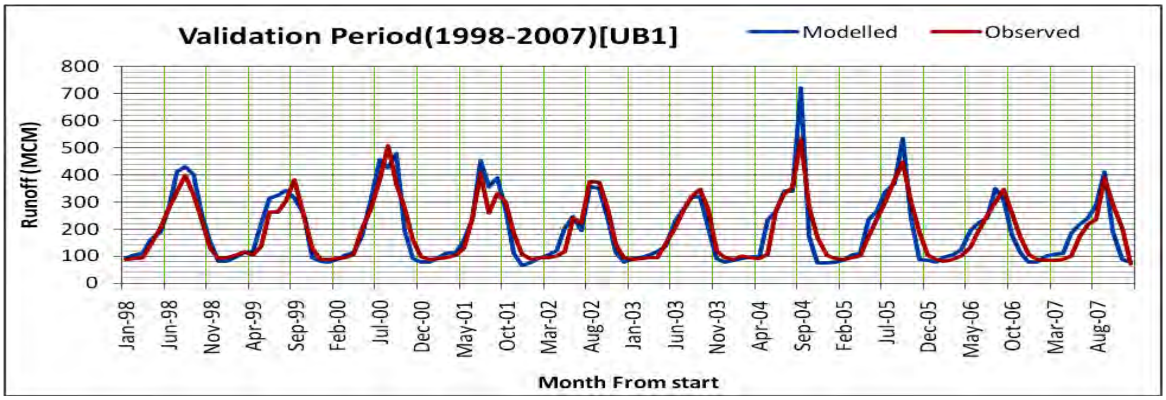
APPENDIX E

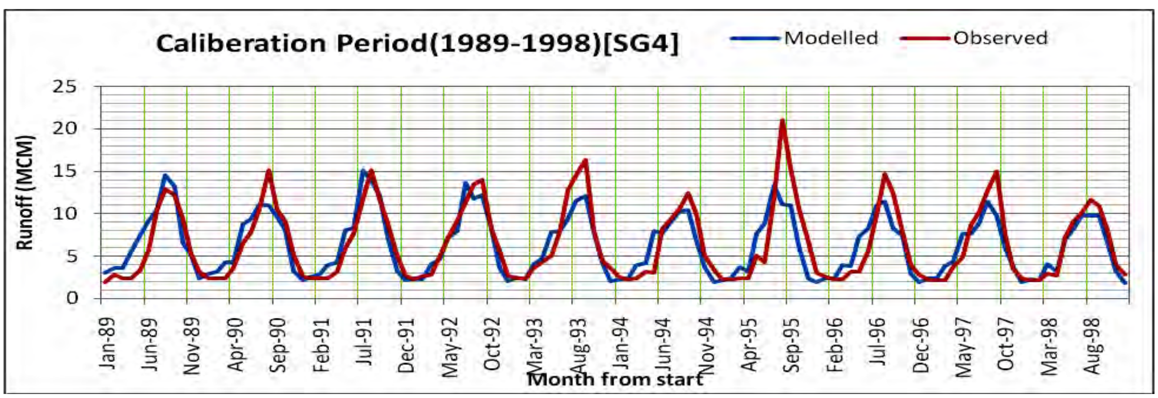
Comparison of Observed and Modeled Monthly flow and goodness-of-fit criteria

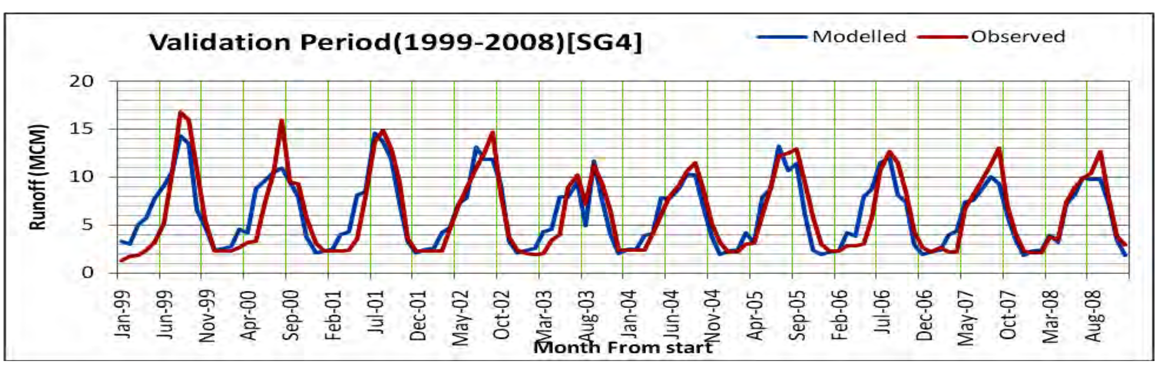


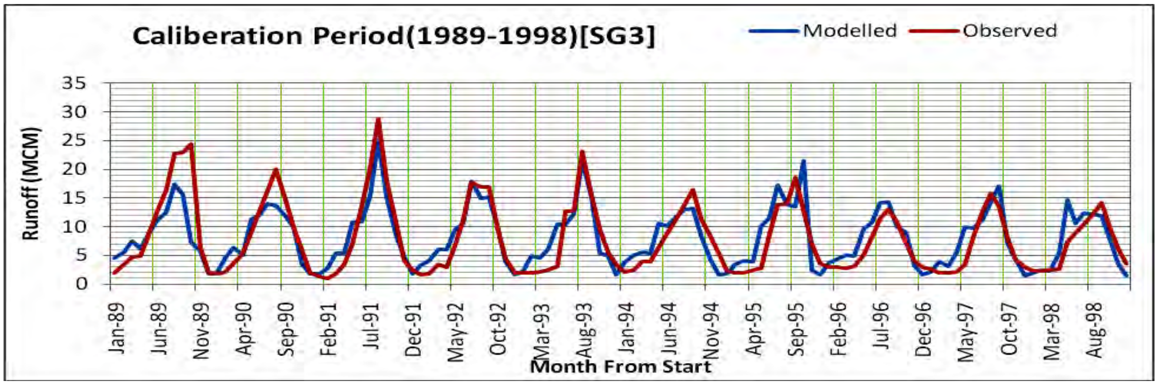


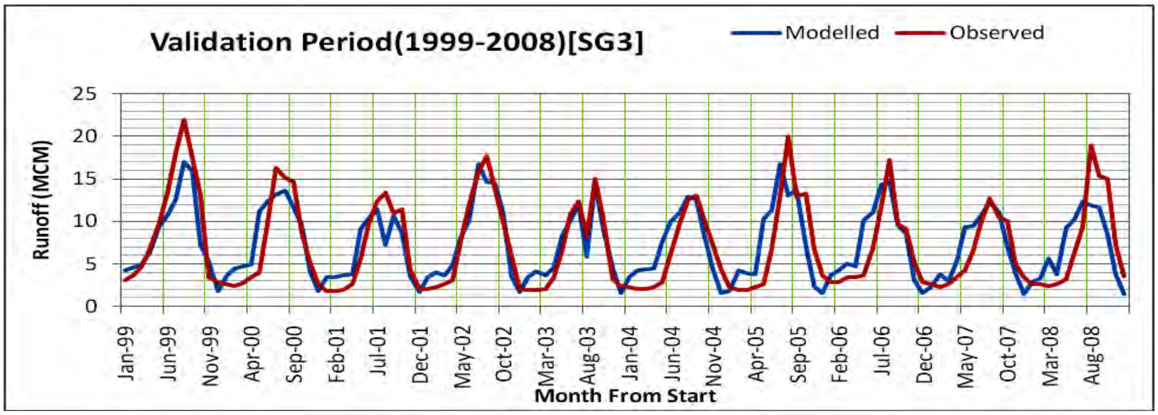

Caliberation Period(1988-1997)[UB1]
Modelled
Observed
Runoff (MCM)
Month From start

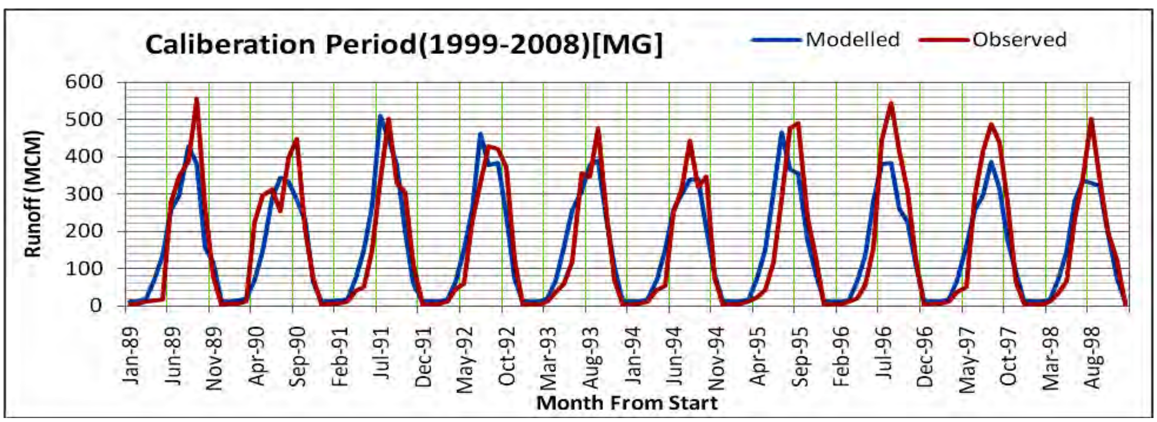

Validation Period(1998-2007)[UB1]
Modelled
Observed
Runoff (MCM)
Month From start

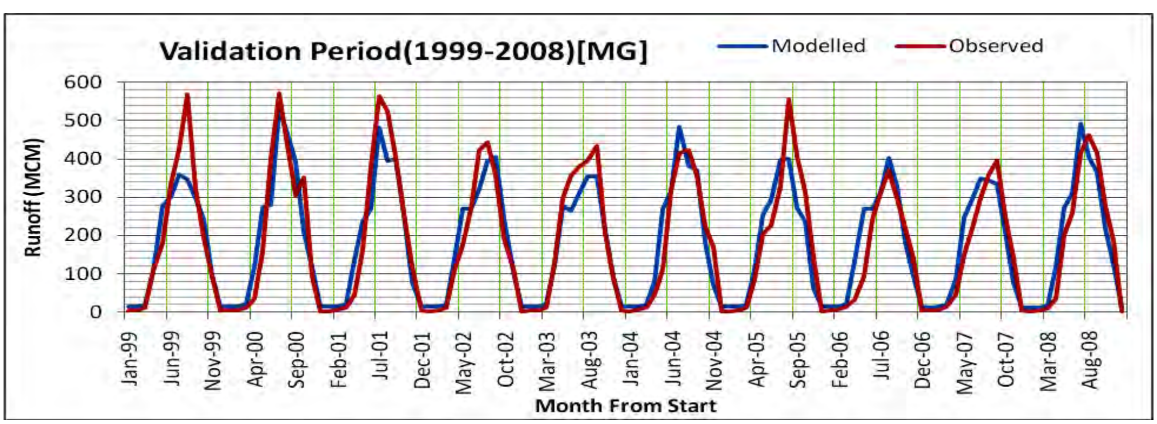

Caliberation Period(1989-1998)[SG4]
Modelled
Observed
Runoff (MCM)
Month from start

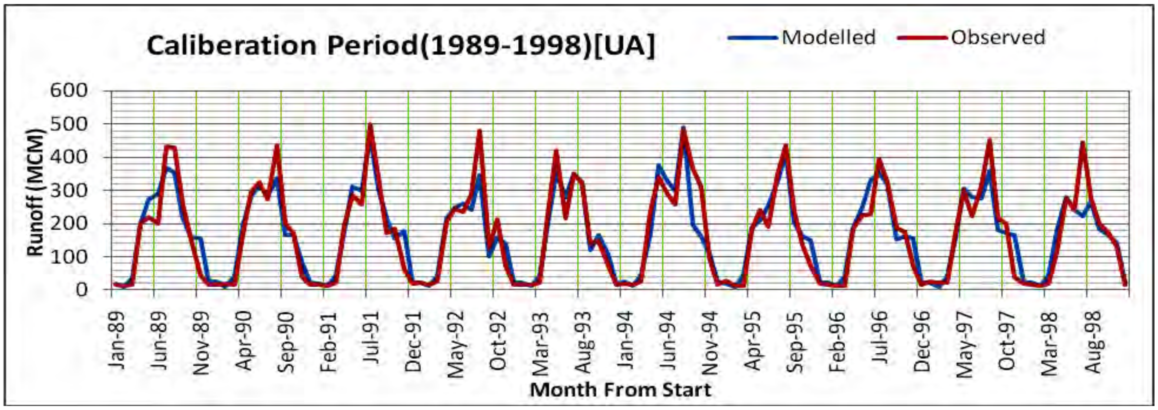

Validation Period(1999-2008)[SG4]
Modelled
Observed
Runoff (MCM)
Month From start

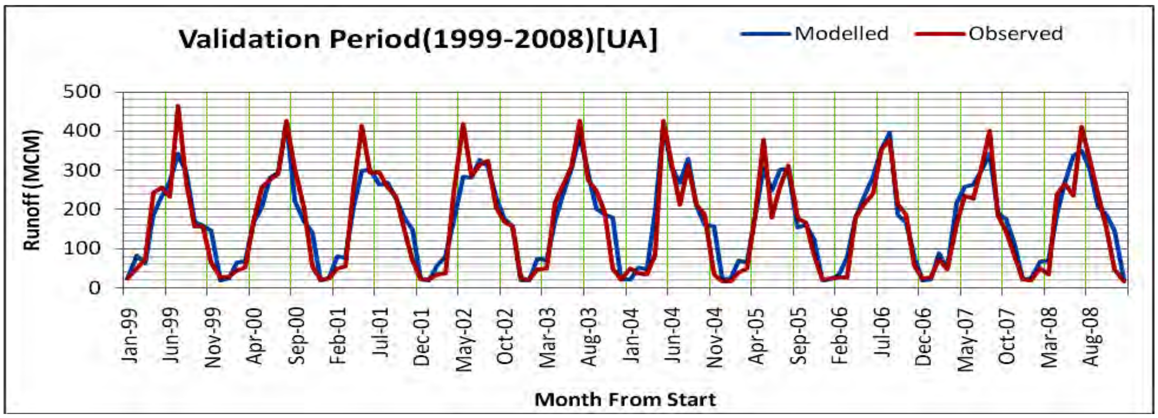

Caliberation Period(1989-1998)[SG3]
Modelled
Observed
Runoff (MCM)
Month From Start

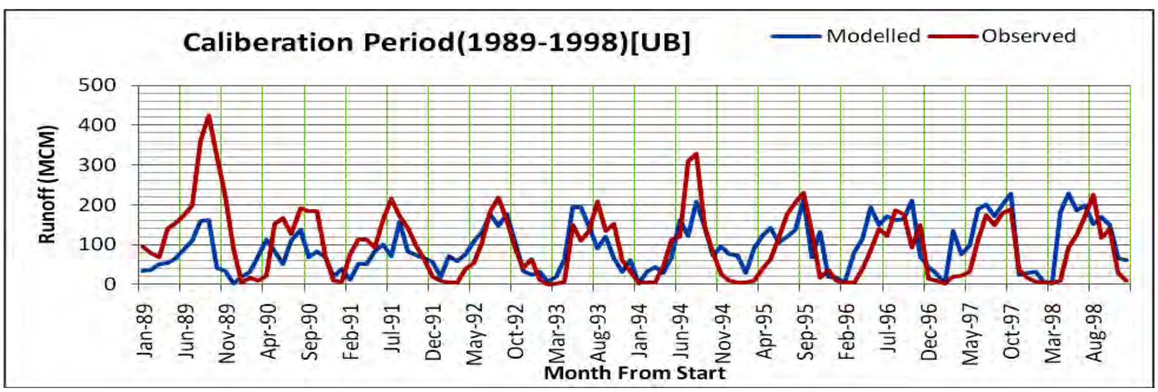

Validation Period(1999-2008)[SG3]
Modelled
Observed
Runoff (MCM)
Month From Start

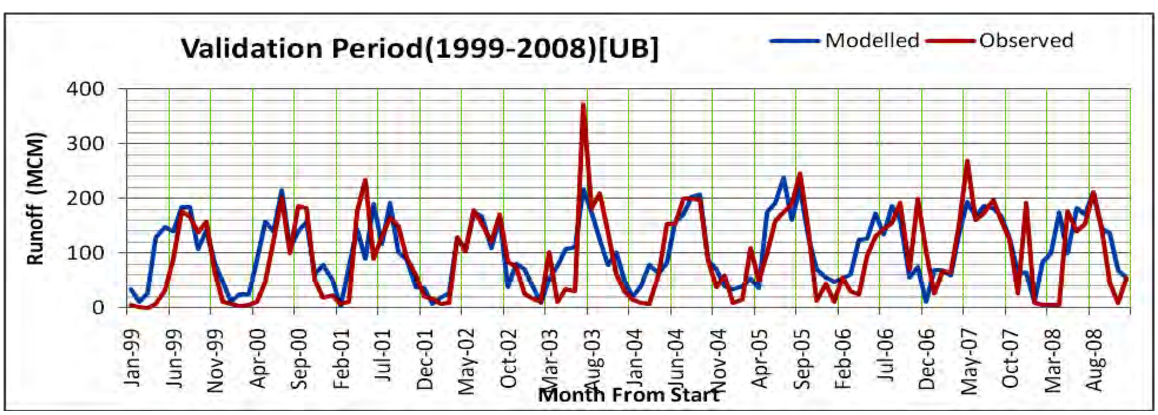

Caliberation Period(1999-2008)[MG]
Modelled
Observed
Runoff (MCM)
Month From Start

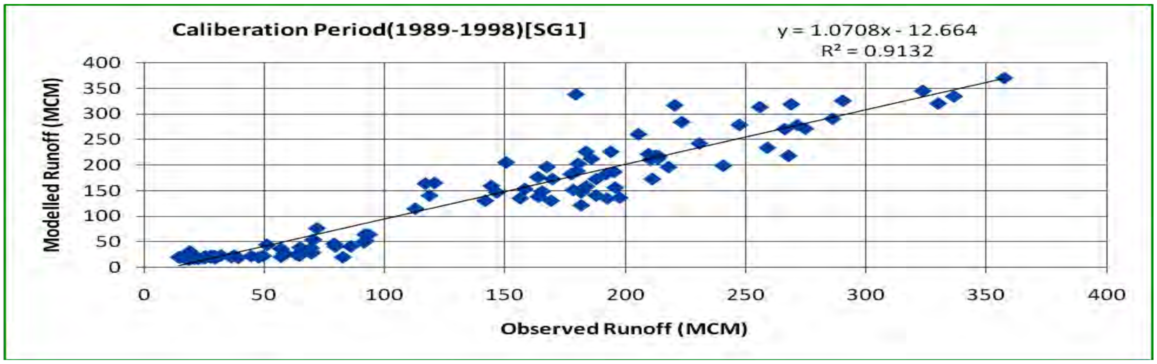

Validation Period(1999-2008)[MG]
Modelled
Observed
Runoff (MCM)
Month From Start

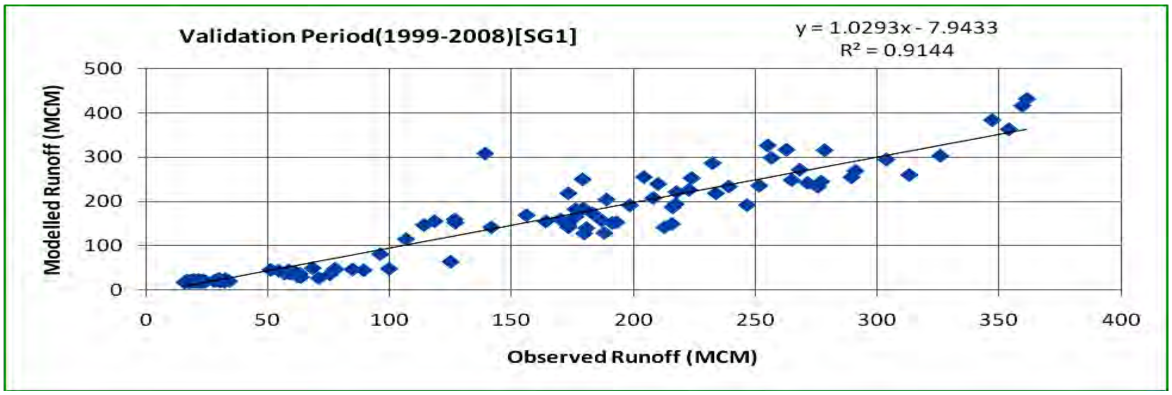

Caliberation Period(1989-1998)[UA]
Modelled
Observed
Runoff (MCM)
600
500
400
300
200
100
0
Jan-89
Jun-89
Nov-89
Apr-90
Sep-90
Feb-91
Jul-91
Dec-91
May-92
Oct-92
Mar-93
Aug-93
Jan-94
Jun-94
Nov-94
Apr-95
Sep-95
Feb-96
Jul-96
Dec-96
May-97
Oct-97
Mar-98
Aug-98
Month From Start

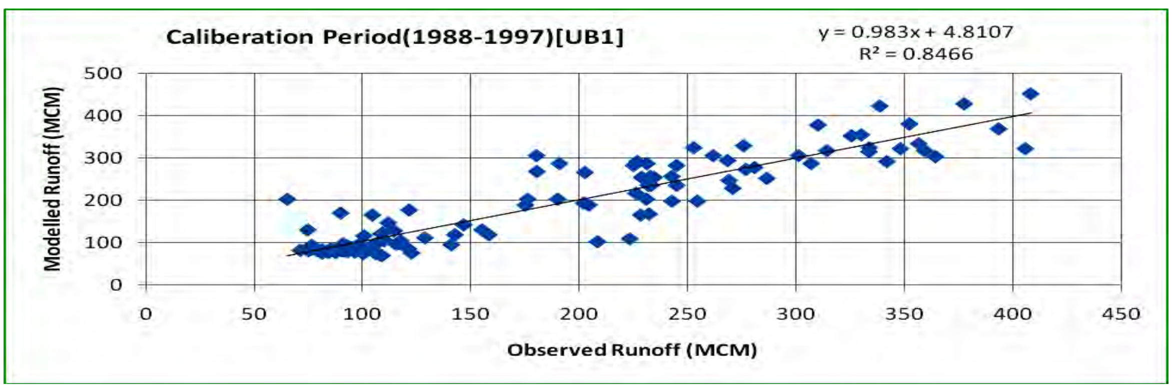

Validation Period(1999-2008)[UA]
Modelled
Observed
Runoff (MCM)
500
400
300
200
100
0
Jan-99
Jun-99
Nov-99
Apr-00
Sep-00
Feb-01
Jul-01
Dec-01
May-02
Oct-02
Mar-03
Aug-03
Jan-04
Jun-04
Nov-04
Apr-05
Sep-05
Feb-06
Jul-06
Dec-06
May-07
Oct-07
Mar-08
Aug-08
Month From Start

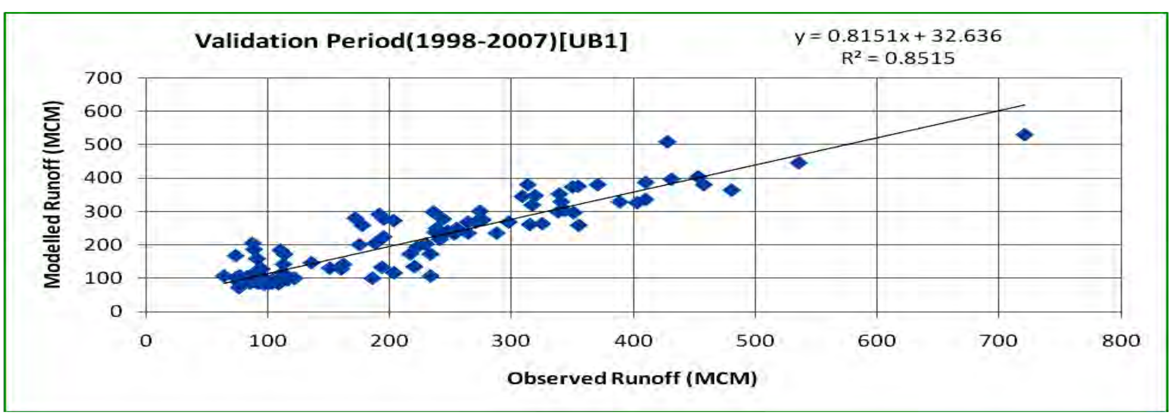

Caliberation Period(1989-1998)[UB]
Modelled
Observed
Runoff (MCM)
500
400
300
200
100
0
Jan-89
Jun-89
Nov-89
Apr-90
Sep-90
Feb-91
Jul-91
Dec-91
May-92
Oct-92
Mar-93
Aug-93
Jan-94
Jun-94
Nov-94
Apr-95
Sep-95
Feb-96
Jul-96
Dec-96
May-97
Oct-97
Mar-98
Aug-98
Month From Start

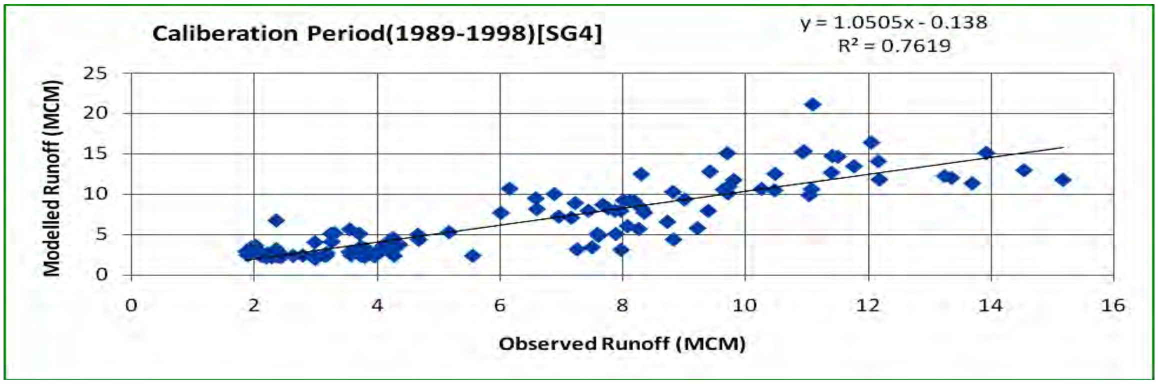

Validation Period(1999-2008)[UB]
Modelled
Observed
Runoff (MCM)
400
300
200
100
0
Jan-99
Jun-99
Nov-99
Apr-00
Sep-00
Feb-01
Jul-01
Dec-01
May-02
Oct-02
Mar-03
Aug-03
Jan-04
Jun-04
Nov-04
Apr-05
Sep-05
Feb-06
Jul-06
Dec-06
May-07
Oct-07
Mar-08
Aug-08
Month From Start

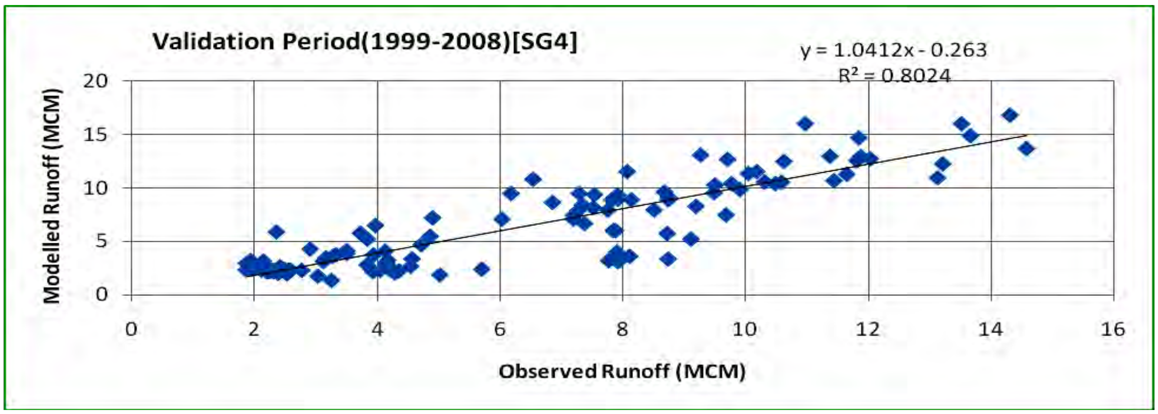

Caliberation Period(1989-1998)[SG1]
y = 1.0708x - 12.664
R² = 0.9132
Modelled Runoff (MCM)
Observed Runoff (MCM)

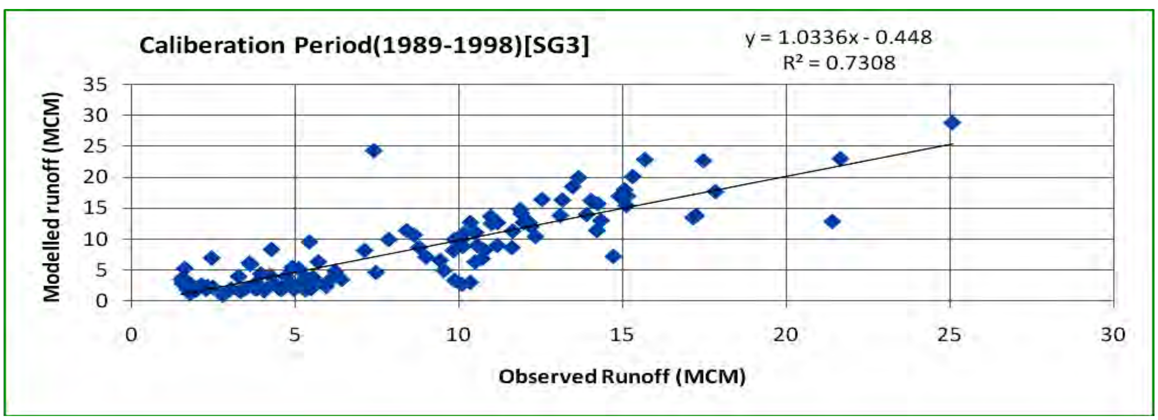

Validation Period(1999-2008)[SG1]
y = 1.0293x - 7.9433
R² = 0.9144
Modelled Runoff (MCM)
Observed Runoff (MCM)

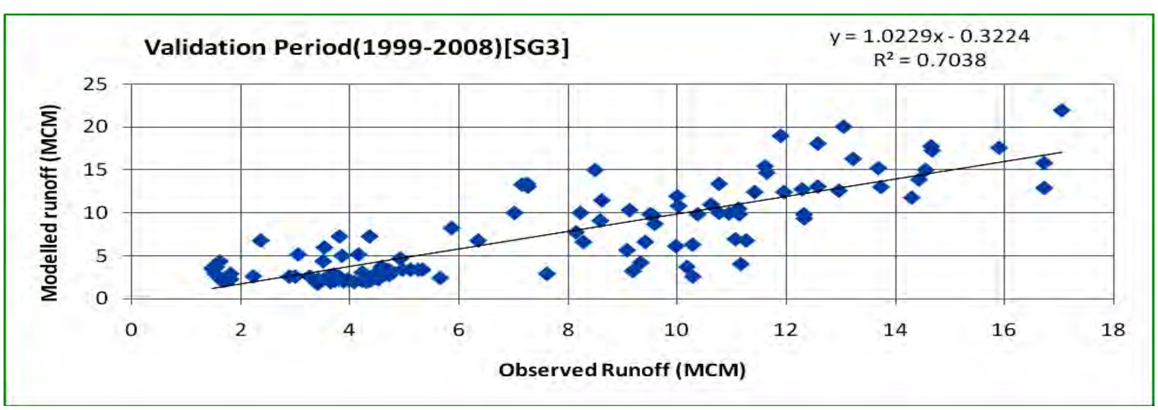

Caliberation Period(1988-1997)[UB1]
y = 0.983x + 4.8107
R² = 0.8466
Modelled Runoff (MCM)
Observed Runoff (MCM)

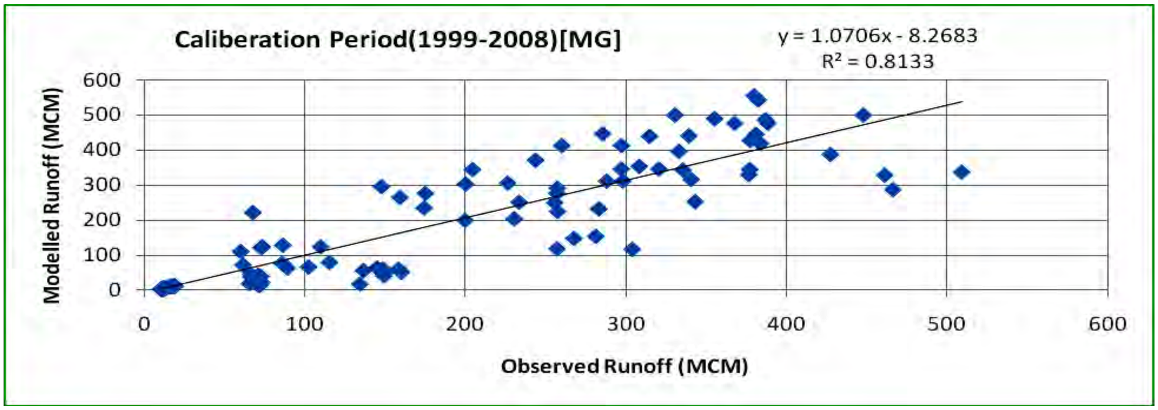

Validation Period(1998-2007)[UB1]
y = 0.8151x + 32.636
R² = 0.8515
Modelled Runoff (MCM)
Observed Runoff (MCM)

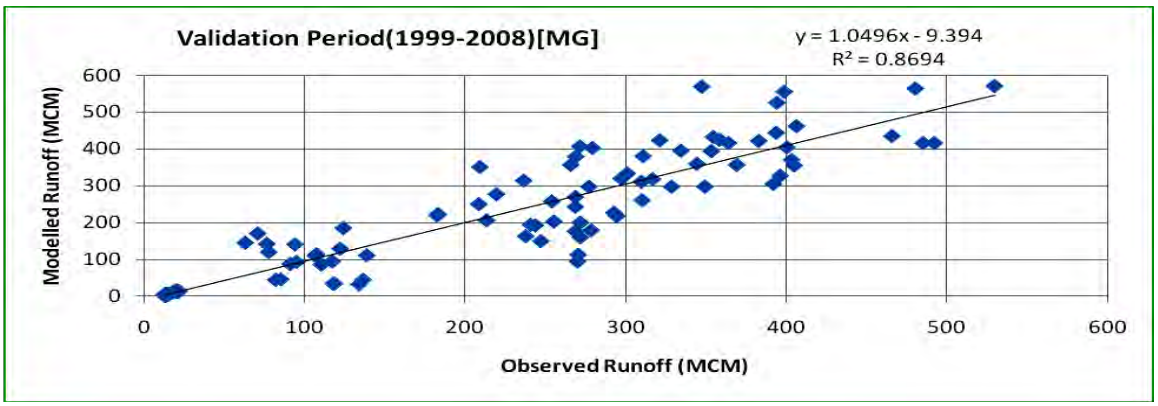

Caliberation Period(1989-1998)[SG4]
y = 1.0505x - 0.138
R² = 0.7619
Modelled Runoff (MCM)
Observed Runoff (MCM)

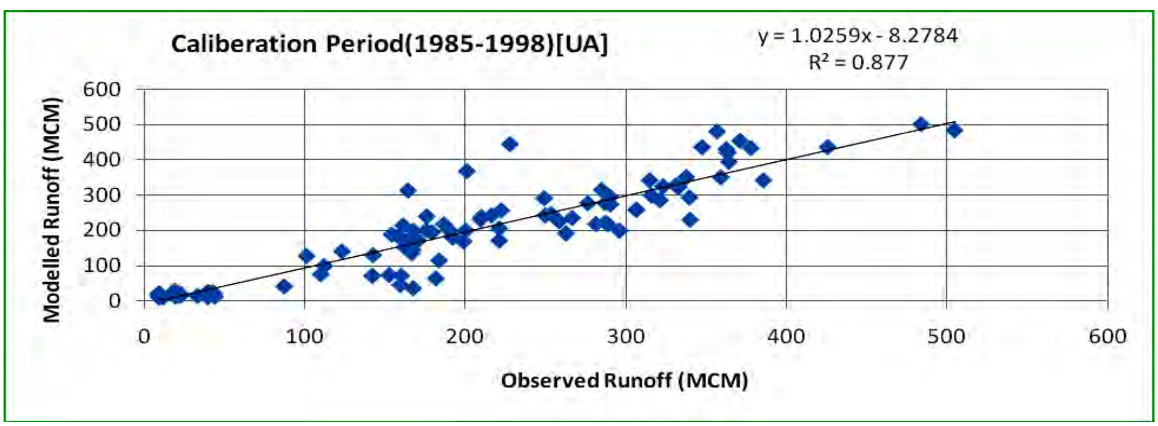

Validation Period(1999-2008)[SG4]
y = 1.0412x - 0.263
R² = 0.8024
Modelled Runoff (MCM)
Observed Runoff (MCM)

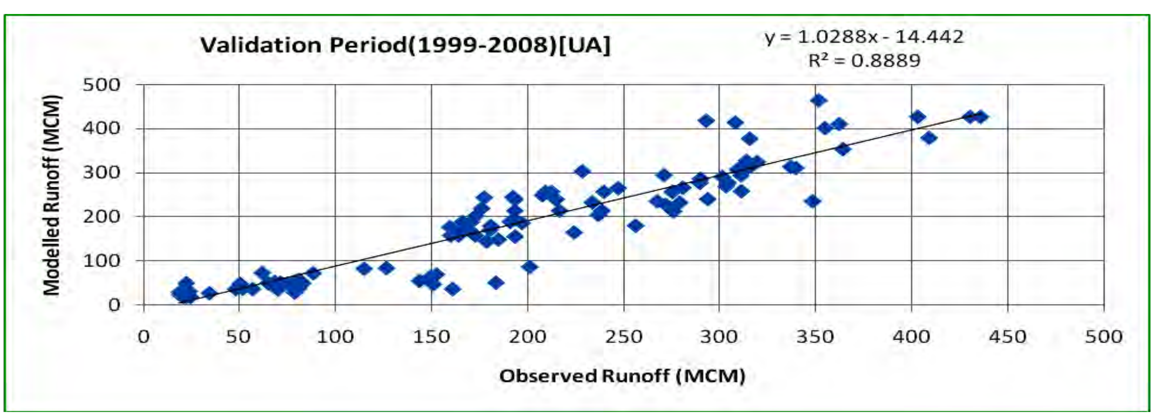

Caliberation Period(1989-1998)[SG3]
y = 1.0336x - 0.448
R² = 0.7308
Modelled runoff (MCM)
Observed Runoff (MCM)

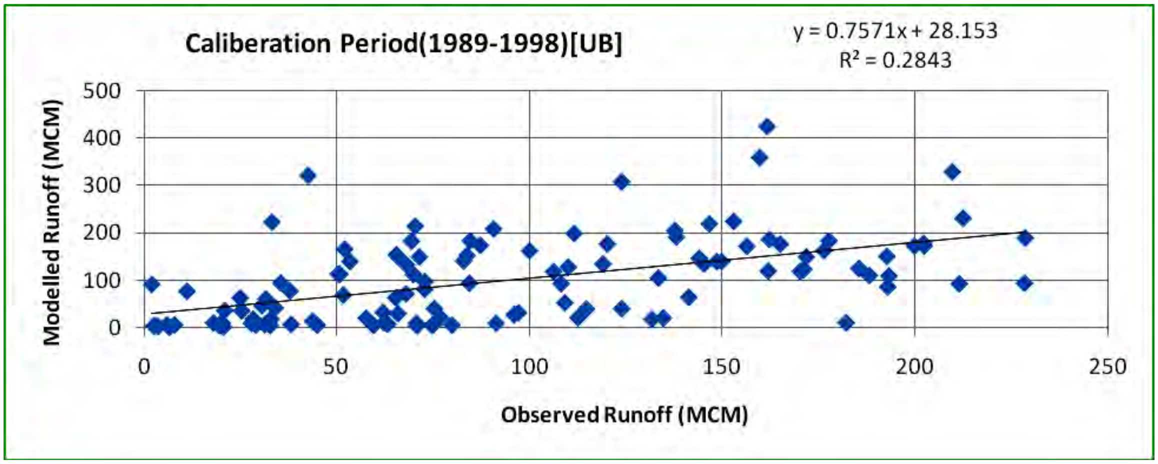

Validation Period(1999-2008)[SG3]
y = 1.0229x - 0.3224
R² = 0.7038
Modelled runoff (MCM)
Observed Runoff (MCM)

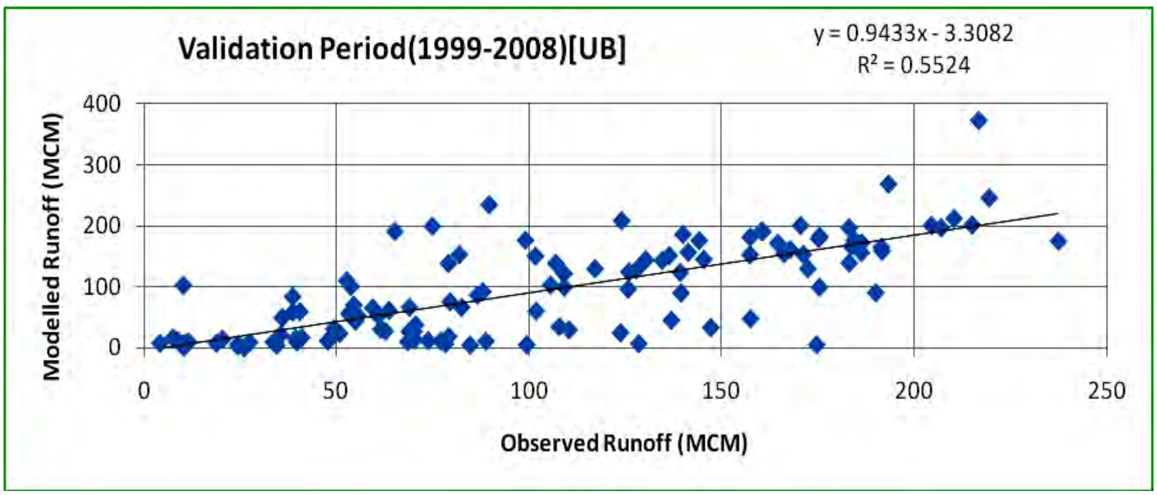

Caliberation Period(1999-2008)[MG]
y = 1.0706x - 8.2683
R² = 0.8133
Modelled Runoff (MCM)
Observed Runoff (MCM)
0
100
200
300
400
500
600


Validation Period(1999-2008)[MG]
y = 1.0496x - 9.394
R² = 0.8694
Modelled Runoff (MCM)
Observed Runoff (MCM)
0
100
200
300
400
500
600


Caliberation Period(1985-1998)[UA]
y = 1.0259x - 8.2784
R² = 0.877
Modelled Runoff (MCM)
Observed Runoff (MCM)
0
100
200
300
400
500
600


Validation Period(1999-2008)[UA]
y = 1.0288x - 14.442
R² = 0.8889
Modelled Runoff (MCM)
Observed Runoff (MCM)
0
50
100
150
200
250
300
350
400
450
500





APPENDIX F
Statistical characteristics of Regression equation

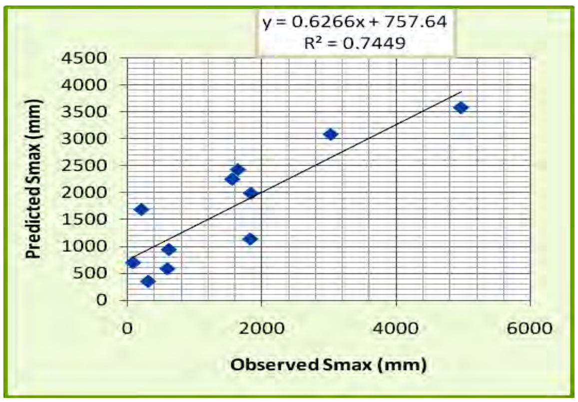
Coefficients Smax, α and ε obtained from linear regression and Sum of error

- **Max. Catchment holding capacity (Smax).**

river	Area (km2)	P (mm)	PET(mm)	Slope (%)	Observed Smax(mm)	Predicted Smax(mm)
Getcha	97	1131.55	1871.20	17.00	591	591.00
Gilo	2437	890.84	1515.98	8.70	4967	3576.18
Birbir	2563	1513.98	1479.08	3.41	203	1689.67
Gumero	106	1688.75	1583.82	28.37	1826	1141.33
Keto	1006	878.38	1529.15	11.00	1554	2250.99
Geba	1894	914.73	1542.60	7.10	1641	2427.73
Sori	1622	968.97	1622.56	3.01	612	947.22
Uka	52.5	2198.52	1659.18	14.20	303	358.39
Alwero	2800	824.81	1357.07	6.80	3025	3081.41
Mesha	1653	1242.69	941.39	6.00	1835	1990.24
Pokwo	978	743.86	1547.46	5.10	138	1004.68

Target Cell (Value Of)

Name	Original Value	Final Value
Equal to	33.45028	Obs. Smax
Changing Cells		
Name	**Original Value**	**Final Value**
a-Coefficient	0.090	0.218
b-Area	0.710	0.777
c-P	0.125	0.228
d-PET	-0.112	-0.001
e-S	0.930	0.972

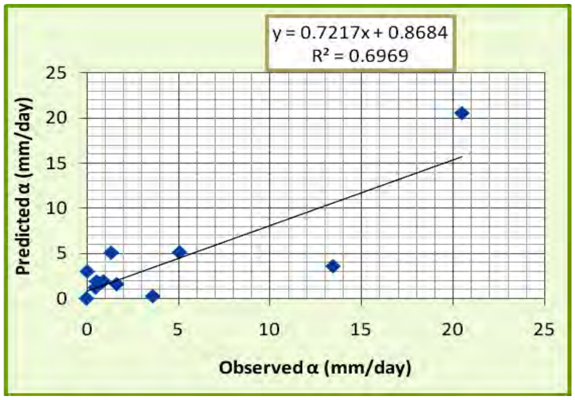


- **Alpha (α)**

river	Area (km2)	P (mm)	PET(mm)	Slope (%)	Observed α(mm/day)	Predicted α(mm/day)
Getcha	97	1131.55	1871.20	17.00	20.50	20.50
Gilo	2437	890.84	1515.98	8.70	13.46	3.56
Birbir	2563	1513.98	1479.08	3.41	0.92	1.89
Gumero	106	1688.75	1583.82	28.37	1.65	1.57
Keto	1006	878.38	1529.15	11.00	1.35	5.05
Geba	1894	914.73	1542.60	7.10	0.04	2.98
Sori	1622	968.97	1622.56	3.01	0.49	1.19
Uka	52.5	2198.52	1659.18	14.20	5.08	5.10
Alwero	2800	824.81	1357.07	6.80	0.55	1.87
Mesha	1653	1242.69	941.39	6.00	0.004	0.003
Pokwo	978	743.86	1547.46	5.10	0.71	1.61

Target Cell (Value Of)

Name	Original Value	Final Value
Equal to	2.36862E+11	Obs. Alpha
Changing Cells		
Name	**Original Value**	**Final Value**
f-Coefficient	0.101	3.39812E-11
g-Area	-0.011	-0.05695442
h-P	1.235	1.164367638
i-PET	2.145	2.069314624
j-S	1.302	1.273539431



- **Epselon (ε)**

river	Area (km2)	P (mm)	PET(mm)	Slope (%)	Observed ε	Predicted ε
Getcha	97	1131.55	1871.20	17.00	0.26	0.26
Gilo	2437	890.84	1515.98	8.70	0.08	0.09
Birbir	2563	1513.98	1479.08	3.41	1.00	0.03
Gumero	106	1688.75	1583.82	28.37	1.29	0.59
Keto	1006	878.38	1529.15	11.00	0.54	0.13
Geba	1894	914.73	1542.60	7.10	2.91	1.28
Sori	1622	968.97	1622.56	3.01	0.31	0.02
Uka	52.5	2198.52	1659.18	14.20	0.93	0.23
Alwero	2800	824.81	1357.07	6.80	0.40	0.07
Mesha	1653	1242.69	941.39	6.00	0.33	0.56
Pokwo	978	743.86	1547.46	5.10	1.35	0.04

Target Cell (Value Of)

Name	Original Value	Final Value
Equal to	22.37078	Obs. epselon
Changing Cells		
Name	**Original Value**	**Final Value**
k-Coefficient	0.1	0.001662
l-Area	0.003	-0.00911
m-P	0.213	0.194391
n-PET	-0.021	-0.04094
0-S	1.432	1.424502