Addis Ababa University
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Predicting Discharge at Ungauged Catchments Using Rainfall-Runoff Model

(Case study: Omo-Gibe River Basin)

by

Bogale Tesfaye

July 2011

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Advisor: Dr. Bayou Chane

Thesis submitted to School of Graduate Studies, Addis Ababa Institute Technology, in partial fulfillment of the requirements for the Degree of Masters of Science in Civil Engineering (Hydraulic Engineering Major).

July 2011

Certification

I, the undersigned, certify that I read and hear by recommend for acceptance by Addis Ababa Institute of Technology a dissertation entitled "Predicting Discharge at Ungauged Catchments Using Rainfall-Runoff Model (Case study: Omo-Gibe River Basin)**”** in partial fulfillment of the requirements for the degree of Master of Science in Hydraulic Engineering.

Dr. Bayou Chane

(Supervisor)

Declaration

I, Bogale Tesfaye Kelkay, declare that this dissertation is my own original work and that it has not been presented and will not be presented by me to any other University for similar or any other degree award.

Signature: ________________________________

Acknowledgements

Above all I thank the almighty of GOD for his mercy and grace upon me during all my works and in all my life.

Very special thanks to my supervisor, Dr. Bayou Chane, for giving me valuable guidance and for his friendly approach throughout my research.

I would like to express my sincere gratitude to the Addis Ababa University, department of civil Engineering staffs who gave me the post-graduate courses.

My gratitude also goes to the Ministry of Water Resources, particularly for staff members under the Department of Hydrology, GIS and Library and National Metrological Agency (NMA) for providing hydrological and metrological data for free.

Last but the bests, I would like to thank my wonderful family and friends for their ultimate support throughout my life.

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Abstract

This paper deals with predicting discharge at ungauged catchments, the case of Omo-Gibe 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 Omo-Gibe river basin, most of the catchments are ungauged. Hydro-meteorological data from twenty four metrological and twenty two 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 40 to 3242 km^2. Key model parameters considered consist of sub-surface runoff coefficient (α), surface runoff coefficient (ε), and maximum water holding capacity of catchments (S_{max}). These parameters are calibrated using an automatic optimizing routine of the WATBAL model and through routine iteration; S_{max} is found to vary from 3403mm to 466mm, α from 64mm/day to 0.26mm/day and ε from 9.6 to 2.6. Some more model parameters, namely, direct runoff coefficient (β), subsurface runoff coefficient (γ), and base flow (R_b) are calibrated manually. The hydrograph characteristics of observed and simulated events are compared using various evaluation criteria consisting of Nash-Sutcliffe coefficient (NS) greater than 0.6, relative volume error (RVE) 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, 73% fulfilled the criteria. Based on availability of required data, six physical catchment characteristics (PCCs) are selected among those commonly used in many regionalization studies. These are catchment area, mean annual precipitation, mean annual evapotranspiration, average catchment slope, longest flow path and mean catchment elevation. In addition to the PCCs, input data including precipitation, observed flow, temperature, relative humidity and sunshine are used in the WATBAL rainfall-runoff model. Four parameter regionalization methods (multiple regression, spatial proximity, area ratio and sub-basin mean) were applied to transfer model parameter values from the gauged to the ungauged catchments.

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List of Acronyms

Alpha	Sub-surface runoff parameter in WATBAL model
Beta	Direct runoff parameter in WATBAL model
CDF	Cumulative distribution function
DEM	Digital elevation model
El	Mean elevation of watershed
Epsilon	Surface runoff
F-Test	Value which indicates the significance level of the regression
GMT	Greenwich Mean Time
IAHS	Prediction in Ungauged Basin initiative by the International Associations of Hydrological Science
Lon	Longest flow path
MoWR	Ministry of Water Resource
MPs	Model parametrs
NMA	National Meteorological Agency
NS	Nash-Sutcliffe coefficient
OMGRBIDMP	Omo-Gibe River Basin Integrated Development Master Plan Study
PCCs	Physical catchment characteristics
PET	Potential evapotranspiration
PUB	Prediction in Ungauged Basins
RVE	Relative Volume Error
R^2	Coefficient of Determination
S-max	Maximum catchment water-holding capacity Parameter in WATBAL model
WATBAL	An integrated water balance model

CHAPTER ONE

1. Introduction

1.1. Background

Sustainable water resources planning and management requires data to enable quantification of water quality and quantity. Information is required on the rates of transfers and storage of water within a catchment. Lack of adequate hydrological data introduces uncertainty in both the design and management of water resources systems. And, absence of information about the quantity and quality of water resources arises from poorly developed hydrological networks.

Hydrological data are indispensable for assessment of water resources. Information on water level in rivers and lakes, discharge, sediment and water quality is necessary for a range of projects, in some of which, information on time series, maxima or minima of the variable may be needed. Among examples of areas for which hydrological information is essential, are: water supply planning and water engineering works like dams, reservoirs, spillways, canals, diversions, hydropower, etc. Moreover, availability of hydrological data in real time is needed for management of water resources, reservoir operation, and in particular, flood forecasting and control. Without adequate knowledge of water resources, uninformed decisions are likely to be made, which are not adequate to the rising water stress on the “thirsty planet”.

It is likely that most catchments of the world are ungauged or poorly gauged. Therefore, reliable estimation of continuous stream flow time-series in ungauged catchments has remained a largely unsolved problem. Although significant insight has been gained in recent years, the establishment of the Prediction in Ungauged Basin initiative by the International Associations of Hydrological Science (IAHS) shows that much has still to be done in this area (Wagener and Wheater, 2006). Several ways of obtaining the required information are addressed in literature. Analyzing the methods that has been attempted to estimate the runoff from unguaged catchment from the previous studies, regionalization of model parameters, which is the process of transferring model parameter from comparable catchment to catchments of interest, was the common approach. It is possible to acquire necessary information in order to reduce model parameter uncertainty and uncertainty in predictions of discharge regimes in ungauged catchments.

1.2. Statement of the problem

A better understanding of the hydrological characteristics of different watersheds of Omo- Gibe River Basin is of considerable importance because of the country's interest in the utilization of its water resources, the need to improve and augment 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. Omo-Gibe 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 Omo-Gibe 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 bearing on local developments and downstream users.

1.3. 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 uncertaininty 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 uncertainity in discharge prediction of ungauged catchments unlike that of gauged catchments.

The problem with developing even the simplest models lies primarily in data availability. Most established hydrological models are data intensive, but the Omo-Gibe river basin has limited rain gauge coverage, very short records of long term temperature, wind, relative humidity and evapotranpiration, a few gauged-catchments, and very scarce daily data. The basin is large and has complex characteristic which, together with the lack of data, creates severe constraint to the application of sophisticated hydrological models.

Application of physically based models is practically not feasible for ungauged catchments because of their need for a variety of high quality intensive data. Instead, conceptual models which have fewer parameters are applied, and for this research a lumped conceptual water balance model called WATBAL is selected.

For the Omo-Gibe basin, hydrological data for twenty two well gauged catchments is available from the Ministry of Water & Energy and twenty four meteorological stations from the National Meteorological Agency (NMA). By using well gauged data and establishing relationships between conceptual model parameters and physical catchment characteristics, parameters for WATBAL model can be determined for poorly gauged catchments. This reduces parameter uncertainty and ensures reliable prediction of discharge regimes.

1.4. Objectives of the study

1.4.1. General objective

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

1.4.2. Specific objectives

- To determine WATBAL model parameters required to estimate monthly flow for ungauged watersheds
- To identify catchment characteristics that can be used for predicting flow for ungauged catchments.
- 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.

1.5. 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?

1.6. Outline of the thesis

In this study a method of regionalization is applied to predict discharges at ungauged catchments. Chapter 2 describes the literature review related to the objectives of this study. Next, a description of the hydrological cycle and rainfall-runoff processes are given and an overview of rainfall-runoff models is discussed. Further model selection criteria and the selected model are described. A description of the study area is given in chapter 3.The main characteristics of the catchment are presented in this portion. To reach the objective of this study, the data collected from different national organization should be processed. This is explained in chapter 4. In 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. In chapter 6 a detailed discussion is raised against the results of model calibration and validation and Regionalization processes. In chapter 7 conclusions on the stated objective are presented. In addition, some recommendations are made.

CHAPTER TWO

2. Literature Review

2.1. Hydrological process

The processes occurring in and above a catchment, from formation of rainfall to generation of stream flow that leaves the catchment through a river, are many and complex. The most important ones, with respect to rainfall-runoff transformation, are described here. This will lead to a better understanding of the rainfall-runoff processes conceptualized by the WATBAL model.

Catchment modeling requires a clear understanding on the hydrologic cycle at catchment scale. The catchment hydrologic cycle involves many processes. Many hydrologists investigated this cycle by a number of studies. A summary of the cycle is given by Chow et al. (1988) and a brief description illustrated in Figure 2.1.

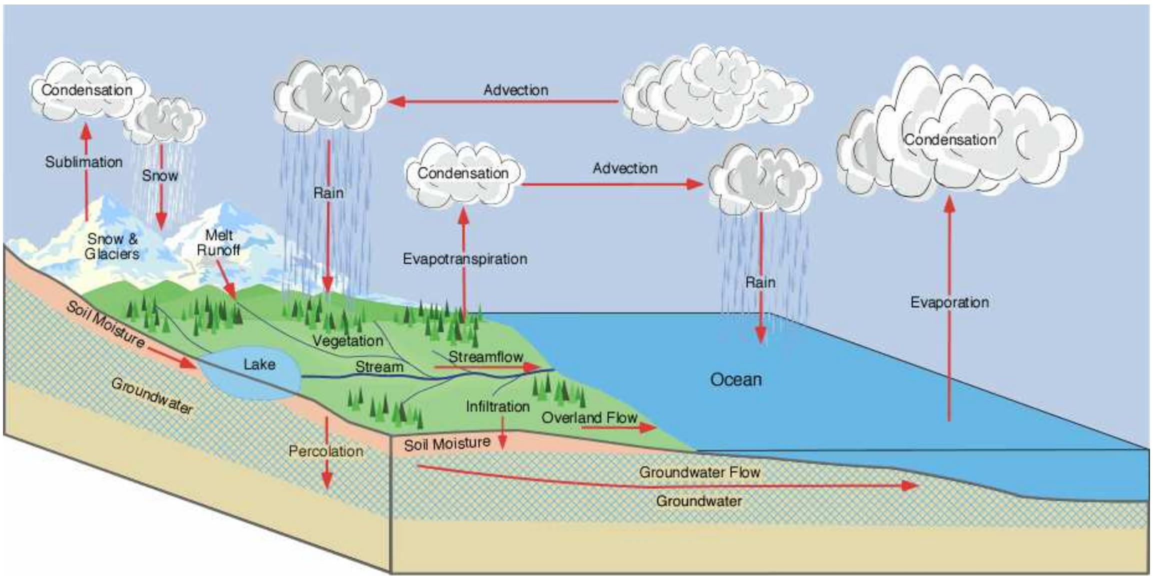


Figure 2.1: Hydrological cycle

The basis of generating rainfall-runoff processes lies in the hydrological cycle. The hydrological cycle can be explained by the interdependence and movement of all forms of water on earth. It usually is described in terms of six major components which are precipitation, infiltration, evaporation, transpiration, surface runoff and groundwater flow. This is shown in Figure 2.1.

While the driving force of this circulation is derived from the radiant energy received from the sun, evaporation can be stated as the start of the cycle. Therefore, the ocean is the earth's principal reservoir; it stores over 97 percent of the terrestrial water. Water evaporates into water vapor, where it contributes to clouds formation in the atmosphere. Here it condensates and may give rise to precipitation (e.g. rainfall or snowfall). In the terrestrial portion of the cycle not all of this precipitation reaches the ground surface because some is intercepted by the vegetation cover or by the surfaces of buildings and other structures, and respectively transpires and evaporates back into the atmosphere. The precipitation reaching the ground surface may then collect in order to form surface runoff, it may infiltrate into the ground or it evaporates back up into the sky (Ward and Robinson, 1990). After infiltration of the precipitation into the soil, the flow process becomes very unpredictable since the catchment runoff behavior is closely related to the subsurface physiographic, geometry and geology. This aspect (i.e. these flow processes) is expounded in the following section. In addition, another dominating process arising from catchment precipitation which contributes to rainfall-runoff generation is described.

2.2. Rainfall-runoff components at catchment scale

Catchment precipitation lies on the basis of runoff generating. Through four aggregated flow processes, precipitation can arrive at the outlet point of the catchment. These are through:

- direct precipitation onto the water surface;
- overland flow;
- through flow;
- Groundwater flow.

These terms are used widely and relatively unambiguously in the literature. However, based on the conditions of the soil which the precipitation bears, the last three flow processes each can embrace several distinctive flow processes. This is outlined below and is illustrated in Figure 2.1 above.

a) Direct precipitation onto the water surface

Not all of the four addressed flow processes are of equal importance in contributing to the total channel discharge. For example, the contribution of direct precipitation onto the water surface is normally small simply because the perennial channel system occupies only a small percentage of catchment areas. However, where catchments contain a large area of lakes or swamps, open channel precipitation may be persistently important (Ward and Robinson, 1990). Furthermore, this flow process is unambiguous.

b) Overland flow

Precipitation falling on the surface, resulting in a flow of water over the land surface by means of a thin water layer sheet flow is called overland flow. Two types of overland flows can be distinguished based on the conditions of the soil which the precipitation bears. These are the Hortonian overland flow and the saturation excess overland flow.

- The Hortonian overland flow occurs when the intensity of the rainfall is greater than the infiltration capacity of the soil and when the rainfall causes storage of water at the land surface. This happens when rainfall events are heavy and where mountainous slopes are bare or covered by thin vegetation.
- The saturation excess overland flow occurs when the soil becomes saturated due to the rise of the phreatic groundwater level up to the land surface. Since the infiltration capacity becomes zero, the precipitation cannot infiltrate anymore and will runoff on top of the land surface. It is mostly generated at the bottom part of hill slopes with shallow phreatic groundwater levels.

c) Through flow

Water that does infiltrate into the soil and then moves laterally through the upper soil horizons towards the stream channel is called through flow. This through flow takes place above the phreatic groundwater level. The water above the phreatic groundwater level occurs in two distinct forms, which are in unsaturated form and saturated form. Three types of through flow can be distinguished, which are the unsaturated subsurface flow, the perched subsurface flow and the macro pore flow.

- Unsaturated subsurface flow arises from infiltrating water entering the subsurface and mostly has a vertical flow direction. This movement of water takes place due to suction head gradients.
- Perched subsurface flow occurs where lateral conductivity in the surface horizons of the soil is substantially greater than the overall vertical hydraulic conductivity through the

soil profile. When for instance an impermeable rock layer underlies a top layer, subsurface water will be discharged on top of this rock layer.

- Water moving through macro pores and / or small natural pipes is called macro pore flow. Water flow exhibits as 'free' flow and, as such, is not controlled by suction head gradients. It can occur either in the saturated as well as the unsaturated form.

d) Groundwater flow

The groundwater flow is the flow of water in the saturated zone. Since water commonly only moves very slowly through the ground, the outflow of groundwater into the channel may lag behind the occurrence of precipitation by several days, weeks or even years. It tends to be very regular since the saturated zone acts as a large storage zone of percolated water. In general, groundwater flow represents the long-term component of total runoff and is particularly important during dry spells when precipitation, overland flow and through flow are absent. In addition, the groundwater flow contribution can be rapid or delayed (Ward and Robinson, 1990).

2.3. Classification of hydrological 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 linking the input and the output variables. These variables may be functions of space and time, and they may also be probabilistic or random variables which do not have a fixed value at a particular point in space and time but instead are described by probability distributions.

Abstract models are classified according to three main criteria:

- Randomness (deterministic or stochastic)
- Spatial variation (lumped or distributed)
- Temporal variation (time-dependent, time-independent)

A number of different abstract models as given in Figure 2.2 are available. The simplest type of model will be a deterministic lumped time-independent model, and the most complex type would be a stochastic model with space variation in three dimensions and with time variation (Chow et al. 1988).

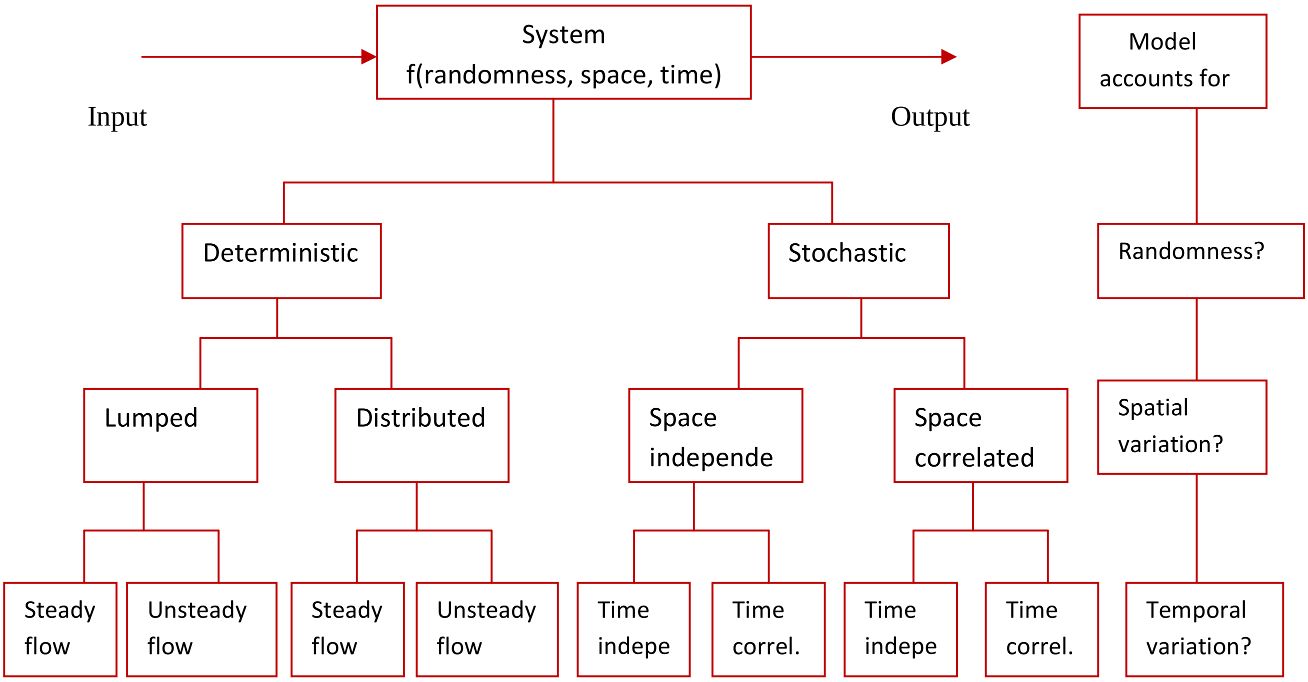


Figure 2.2: Classification of hydrological models

Among all hydrological models, some have many possible applications (with varying degree of availability) while others concentrate only on one or two applications. Some make approximate estimates from limited information, but others require a great deal of descriptive data, detailed computation, and large amount of computer time.

2.4. Model selection

The above model classifications must be considered when selecting the appropriate hydrological model in order to contribute to the stated objectives. At first sight, physically-based models are the most appropriate in modeling rainfall-runoff process while it is the most elaborate way of modeling the rainfall-runoff processes. By the rapid improvement of computational power, the physically-based models became practically applicable in the nineties. There has been considerable discussion regarding the pros and cons of this type of model by Beven (1989). In general it is concluded that physically based distributed hydrological modelling has clear limitations. Further, these models suffer from extreme data demand, scale-related problems (e.g. the measurement scales differ from the process and model scales) and over-parameterization. Therefore, in order to predict rainfall-runoff in gauged and ungauged catchments these models mostly are not practically applicable.

On the contrary, conceptual models normally perform at least as well as physically-based models in predicting discharge regimes and furthermore they do not require huge complexity as physically-based models do. Conceptual models can be considered as a nice compromise between the need for simplicity on the one hand and the need for a firm physical basis on the other hand. This is due to the fact that these models usually are able to capture the dominating hydrological processes at the appropriate scale with accompanying formulations and therefore are very suitable when used in the process of regionalization.

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 [min (+/-), hr (+/-), day (+/-), month (+/), flexible] (where "+" means given and larger time step, and "-" means given and shorter time step). Rank: [0-2]; models with flexible time step receive the highest rank 2, models with limited time step but at least partially applicable in the project get 1, and models with time steps that cannot be applied in the project get 0 (not used).Weighting factor(25%).
b) Spatial scale: For what basin size is the model developed or recommended to be used [small (urban areas), medium (up to 1000 km^2), large (>1000 km^2), flexible size]. Rank: [0-2]; 2 for flexible size, 1 for models with partially applicable spatial scale, and 0 for inapplicable models (not used). Weighting factor (5%).
c) Cost: Price of the model. Rank: [0-2]; 0 for expensive models, 1 for models with medium cost and 2 for models in public domain. Expenses related to technical support are also considered here. Weighting factor (30%).
d) Set-up time: Approximate time needed to set the model into operational use [short, medium, long]. Rank: [0-2]; 1-low, 2-medium, and 0-high. Weighting factor (5%).

e) Expertise: What scientific expertise is required to use the model adequately [low, medium, high]. Rank: [0-2]; 1-low, 2-medium, and 0-high. Weighting factor (5%).

f) Technical support: Support available for to set, calibrate and use the model. Rank: [0-2]; 0 if no support is available, 1 for limited support and 2 for full support. Weighting factor (5%).

g) Documentation: What documentation is available about the model, such as user's guides, reference manuals, web pages, newsletters, etc… [bad, medium, good]. Rank: [0-2]; 0 bad, 1-medium, and 2-good. Weighting factor (10%).

h) Ease-of-use: Describes computer-related user-friendliness of the model, taking into account GUI, input-output (I/O) operations, and visualization options [easy, medium, difficult]. Rank: [0-2]; 2-easy, 1-medium, and 0-difficult. Weighting factor (10%).

i) Operating System: Computer operation system required for the model [UNIX, DOS, Mac, Win 95, 98, Me, 2000, XP]. Rank: [0-2]; 2 for Windows based applications, 1 for DOS applications, and 0 for other operation systems. Weighting factor (5%).

j) Advantages and disadvantages: Summarizes pros and cons of a given model. Rank: [-].

k) References: Lists the key reference(s) to the model in the literature. Rank: [-].

The total score gives the sum of all ranked criteria [0-100%] and not known items received during the ranking process the median value, in order to minimize any potential errors resulting from misclassification.

An attempt is made to select hydrological model that addresses the stated objectives of the study based on the above criterion and is shown in Table 2.1.

Table 2.1: Comparison and selection of hydrological model

Model / criterion	WATBAL	Pitman model	abcd Model	HBV	PRMS
Temporal scale	Day+	Day+	Day+	Day-	Day-
Spatial scale	Flexible	Flexible	Flexible	Flexible	Flexible
Cost	Public Domain	Not known	Not known	Not known	Public Domain
Set-up time[Short/Medium/Long]	Short	Short	Short	Medium	Long
Expertise[Low/Medium/High]	Low	Medium	Low	Medium	High
Technical support	Limited support	Limited support	Limited support	Full support	No support
Documentation [Bad/Medium/Good]	Good	Not known	Not known	Medium	Not known
Ease of use[Easy/Medium/Difficult]	Easy	Medium	Easy	Medium	Difficult
OS (operating system)	Win 95+,MS Excel 5.0+Add-in	Win 95+,MS Excel 5.0+ Add-in	Win 95+,MS Excel 5.0+ Add-in	Win 95, NT	DOS, UNIX
Advantages	Easy to use, Low data requirements, Both event and continuous simulations	Easy to use, Low data requirements Both event and continuous simulations	Easy to use, Low data requirements Both event and continuous simulations	All hydrologic processes modeled Fairly low data requirements	Parameter optimization and sensitivity analysis capabilities
Disadvantages	No event simulations Empirical parameters	Limited information available	Limited information available	Designed for daily time step *Simplified soil moisture dynamics Limited information available	DOS I/O operations No support Limited available information
References	Yates , 1994	Pitman , 1973	Alley, 1984	Lindstrom et al.(1997) SHMI (2003)	Leavesley et al. (1983)
Total score [0-100%]	92.5	70	72.5	47.5	40

As shown in Table 2.1, the HBV-96 and PRMS models need daily time step data and are not compatible with the available data. Further the set up time and expertise required is high with no documentation available. The Pitman model and the abcd model can be applicable for the stated objective of the study except with their limitation with documentation and accessibility.

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 and it is recommended for giving good results in predicting MPs that are used to estimate flow of ungauged catchments.

The main drawback related to WATBAL model is that, some of the model parameters are usually calibrated (optimized) manually by trial and error method which sometimes leads to subjective judgment of the model parameter values. In order to reduce the subjective judgment, crosschecking of the optimized model parameters with prior range of previously done studies can be carried out.

2.5. WATBAL model

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 (See Figure 2.3). The simplified representation of soil moisture dynamics has been shown to adequately represent runoff changes due to climate fluctuations (Yates and Strzepek, 1994). The second is the estimation of potential evapotranspiration, for which there are three possible alternatives, depending on data availability.

a) 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 (See Figure 2.3). The water balance component of the model comprises six parameters related to direct runoff (β), surface runoff (ε), sub-surface runoff (α and γ), maximum catchment water-holding capacity (S_{max}), baseflow (R_b).

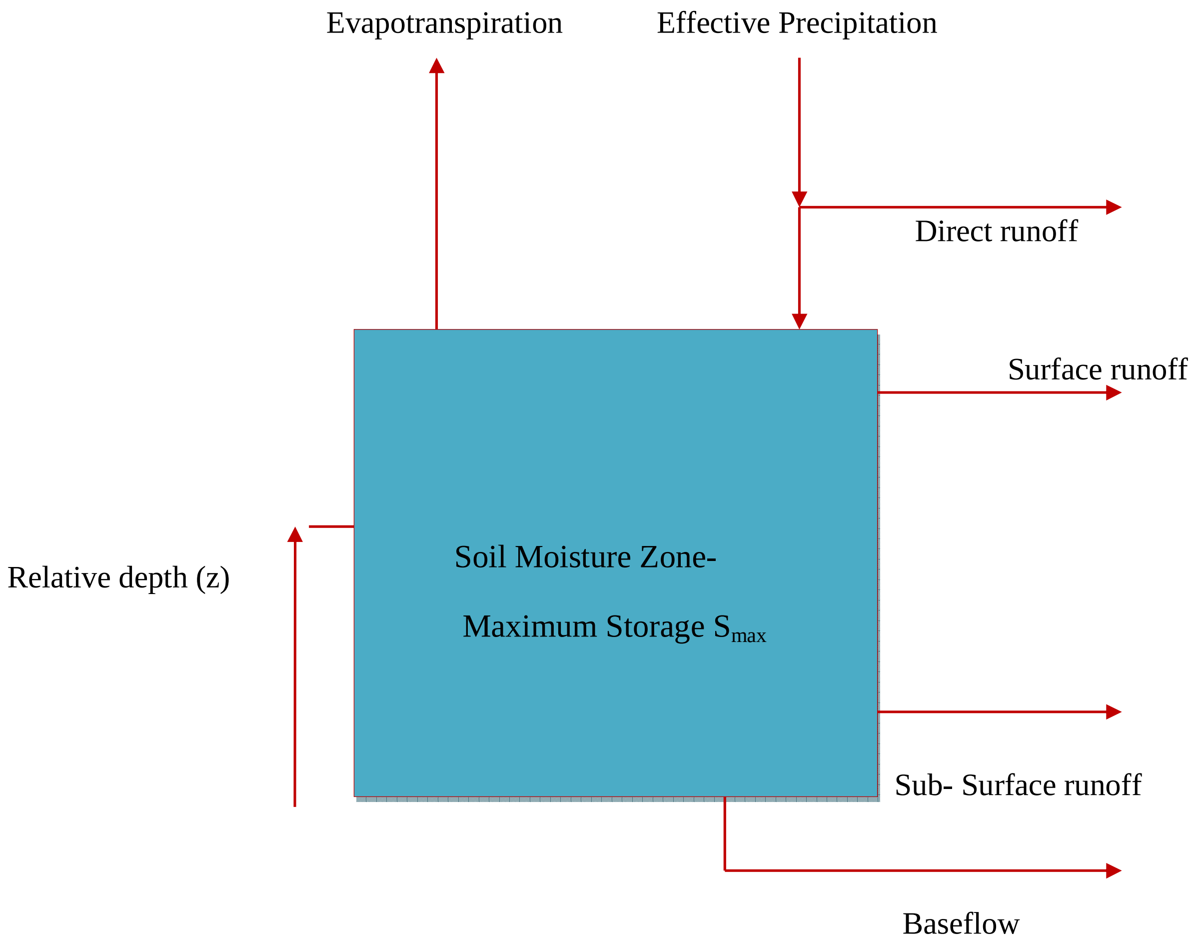


Figure 2.3: Conceptualization of the WATBAL model water balance

The monthly soil moisture balance is written as:

$$S_{\max}\frac{dz}{dt} = P_{eff}(t)(1-\beta) - R_s(z,t) - R_{ss}(z,t) - E_v(Pet,z,t) - R_b \text{............}(2.1)$$

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 (unitless) ($0 \leq z \leq 1$)

S_{max}, 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 S_{max} 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, $P_{eff.}$ A calibration parameter, ε, allows for surface runoff to vary both linearly and non-linearly with storage (Yates, 1996).

$$R_s(z,P,t) = \begin{cases} z^{\varepsilon}(P_{eff} - R_b) & \text{for } P_{eff} > R_b \\ 0 & \text{for } P_{eff} \leq R_b \end{cases} \quad \text{.................(2.2)}$$

Sub-Surface runoff R_{ss}, 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.

$$R_{ss} = \alpha \ z^{\gamma} \text{..........................(2.3)}$$

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

$$R_d = \beta P_{eff} \quad \text{.............................(2.4)}$$

The base flow (R_b) must be determined by the user and entered into the model as a constant value. Total runoff for each time step is the sum of the four runoff components:

$$R_{total} = R_s + R_{ss} + R_b + R_d \text{ ………. (2.5)}$$

In most places in Africa and thus in Ethiopia snow melt is not a concern. Potential evapotranspiration is computed using one of the following 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. A non-linear relationship (based on Kaczmarek, 1993) is used to compute actual evapotranspiration from potential evapotranspiration.

$$E_v(z, Pet, t) = Pet\left(\frac{5z - 2z^2}{3}\right) \quad ....(2.6)$$

b) 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 optimise parameters until the model output becomes an acceptable estimate of the observed runoff regime. This necessitates to have observed runoff data against which parameter values are calibrated. Ideally, a split sample test should be performed in which observed runoff record is split into two segments that are used for calibration and validation of the model. If the statistical values derived from the calibration and validation procedure are above threshold values, then the fitted model parameters are deemed acceptable.

Model parameters are found through empirical analysis of monthly and annual runoff data. Key model parameters are α, ε and S_{max}. Within the model, an automatic optimising routine can be utilised to calibrate the above three parameters. Statistical relationship is used 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.

S_{max} has units of mm. Regions with higher runoff coefficients (i.e. average annual rainfall (mm)/average annual precipitation (mm)) generally have larger S_{max} and vice-versa. 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). 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 (See equation 2.2). Smaller values of ε represent an increase in the contribution of surface runoff; therefore, smaller ε is generally associated with smaller soil moisture capacities and greater surface runoff (e.g. tundra and chaparral). Regions with larger baseflows and flatter runoff hydrographs generally have a higher contribution of runoff from sub-surface flow. Higher values of ε tend to reduce the contribution from surface runoff.

c) 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 Application. When WATBAL is loaded it is run from a button (runoff) on the Excel toolbar. This button gives access to both Dialog boxes. Below is a description of how to load the model as well as descriptions of the Dialog boxes.

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 not to 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 is no limitation on the number of years when performing analysis on a monthly time scale or longer.

CHAPTER THREE

3. Description of the Study Area

3.1. Location of study area

The Omo-Gibe river basin is one of the major river basins in Ethiopia and is situated in the southern part of the country. It lies between 4°00'N & 9°22'N latitude and between 34°44'E & 38°24'E longitude and covers an area of some 79,000 km^2 with a length of 550 km and an average width of 140 km.

It is an enclosed river basin that flows in to the Lake Turkana in Kenya which forms its southern boundary. The western watershed is the range of hills and mountains that separate the Omo-Gibe Basin from the Baro-Akobo Basin. To the north and northwest the basin is bounded by the Blue-Nile Basin with small area in the northeast bordering the Awash Basin. The whole of the eastern side borders the Rift Valley Lakes Basin (Richard Woodroofe and Associates, 1996).

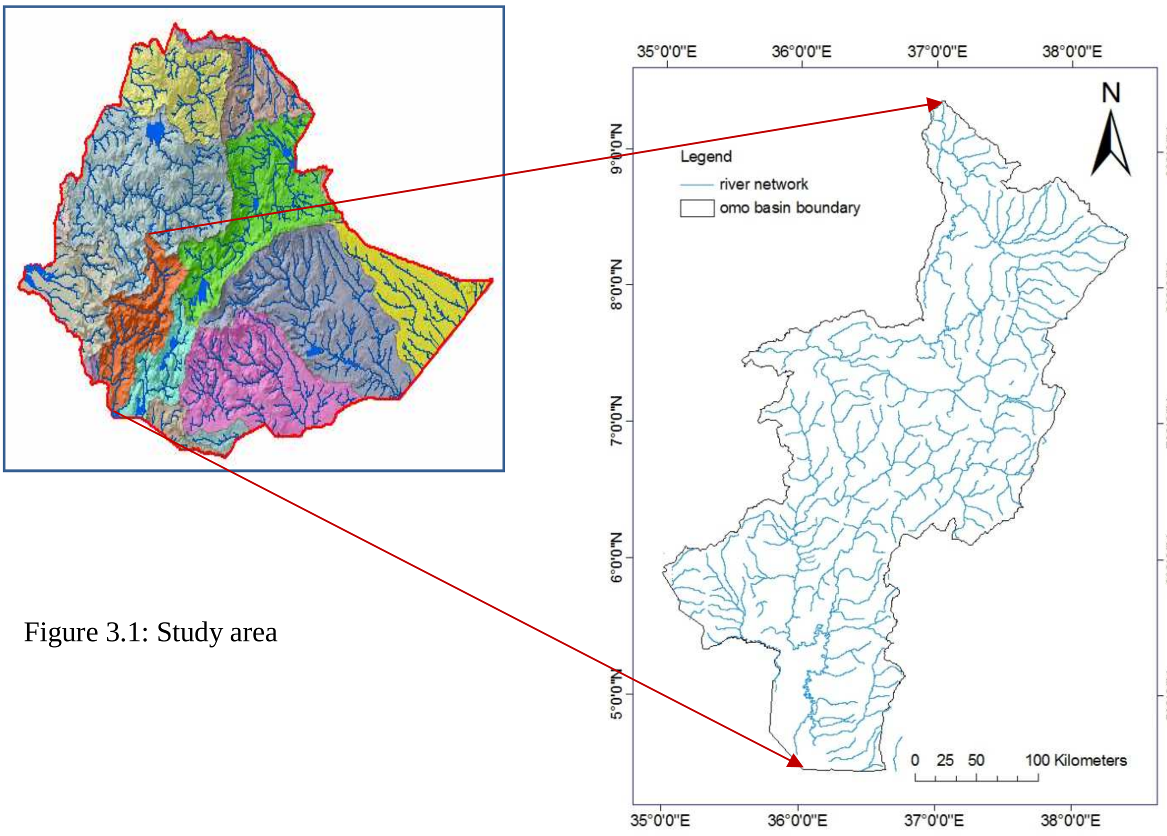


Figure 3.1: Study area

3.2. Climate

3.2.1. Rainfall

In terms of rainfall the Basin can be split in to four regions, three of them having a unimodal and one is a bimodal rainfall regime. The northern part of the basin, including Bako, Weliso, Welkite and south to just north of Jima, has rainfall for about seven months, from March to September with a range of 1100-1800 mm per annum. The small rains are from March to May and the main from June to September with a marked increase in July and august.

The north-center area, including bonga, jima and Sodo, has a more even distribution of rainfall over March to September without any peak in July and august. The region generally receives more than 1200mm, rising to 2000 mm on the western fringes north of Bonga.

The southern-center area, including Maji, Jinka and Sawla, has a prolonged rainy season of nine months. The amount varies from 600 mm in the lower valleys to about 1800 mm in the hilly areas around Maji and in the west. Field observations and local experience indicate that around Sawia, at least, the rainfall pattern is different to the north with the major rains in February and March rather than later in the year. The evidence for this prolonged rainy season was confirmed by field experience with wet conditions experienced from March through November.

Generally according to the isohyetal map of the OGMP, the rainfall ranges from over 1900 mm/year in the northern and western part of the basin, to about 300 mm/year in the lower part of the basin near Lake Turkana.

3.2.2. Temperature

The mean annual temperature in the Basin varies from 16˚C in the highlands to the north to over 29˚C to the south, reflecting the correlation between temperature and elevation. There is little variation in the minimum temperature (around 10˚C for most of the year) but the maximum drops markedly during July and August to 20˚C compared to a maximum of 27˚C.Wishwish, to the west of the Basin shows this pattern with slightly slower values and less variation in the maximum. Jinka, to the south of the basin, has the highest average temperatures and shows increased variability in the period November to March, when rainfall is the lowest.

3.2.3. Relative humidity

The highest relative humidity occurs when the rainfall is the highest, reaching an average of over 80% in the high ground to the west of the Basin. To the south of the basin the average value drops below 65%.The seasonal variation in humidity follows a similar pattern to the rainfall.

3.2.4. Sunshine

As the major factor affecting the average daily hours of sunshine on the Basin is the cloud factor, with relatively little effect due to the seasonal movement of the earth. Thus there are relatively low sunshine levels in the west highlands to the west of the basin. There are marked minima for all stations in June and September. Jinka has the longest hour of sunshine, with a minimum in August, but this is less marked than for other stations.

3.3. Topography and slope

The topography of the Omo-Gibe basin as a whole is characterized by its physical variation, especially the difference between the northern two thirds which has mountainous to hilly terrain cut by the deeply incised gorges of the Omo, Gojeb and Gilgel Gibe rivers and the southern one third which is alluvial Plain punctuated by hilly areas.

The northern watershed Bako is characterized by high mountains 2800 m with steep slopes and rolling upland Plateaus and basins with most slopes greater than 15%. The north-west boundary is marked by mountains with altitudes of 2000-2500 m and rolling dissected upland basins with areas by depressions with drainage deficiencies, such as the Bako Plain at an attitude of 15-30% the north-Eastemmost border of the Basin is characterized by severe dissection of the upper reaches of the Wabe River.

This pattern continues south from Hosaina towards Sodo with rolling dissected upland plateau forming the highland which is being eroded into by the Omo and Gibe gorges exposing the underlying basalts. Between these highlands and the gorge itself the landform is one of an undulating to rolling plain often exhibiting severe erosion, cut by deeply incised rivers. Most solpes are Greter than 10% and the altitude range is 1650-1850 m.

The central part of the Basin, north and west of the Omo gorge, south of the Gibe Gorge and around Jima, Bonga, Chida, Waka and south to Berehuma, is composed primarily of high relief hills and mountains of 2000-3300 m. North of the Gojeb River the upland areas are relatively undissected but to the south the Kulo Konta hills are severely dissected. These hills are interspersed with relatively narrow undulating upland basins with altitudes of 1800-2000m along the Gilgel Gibe east of Jima and on the upper Gojeb west of Jima.

East of the Omo River the area towards the eastern boundary is almost a basin, with range topography, mountains forming the interfluves between flat to undulating valley floors. The mountainous areas are at altitudes of 2600-2800 m with some crests reaching 3500 m and the valley floors at 1000-1500 m. south to Jinka the relief flattens out to low hills developed on basalt and basement complex granites and gneisses at altitudes of 500-1400m with most slopes 10-15% but steeper in places, this continues to the Basin's southern boundary with the Rift Valley.

This landform, an undulation and dissected hillocky plain with slopes of up to 10%, also forms the Omo-Gibe Basin's south-western boundary with the Baro-Akobo Basin in the Tirma Tid area at altitudes of 1000-1200m. North to Maji, relief and altitude increase to 2500 m and most slopes of 30% or more.

The lower Omo Basin lies at 400-600 m and is composed of gently sloping alluvial-colluvial plains in the North and alluvial plains and fans of varuing degrees of dissections in the south. These alluvial-colluvial plains extend far into the Kulo Konta hills at their northern extent and are among the most inaccessible areas of the basin. Further south, occasional low relief hills and severely dissected vocanic cones and lava flow crop out of the alluvial plain to attitudes of 1000m or so.

The lower Omo plain is characterized by the fact that it is a relatively recent feature formed by successive movements of Lake Turkana and, though it is relatively flat, it contains numerous beach ridges and depressions. The Omo delta, in the south of the Basin and at the northern end of Lake Turkana has aggraded to such an extent in recent years only some 25km^2 of the lake is in Ethiopia.

3.4. Land cover and land use

In very broad terms, most of the northern catchment is under extensive cultivation with increased land pressure meaning the expansion of cultivated areas into increasingly marginal lands at the expense of woodlands. Forested areas are now confined to areas too steep and inaccessible to farm, such as west of Shenen, Botor Becho and between Limu Genet and Jima where a forest often has an understory of coffee.

The Basin boundary west of jima and in the Bonga area has extensive tracts of high forest, though even in this relatively inaccessible area encroachment is noticeable.

The flatter poorer drained bottomlands of the northern catchment are usually not cultivated but are used for dry season grazing and, if suitable, brick making. They are also favored for eucalyptus plantations.

The Gibe, Gojeb and Omo gorges are relatively unpopulated and support a cover of open woodland and bush land with grasses though in accessible areas, such as where the Addis Ababa to Jima road crosses the Gibe Gorge, woodlands are being cleared for charcoal.

The eastern catchment boundary has some of the most densely populated and intensively farmed areas in the country, let alone the Basin. The Gurage area in the North and welayita sodo in the south is dominated by a farming system based on enset.

South of Sodo towards Sawla the landscape is one of high mountains with broad valleys which are less intensively cultivated.

The south of the Basin, generally south of a line from Bonga to Chida and on to Waka in the west and east of the Omo River, is more sparsely populated with a greater proportion of natural vegetation, though even here the high forest especially is being decimated at an alarming rate.

In the south-west, open combreturm woodland with a thick grass cover dominates the lowland with remnants of high forest and encroaching cultivation on higher ground. To the east of the Omo River the vegetation is mainly open acacia bush land with a very thin grass cover. These areas are populated by pastoralists who also grow some crops on the flood retreat of the Omo and on stored soil moisture in other low lying areas.

The south most part of the Basin, the Omo detta has aggraded greatly in recent years but is still predominantly wetland and marsh with some areas of grassland. Again there is some cropping on the retreating flood.

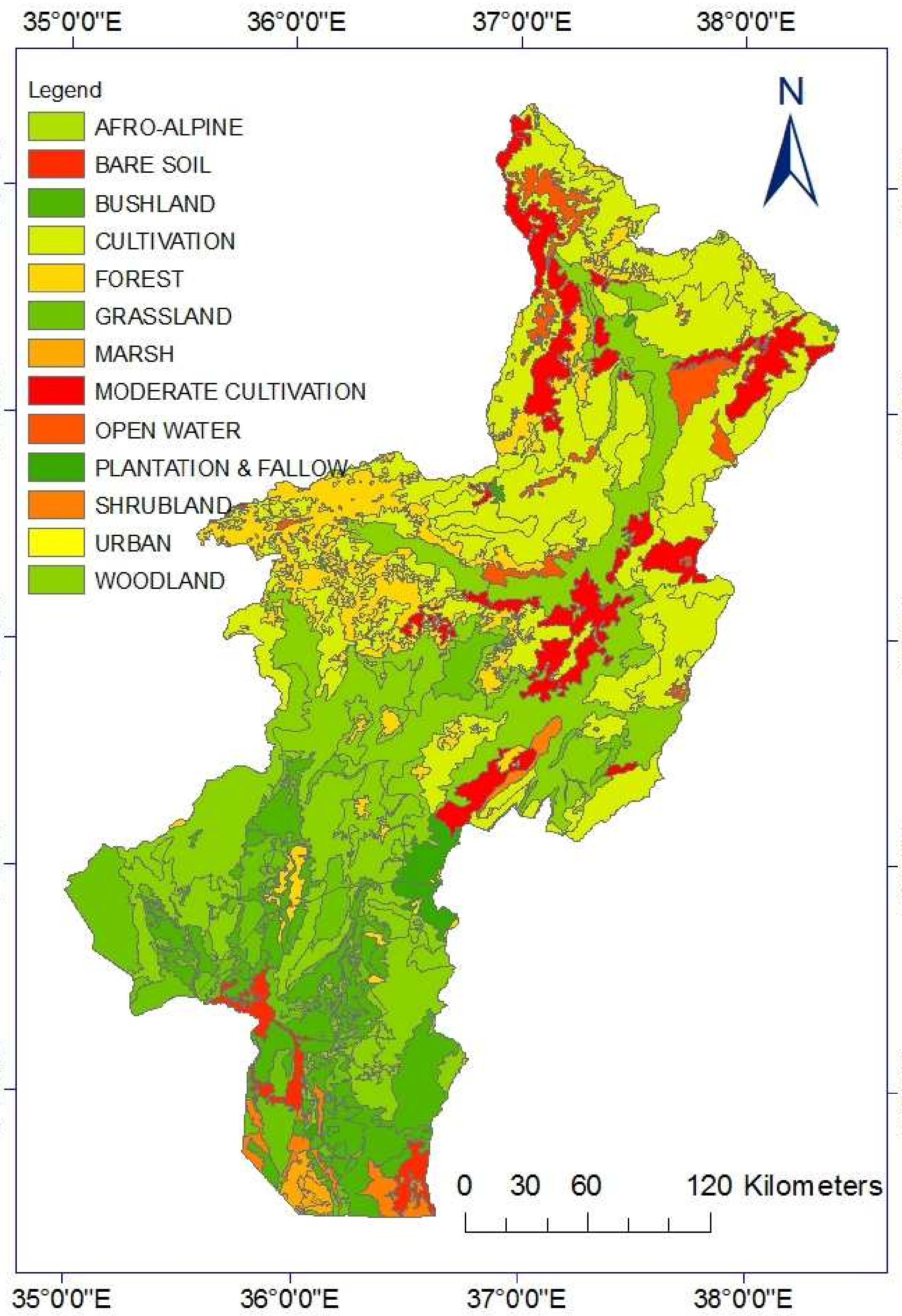


Figure 3.2: Land cover of Omo-Gibe river basin

3.5. Geology and soil type

3.5.1. Geology

The geology of the Omo-Gibe Basin can be divided tentatively in to five groups of rocks according to their age relationships. These groups are:

- The pre-Cambrian crystalline basement rocks
- The early ’flood basalts’ of late Eocene to early Miocene age
- A transitional series of intercalated basaltic and felsic volcanic of late Oligocene to early Miocene age
- A series of felsic volcanics ranging from early Miocene to late Miocene in age
- The post-rift sediments and volcanics, of Poliocene and Quaternary age

Approximately 11% of the Omo-gibe Basin is underlain by Pre-cambrian metamorphic gneisses consisting of felsic meta-sediments and mafic meta-volcanics that represent the older ‘cratonic’ granite-gneiss terrain to the west and a younger ‘oceanic’ to the east. The younger oceanic ‘greenstones’ have been overthrust to the west onto the older craton.The main thrust zone, in the Sharma region west of the lower Omo River is marked by intense shearing and cataclasis.

Approximately 80% of Omo-Gibe Basin is underlain by Tertiary volcanic rocks. Also the Basin occupies the combined Omo and Usno rift valleys which are failed north extension of the lake Turkana-Ethiopian Rift system. In the north part of the Basin, the rives have exploited the extensive fault zones to cut deep gorges. The eroded material has been deposited in the lower part of the Basin as a thick sequence of Quaternary alluvial deposits.

3.5.2. Soil type

The soils in the Omo-Gibe Basin are for the most part permeable and well drained. In the upper and middle parts of the basin this is true of valley slopes near the catchment divide while the valley bottoms have significant areas of less permeable soils with impeded drainage. In the lower Omo, the sedimentary floodplain is mostly characterized by poor drainage.

CHAPTER FOUR

4. Data Collection, Assembling and Gap-filling

4.1. General

According to the theories discussed in chapter two, three basic data sets are necessary for the modeling work. These are the meteorological data (rainfall, temperature, relative humidity and sunshine hours), the hydrological (stream flow) data and the other data called catchment physiographic data.

The WATBAL model requires meteorological and hydrological input data in a monthly time step including rainfall, temperature, relative humidity, sunshine hours and monthly flow data at the sub-basin outlet. Monthly cumulative rainfall, mean maximum and minimum temperatures, mean relative humidity and mean sunshine hours data were compiled for all available stations in the basin. Most of the meteorological stations for which data were collected are located inside the basin and some are located around it. Record lengths of these stations vary from a few years to more than 25 years.

Taking into account the length of record, continuity of data, concurrent period of observation and the distribution of stations in the sub-basin, twenty four meteorological stations are selected for the study. The distribution of these stations within the sub-basin is not even. Hence, the Thiessen Polygon method was used to estimate the areal rainfall and minimize the error introduced by spatial variability. The method is also used to estimate temperature, relative humidity and sunshine hours.

4.2. Hydrological data

Hydrological data were the leading 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 hydrological data made available comes from different source of area.

- From Ministries of water resource (MOWR), Hydrology Department, monthly flow data of twenty two stations from 20 to 39 years have been collected.

- From different project reports which have been done on Omo-Gibe river basin like Omo-Gibe river basin integrated development master plan.

Even though more than 45 hydrometric stations are found in the basin, only 22 gauging stations data were accessible from MoWR, Hydrology Department, for this study. The hydrometric discharge data were available in each station ranging from 20 to 39 years records. Summary of hydrological data is shown in Table 4.1.

Table 4.1: Summary of Hydrological Data

S.no	River	Station(site)	Reference	Sub-catchm.	Area (km^2)	X-Coordinate	Y-Coordinate	Missed data (%)	Remark
1	Sokie	Nr. Areka	92009	Sokie	103	358656.84	790527.43	23.86	filled & extended
2	Ajancho	Nr. Areka	92010	Sokie	306	358650.7	788315.95	19.32	filled & extended
3	Great GHB	Nr. Abelt.	91001	Gibe	15746	343590.65	910002.34	0	filled
4	Wabi	Nr. Wolki	91004	Wabe	1866	364528.81	912144.59	21.59	filled
5	Megacha	@ Gubre	91005	Gorombo	286	367810.29	904394.2	26.89	filled
6	Gojeb	Nr. Endber	91007	Gorombo	109	378803.42	895516.97	4.55	filled
7	Gilgel G.	Nr. Asen.	91008	Gilgel Gibe	2966	299284.45	857090.12	7.58	filled
8	Walga	Nr. Wolki.	91010	Walga	1792	345832.95	921053.07	25.38	filled
9	Gojeb	Nr. Shebe	91011	Gojeb	3577	210786.67	821033.23	10.61	filled
10	Seka	Nr. Seka	91017	Gilgel Gibe	294	251754.16	840722.56	6.06	filled
11	Bidru Awa	Nr. Sokuru	91019	Gilgel Gibe	41	323624.9	875793.14	11.36	filled & extended
12	Ghibie	Nr. Baco	91020	Gibe	288.1	285699.27	1008697.3	4.17	filled
13	Amara	Nr.Shebak.	91021	Amara	68.8	294471.29	1004226.2	10.61	filled
14	Werabesa	Nr. Tolie	91022	Werabessa	234	329354.96	932173.96	25	filled & extended
15	Kito	Nr. Jimma	91023	Gilgel Gibe	85	260640.66	851740.16	21.59	filled
16	Awaitu	@ Jimma	91024	Gilgel Gibe	72	260629.44	849527.62	16.67	filled
17	Woshi	Nr. Dimbra	91025	Sherma	47.5	170940.73	810215.04	4.55	filled
18	Kulti	Nr.Tedel.	91026	Walga	350	353580.09	932084.69	35.61	filled
19	Darghe	Nr. Tedel.	91027	Walga	457.5	337050.66	928826.4	42.8	filled & extended
20	Bulbule	Nr. Serbo	91032	Gilgel Gibe	526	288163.25	837228.89	29.17	filled & extended
21	Guma	Nr. Andra.	92004	Guma	231.2	196243.91	791238.74	1.89	filled
22	Dincha	@ Bong	92005	Guma	443.7	199592.89	796752.48	4.55	Filled

As shown in Figure 4.1 the distribution of the gauging stations within the basin is dense in the northern part of the basin and on the other hand the south western parts of the basin have very low density.

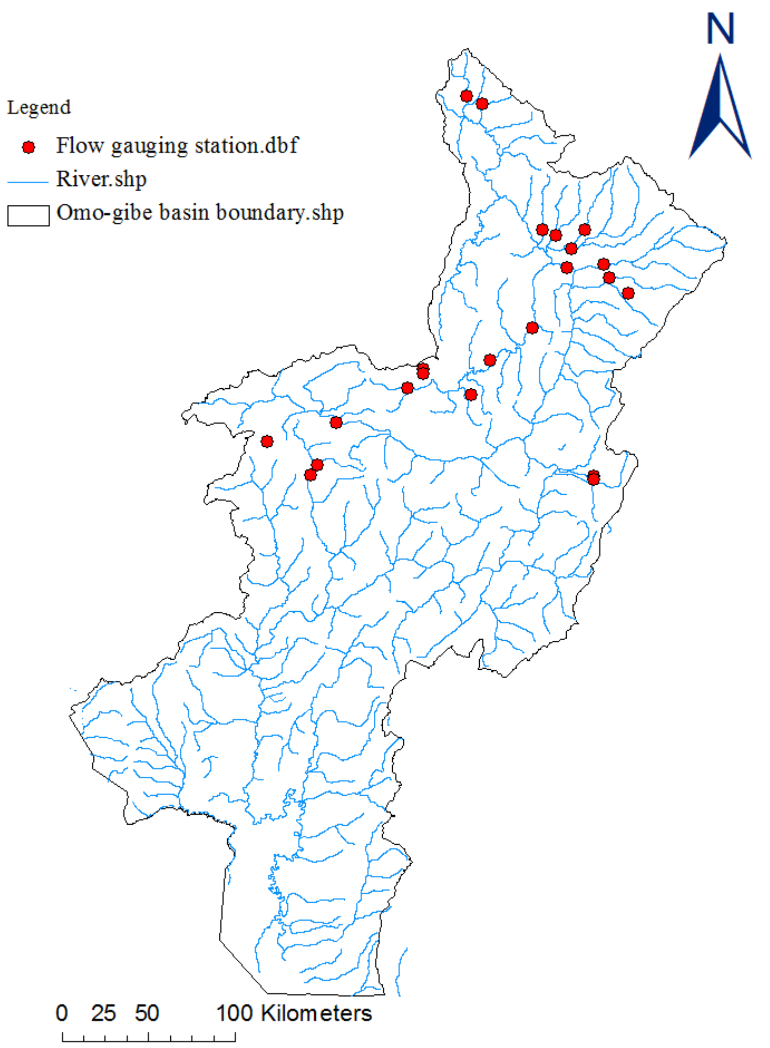


Figure 4.1: Omo-Gibe River Gauging stations

Most of the time, long term data for the design and planning of water resource projects are not always available. The only means is either to extend the short term data somehow or else to generate the data with the properties of the historical data records.

4.2.1. Flow data infilling and records extension

A number of stations in the basin have incomplete records. In order to make use of the partially record data missing values need to be filled in sequence. To fill the missing recorded stream flow gauging data various methods are available. The missing values were filled with multiple station correlation.

There are also some periods with missed and short gauge records, and efforts were made to fill the missed records and extend the short one for using the data for further analysis. In this report, filling and extension of missed records were carried out by developing correlation between the station with missed data and any of the nearby stations, which ever gives good correlation for common data period**.** Table 4.2 shows regression equation used in filling of missed data and extension of short record length of stations.

Table 4.2:Regression equations used for filling and extension of missed hydrological data

Missed River stations(Y)		Nearby River Stations (X)		Correlation coefficient (r^2)	Equation	Remark
River Name	Id	River Name	Id			
Ajancho	92010	Sokie	92009	0.79	$Y=0.498X^{0.958}$	filled & extended
Sokie	92009	Ajancho	92010	0.789	$Y=1.813X^{0.823}$	filled & extended
Amara	91021	Ghibe Nr. Baco	91020	0.73	Y=1.121X+0.956	Filled
Ghibe Nr. Baco	91020	Amara	91021	0.73	Y=0.654X-0.075	Filled
Awaitu @ Jimma	91024	Ghibe-Seka	91017	0.7	$Y=0.156X^{1.069}$	Filled
Bidru awana Nr. Sekoru	91019	Gojeb Nr. Endeber	91007	0.6	Y=0.22X+0.228	filled & extended
Bulbule	91032	G.gibe Nr.Assendabo	91008	0.9	Y=0.209X-0.256	filled & extended
Darge	91027	Megech	91005	0.71	Y=0.515X+0.233	filled & extended
Dincha	92005	Woshi	91025	0.74	$Y=3.526X^{0.626}$	Filled
Woshi	91025	Dincha	92005	0.74	$Y=0.268X^{1.184}$	Filled

G.gibe @ Abelti	91001	G.gibe Nr.Assendabo	91008	0.86	$Y=3.645X^{1.031}$	Filled
G.gibe Nr.Assendabo	91008	G.gibe @ Abelti	91001	0.86	$Y=0.524X^{0.828}$	Filled
GhibeSeka	91017	G.gibe Nr.Assendabo	91008	0.82	$Y=0.234X^{0.780}$	Filled
Gogeb Nr. Endeber	91007	Wabi	91004	0.86	$Y=0.060X^{0.887}$	Filled
Gojeb shebe	91011	G.gibe Nr.Assendabo	91008	0.74	Y=1.245X+11.71	Filled
Gumma	92004	Dincha	92005	0.74	$Y=1.033X^{1.078}$	Filled
Kitto	91023	Awaitu @ Jimma	91024	0.76	Y=0.627X+0.683	Filled
Kulit	91026	Wabi	91004	0.75	$Y=0.227X^{0.759}$	Filled
Megech	91005	Wabi	91004	0.92	$Y=0.161X^{0.876}$	Filled
Wabi	91004	Megech	91005	0.92	$Y=8.127X^{1.043}$	Filled
Walga	91010	Wabi	91004	0.76	$Y=0.093X^{1.228}$	Filled
Werabessa	91022	Walga	91010	0.6	Y=0.179X+2.074	filled & extended

4.3. Meteorological data

The second most important time series data necessary for this research is rainfall data. The source of raw metrological data in Ethiopia is the National Metrological Service Agency (NMSA). A request for monthly rainfall data of 30 years of period in addition monthly mean temperature, relative humidity and sunshine hour duration data was made to the agency. Following the approval of the agency's higher official, monthly data of up to 25 years period including many more stations that are not exactly used in the model work were collected. Out of the entire available automatic recording stations those which are in or proximate to the watersheds considered for the research work were selected. Accordingly a total of twenty four rainfall stations were selected for use in the research work. The location of these rainfall stations is shown in Figure 4.2.

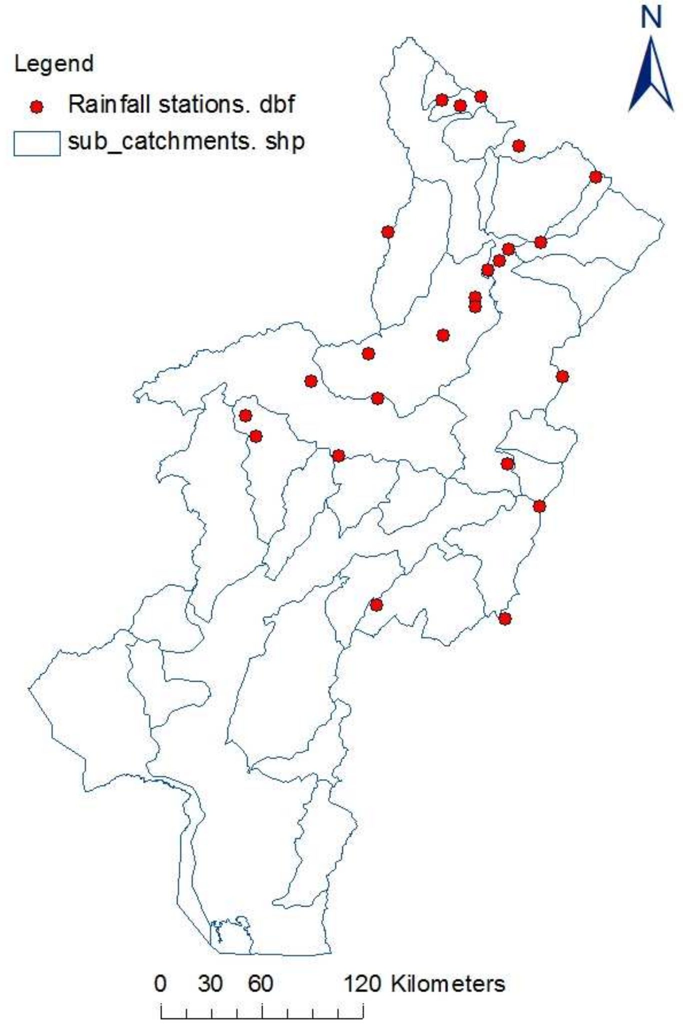


Figure 4.2: Locations of Rainfall Gauging stations

The rainfall records that obtained from NMSA cover the length of years from 1985 to 2006 depending on the available stream flow records particular to catchment being considered. The collected data stretched over these years to obtain adequate match between the rainfall events and the resulting stream flow records. A summary of the rainfall stations with years of record used in the thesis is given in Table 4.3.

According to 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 4.3:Summary of the rainfall stations

S.no	Station Name	Latitude (Degree)	Longitude (Degree)	Elevation (m)	Years of Data used	Missed data (%)	Remark
1	Sawula	6.32	36.88	1500.00	1985-2006	31.06	filled
2	Abelti	8.17	37.53	2050.00	1985-2006	6.44	filled
3	Assendabo	7.77	37.23	2400.00	1985-2006	6.82	filled
4	Atnago	8.32	36.93	1850.00	1985-2006	7.95	filled
5	Babu	7.12	36.67	1880.00	1985-2006	6.44	filled
6	Bonga	7.22	36.23	1650.00	1985-2006	7.20	filled
7	Jimma	7.67	36.83	1725.00	1985-2006	5.30	filled
8	Kumbi	8.12	37.47	1980.00	1985-2006	9.85	filled
9	Meteso	7.43	36.88	2270.00	1985-2006	14.77	filled
10	Saja School	7.97	37.40	2100.00	1985-2006	15.15	filled
11	Sekoru	7.92	37.40	2100.00	1985-2006	15.15	filled
12	Shebe	7.52	36.52	1635.00	1985-2006	11.74	filled
13	Wushwush	7.33	36.17	1950.00	1985-2006	4.17	filled
14	Dilela	8.62	38.05	2400.00	1985-2006	2.27	filled
15	Ejaji	9.00	37.32	1900.00	1985-2006	4.17	filled
16	Gedo	9.05	37.43	2500.00	1985-2006	9.09	filled
17	Gibe Farm	8.23	37.58	1110.00	1985-2006	0.38	filled
18	Hosana	7.55	37.87	2200.00	1985-2006	4.55	filled
19	Tibe	9.03	37.22	1680.00	1985-2006	4.17	filled
20	Wolkite	8.27	37.75	1550.00	1985-2006	14.02	filled
21	Bele	7.08	37.58	1200.00	1985-2006	2.27	filled
22	Wolaita	6.85	37.75	0.00	1985-2006	2.27	filled
23	Tikur Enchini	8.78	37.63	2450.00	1985-2006	4.17	filled
24	Chencha	6.25	37.57	2680.00	1985-2006	31.82	filled

4.3.1. Homogeneity of recording stations

In order to fill the missed rainfall data, and to select representative meteorological stations, checking homogeneity of group stations is essential. The homogeneity of the selected gauging stations monthly rainfall records have been carried out by non.dimensionalizing using equation:

$$P_i = \frac{\overline{P}_i}{\overline{P}} * 100 \qquad (4.1)$$

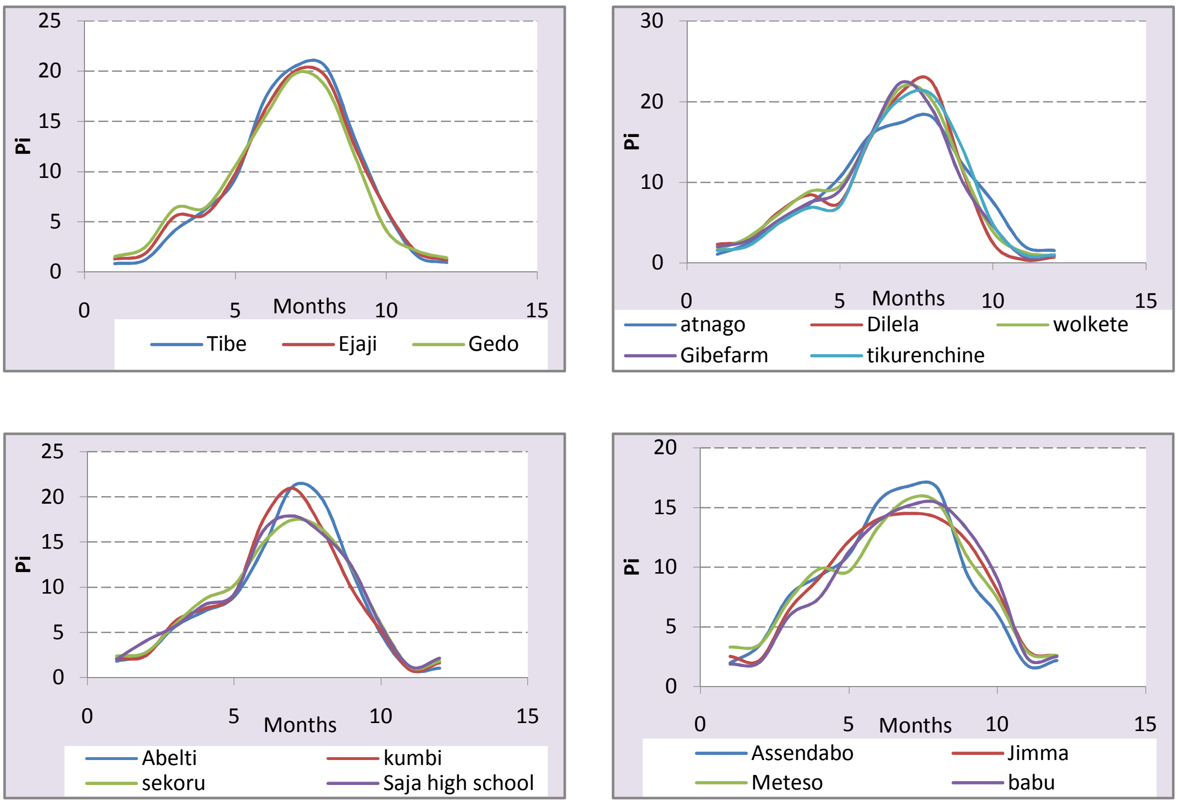
Where:-

P_i=Non dimensional Value of PP for the month i

$\overline{P}_i$=Over years averaged monthly precipitation for the station i

$\overline{P}$ =the over years average yearly precipitation of the station

and plotted to compare the stations included in the computation of area rainfall with each other as shown in Figure 4.3.



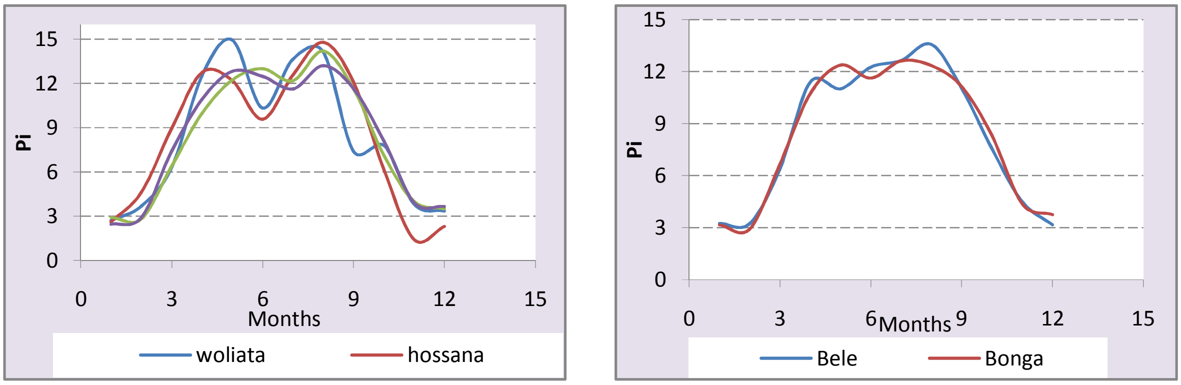
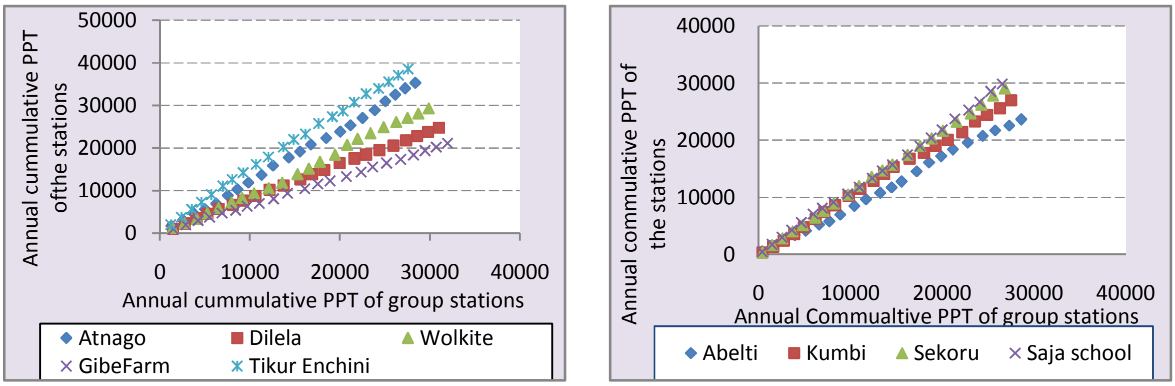


Figure 4.3: Homogeneity Test for areal rainfall stations

4.3.2. 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 totals of the gauge in question are 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.



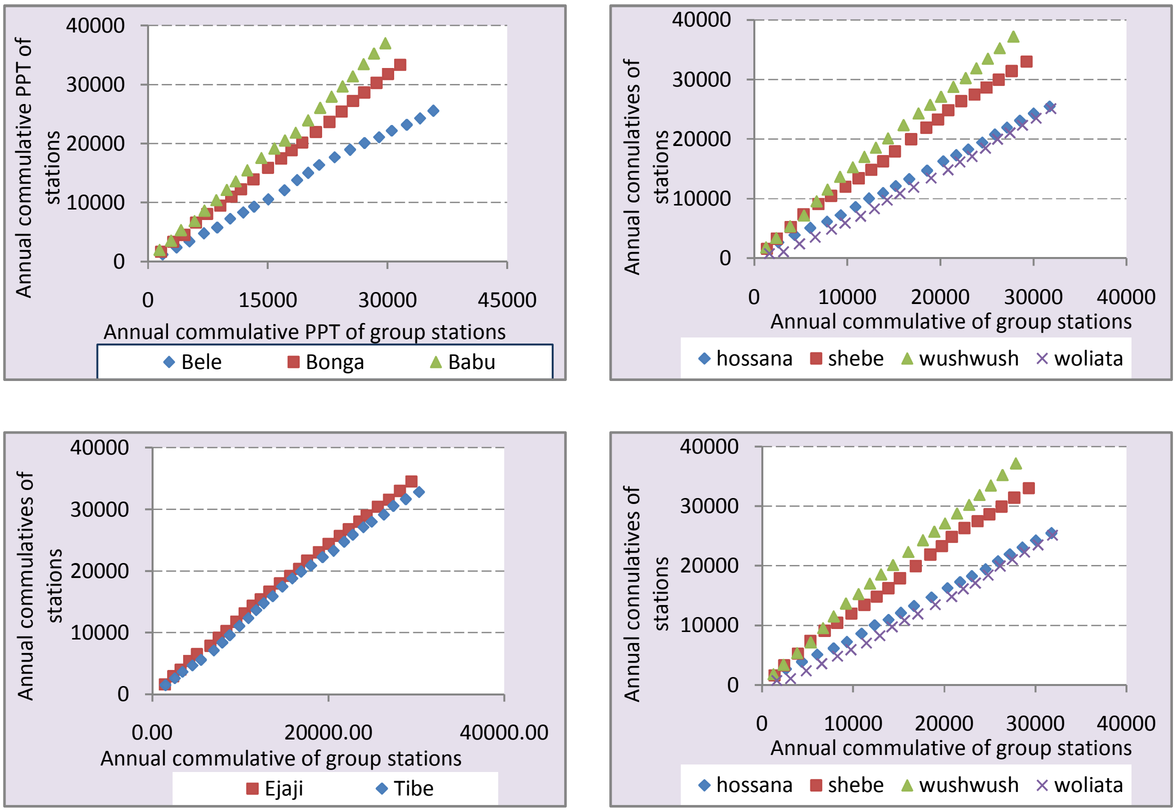


Figure 4.4: Consistency test graph for all the stations

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

4.3.3. Rainfall data gap-filling

Before using the rainfall records of a station, it is necessary to first check the data for continuity and consistency. The continuity of a record may be broken with missing data due to many reasons such as damage or fault in a rain gauge during a period. The missing data can be estimated by using the data of the neighboring stations.

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 m region gauges differs from the annual rainfall at the point of interest by more than 10%, the normal- ratio method is preferable. Because this method is more advanced than station average method and simple, I considered this method for filling missed rainfall data in this study. The general formula for computing P is

$$\overline{\mathrm{P}}_{\mathrm{i}} = \frac{\mathrm{N_x}}{\mathrm{M}}\left(\frac{\mathrm{P_1}}{\mathrm{N_1}} + \frac{\mathrm{P_2}}{\mathrm{N_2}} + \frac{\mathrm{P_3}}{\mathrm{N_3}} \ldots + \frac{\mathrm{P_m}}{\mathrm{N_m}}\right) \qquad (4.2)$$

Where:

N_x=Average annual precipitation at the missing data.

N_1, N_2, $N_{3,}$… N_m=Average annual precipitation at the adjacent site.

The selected, available and missed rainfall data statistics are shown in the Table 4.3.

4.4. Estimation of model input areal 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.

A rain gauge records the rainfall at a single point. This point rainfall record has to be converted to aerial rainfall. The average depth of precipitation over the area under the area of consideration is one of the most important parameter in hydrological analysis.

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.

- 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.
- 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 this thesis work have one or more than one rainfall-gauging stations within or in the vicinity of the boundary of their watershed. For catchments having rainfall gauges more than one, Theissen 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.

By taking two sub-catchments, the Theissen gauge weights developed for sub-catchments with more than one rainfall gauging stations are presented in Table 4:4 and Figure 4.5 while the rest are attached in appendix A.

Table 4.4 Theissen gauge weights for Gilgel-Gibe and Walga sub-catchments

Gilgei Gibe Sub-catchment				Walga Sub-catchment			
S.no	Rainfall stations	Area Weight (km^2)	Gauge Weight (%)	S.no	Rainfall stations	Area Weight (km^2)	Gauge Weight (%)
1	Jimma	951.76	33.88	1	Tikur Enchini	100.36	5.33
2	Assendabo	774.06	27.55	2	Wolkite	688.80	36.55
3	Shebe	312.7	11.13	3	Gibe Farm	21.53	1.14
4	Meteso	770.7	27.43	4	Dilela	1073.63	56.98
	Total	2809.3			Total	1884.32	

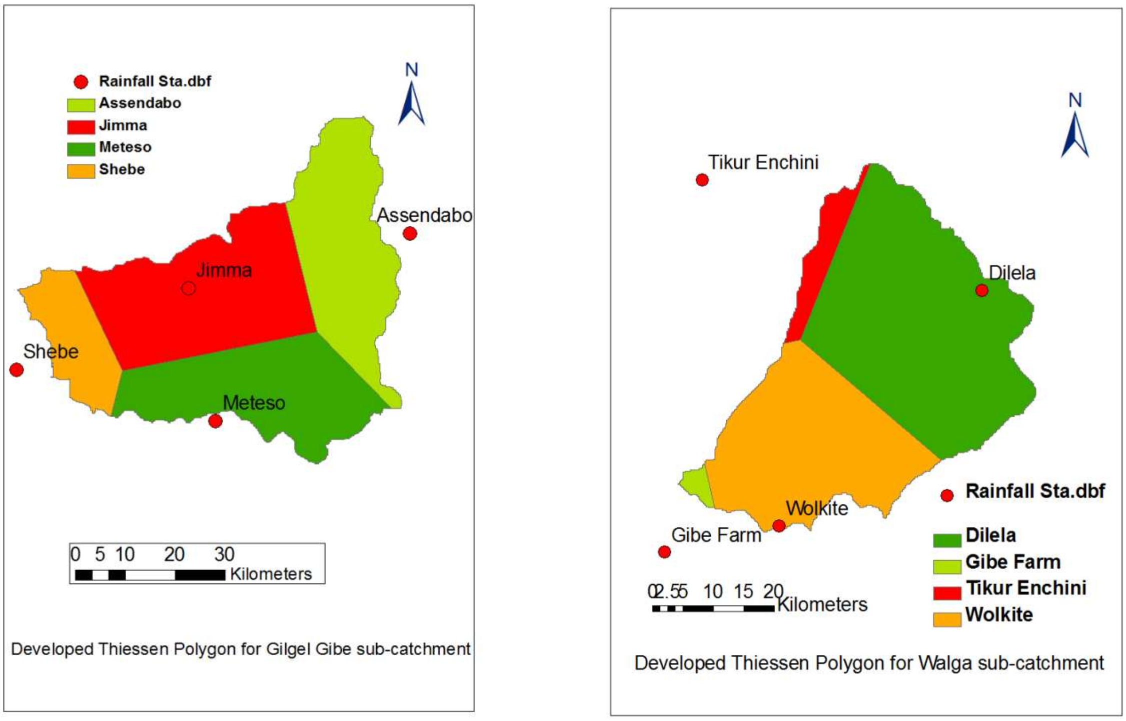


Figure 4.5: Thiessen Polygon Developed for Gilge-Gibe and Walga Sub Catchments

CHAPTER FIVE

5. Methodology

This research work makes use of a hydrological model and regionalization to simulate runoff from gauged and ungauged catchment of Omo-Gibe river basin. The methods used include review of previous studies on the basin, data collection from institutions such as Ministry of water resource, National Meteorological Agency and etc. After collecting the necessary data for the research, filling of missed data and quality checking have been made. Theissen polygon is drawn at different sub catchments to determine the areal model input data by using Arc view GIS.

The approach of regionalization is applied to estimate the flow of ungauged catchments. First; the WATBAL model is calibrated against the observed discharge to determine well performing parameter sets of gauged catchments. Next, a relationship is made between the model parameters (MPs) and physical catchment characteristics (PCCs) to establish the regional model that serves to estimate model parameters for ungauged catchments. Then the WATBAL model is used to simulate the discharges for ungauged catchments.

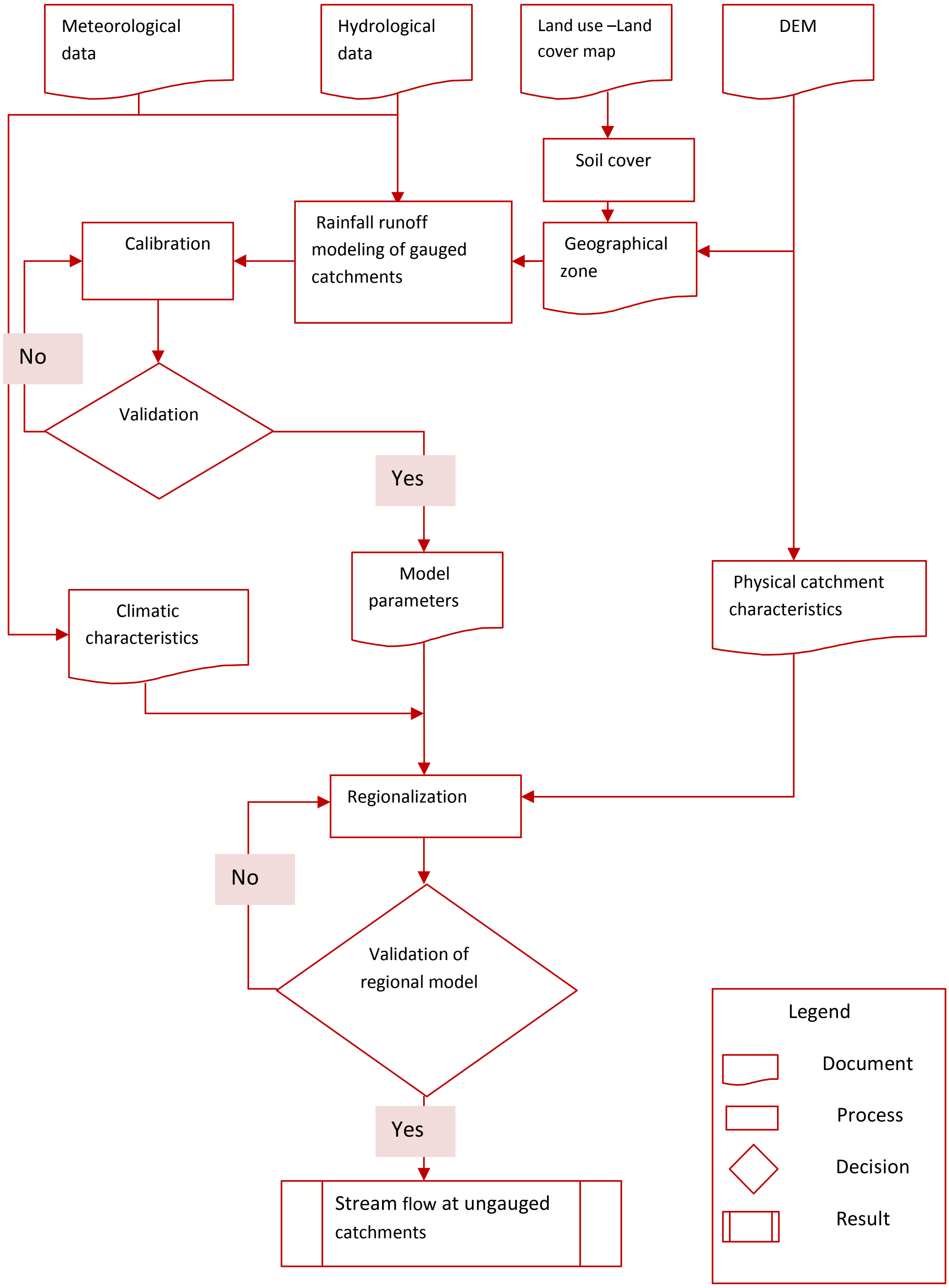


Figure 5.1: Simplified flow chart of the methodology adopted in the research

5.1. Material Used

The materials used for this research are:-

a. Arc view GIS to obtain hydrological and physical parameters and spatial information.
b. SWAT software to delineate the basin and sub basin of the study area.
c. DEM data is used as an input data for SWAT software.
d. Hydrological data (stream flow data).
e. Meteorological data (Rainfall, Temperature, RH, Sunshine hours).
f. WATBAL model.
g. LocClim model to extract temperature and sunshine hour data.
h. SPSS statistical package for developing multiple linear regression between model parameters and physical catchment characteristics.
i. SWAT base flow filter model to separate base flow from stream flow hydograph.

5.2. Model calibration

Any hydrological model must be proven for its reliability, accuracy and predictive ability. At the initial run the model probably will not give satisfactory result as the input data do not reflect the real world with enough accuracy. Hence every hydrological model requires adjustment of the model parameter values, hydrological influences and stresses in order to tune the model. The reliability of the model can be improved by fine-tuning termed ‘model calibration’ or simply ‘calibration’.

The process of model calibration in order to identify the optimum model parameter set is done either by manually or by computer-based automatic procedures. In manual calibration, the user adjusts the parameters interactively in successive model simulations. As this approach mainly depends on the user’s experience, only intelligent steps will be made through the parameter space that will be an advantage. Some previous studies proved that this method demonstrated good model performance (Liden and Harlin, 2000). However manual calibration is subjective and the parameter derived may be prone to be bias due to involvement of user’s experience. Also the process is very time-consuming and it does not have clear point at which the calibration process can be said to be completed. To overcome these disadvantages, automatic calibration has been pursued. In automatic calibration model parameters are adjusted automatically according to a specific search algorithm or optimization algorithm that considers numerical performance measures for the goodness of fit. Further, automatic calibration is fast with respect to manual calibration and the confidence of the model simulation can be explicitly stated.

Calibration of model parameters is done in this study by combining manual trial-and-error and automatic optimization methods through empirical analysis of monthly and annual runoff data. The key model parameters are optimized with an automatic optimising routine of the model while the other model parameters are optimized manually by trial and error. Statistical relationship is used 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.

5.3. Objective functions

In model calibration, the model parameters have to be adjusted until the observed natural system output and the simulated model output show an acceptable level of agreement. The goodness of fit is always evaluated through an objective function which is selected based on several criteria. These criteria should be selected properly to evaluate different aspects of the hydrograph. In this study the criteria that were considered in selecting the objective function are as follows:

a) A good agreement between the average simulated and observed catchment runoff volume (i.e. a good water balance);

$$\mathrm{RVE} = \left(\frac{\sum_{i=1}^{n}(Q_{sim,i} - Q_{obs,i})}{\sum_{i=1}^{n} Q_{obs,i}} * 100\%\right) \qquad (5.1)$$

Where:

RVE =average monthly error between the predicted and observed flow (mm/day),
Q_{sim}=is the simulated flow,
Q_{obs} =is the observed flow,
i =is the time step and
n =is the total number of time steps used during calibration.

This objective function can vary between ∞ and - ∞ but performs best when a value of 0 is generated since no difference between simulated and observed discharge occurs. The relative volume error between +5% and -5% indicate that the model performed well while relative volume error between +5% and +10% or between -5% and -10% indicate that model perform reasonably. However, at the same time the distribution of the discharge throughout the calibration period can be completely wrong. Therefore, this criterion should always be used in combination with another criterion that considers the overall shape agreement.

b) A good overall agreement of the shape of the hydrograph (The Nash-Sutcliffe coefficient)

The Nash-Sutcliffe coefficient (NS) is used to evaluate the overall agreement of the shape of the simulated and observed hydrograph. NS measures the efficiency of the model by relating the goodness of fit of the simulated data to the variance of the measured data. NS coefficient can be defined according to the following equation:

$$NS = 1 - \frac{\sum_{i=1}^{n}\left(Q_{sim,i} - Q_{obs,i}\right)^2}{\sum_{i=1}^{n}\left(Q_{obs,i} - \overline{Q_{obs,\iota}}\right)^2} \qquad (5.2)$$

Where:

NS= the Nash-Sutcliffe coefficient,

Q_{sim}=is the simulated flow,

Q_{obs} =is the observed flow,

i =is the time step and

n =is the total number of time steps used during calibration.

This objective function can vary between 1 and -∞ and performs best when a value of 1 is generated. Besides, due to frequent use of this objective function, it is known that when values between 0.6 and 0.8 are generated, the model performs reasonably well. Values between 0.8 and 0.9 indicate that the model performs very well and values between 0.9 and 1 indicate that the model performs extremely well.

c) 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:

$$r^2 = \frac{Cov(Q_s, Q_o)}{\sigma_s \sigma_o} \qquad (5.3)$$

Where:

Cov (Q_s,Q_o) = the covariance of the observed and simulated(modeled) monthly flow,

σ_s = the standard deviations of simulated(modeled) monthly flow and

σ_o = the standard deviations of the observed monthly flow

5.4. 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 parameters 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. This is called model. Use is made of the split-sample test in this study. 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. In this study data set from 1985 to 1996 is used for calibration while data set from 1997 to 2006 is used for validation.

5.5. 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.

5.5.1. 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).

a) Similarity of spatial proximity

Regarding the similarity of spatial proximity, this method is based on the rationale that catchments that are close to each other will likely have a similar runoff regime since climate and catchment conditions will often only vary marginally in space. So the assumption is made that catchments are highly homogeneous with respect to topographic and climatic properties. Therefore a particular model approach and accompanying calibrated model parameter values from gauged catchments can be derived and applied at the ungauged catchments in order to predict the discharge regime because of this approach parameter uncertainty is reduced.

b) Similarity of catchment characteristics

With regard to the similarity of catchment characteristics, the classical approach of regionalization consists of three steps. The first step implies calibration of the chosen model structure for a large number of catchments for which sufficiently long and informative observations of discharge regimes are available. This can be done using several criteria which are to be established. Secondly, an attempt is made to derive regression equations, which is the most commonly used method, which predicts the model parameter values using one or a combination of physical catchment characteristics (PCCs). Commonly for each model parameter a separate equation is derived. Finally, parameter values for the ungauged catchment can be estimated using the regional model, which comprehends all the established relationships between PCCs and model parameters merged in the hydrological model, and a runoff prediction can be made.

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 common 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. So, in this chapter an attempt is made to develop relationship between the MPs and selected PCCs and other techniques of regionalizing MPs is also explored.

5.6. Selection of physical catchment characteristics

Problems occur in selecting catchment characteristics or descriptors for use in developing methods to estimate flow characteristics of ungauged catchments. A reasonable number of well gauged catchments with good quality data of climate, hydrology, physiographic, lithology and geology should be available to derive PCCs (Mazvimavi D, 2003). However prior to selection of PCCs for regionalization, evaluation has to be done as there may be inter-dependency or inter-correlation between different PCCs. Therefore a preliminary list of PCCs should be composed based on the available data and the physical meaning of the model parameters. Then statistical analysis should be performed to identify the highly correlated PCCs. This study took 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. Selected catchment characteristics are given Table 5.1.

Table 5.1: Catchment characteristics Selected for use in the study

Catchment Characteristic	Description and Data Source
Means of monthly and annual rainfall	Estimated from rain gauge data
Means of monthly and annual potential evaporation	Derived from other meteorological data
Maximum, average, and minimum catchment elevation	Derived from a digital elevation model(DEM)
Longest flow path of the watershed	Derived from a digital elevation model(DEM)

Slope	Derived from a digital elevation model(DEM)
Proportions of the catchment with different lithologies	Derived from GIS department of MoWRE
Proportions of the catchment with different land cover types	Derived from GIS department of MoWRE
Proportions of the catchment with different Soil types	Derived from GIS department of MoWRE

5.7. Regression analysis

The relation between WATBAL model parameters and PCCs allows us to understand and perhaps quantitatively predict how a change in physical properties of a catchment will affect its hydrological response. In order to set up a regional model to predict the model parameters in ungauged catchments, a statistically significant and hydrologically meaning full relation should be established between PCCs and calibrated MPs. After determining the MPs through model calibration and selection of physical catchment characteristics, a method for establishing the relationship is applied (Perera U, 2009). The most commonly used approach is through regression analysis and this approach is used in this study as well.

A regression analysis is the application of a statistical procedure for determining a relationship between variables (Haan, 2002). In this procedure one variable is expressed as a function of other variables. The variable to be determined is termed as the dependent variable while others are called the independent variables. In this study MPs were taken as dependent variable and PCCs were taken as independent variables.

With respect to regionalization two type of regression methods are applied. One is simple regression method, which tries to determine a relationship between one independent variable and a dependent variable. The other type is called multiple regression method, which tries to assess multiple independent variables to explain the dependant variable. This approach is used in this study.

The model for a simple regression reads:

$$Y' = \beta_0 + \beta_1 X_1 \qquad (5.4)$$

The model for a multiple regression reads:

$$Y' = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + ... + \beta_n X_n \quad (5.5)$$

Where:

$\beta_1, \beta_2, \beta_3 \dots \beta_n$	regression coefficients
$X_1, X_2, X_3 \dots X_n$	Independent variables (catchment characteristics)
Y'	Dependent variables (model parameters)
β_o	Intercept of the regression line

A problem in this study is the limited number of available gauged catchments. In principle increasing the number of catchment will increase the reliability and the efficiency of the regional model. It is noted that in this study gauged catchments with RVE in between +10% and -10%, NS value greater than 0.6 and r^2 value greater than 0.7 are used to establish the regional model.

5.7.1. Test significance and strength

When determining the regression equation, a hypothesis test has to be applied in order to determine if the equation is significant. Several hypothesis tests are possible, but for each test, assumptions have to be made. Multiple regression is used to predict model parameters from several independent catchment characteristics. Optimization of catchment characteristics will be by avoiding catchment characteristics that are highly correlated. The R^2 is not the only measure to rely on but also significance of the relation has to be tested. In this study, significance of multiple regression equations is tested by a test of overall significance of regression questions.

A test of the overall significance of regression amounts to testing the hypothesis that all the true regression coefficients are zero and that, therefore, none of the independent variables helps explain the variation of the dependant one. Overall significance of correlation coefficient is established with the help of F-test.

$$Y' = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + ... \beta_n X_n \quad (5.6)$$

H_o: β_1=0, β_2 =0, β_3=0… β_n= 0 all the regression coefficients of model parameters and physical catchment characteristics is zero (null hypothesis),

H_1: $\beta_1 \neq 0$, $\beta_2 \neq 0$, $\beta_3 \neq 0$ … $\beta_n \neq 0$ all the regression coefficients of model parameters and physical catchment chrematistics are not zero (specific-hypothesis reject the null hypothesis).

If $F_{cr} > F_{cal}$ the null hypothesis is accepted (parameter is not associated with catchment characteristics in the population)

If $F_{cr} < F_{cal}$ null hypothesis is rejected (parameter is associated with catchment characteristics in the population)

Where:

F_{cr} is critical T-value determined from F-table (Kohler, 1994) depending on the denominator, degree of freedom (n-m-1 where n number of samples and m number independent variables).

CHAPTER SIX

6. Results and Discussion

6.1. 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. Within the model an automatic optimizing routine can be utilized to calibrate three model parameters and the models use a statistical relationship to reduce the error between the observed and simulated runoff. In this paper the calibrated model parameters deemed to be acceptable if it fulfills the criteria listed in section 5.3 (i.e., Nash-Sutcliffe coefficient, NS greater or equal to 0.6, relative volume error, RVE between -10% and +10% and coefficient of determination, r^2 greater than 0.7).There are 16 catchments that fulfilled these criteria during calibration period (Appendix C). The rest 6 catchments generate poor model efficiencies during calibration and are left in the modeling work. The calibrated model parameters, the model efficiencies and model parameters fixed for all model runs during calibration and validation periods are shown in Table 6.1, Table 6.2 and Table 6.3 respectively.

Table 6.1: Calibrated model parameters for gauged catchments, period (1985-2006)

Sub-Catchments	Area (Km^2)	S_{max}(m)	Alpha, α (mm/day)	Epsilon, ε	SSRC, Gamma, ϒ	Beta, β	Base flow (mm/day)	Z_i	Latitude (deg, north)
Amara Nr.Shebako	68.80	785.31	9.5218	4.9370	2.0	0.0030	0.0213	0.85	9.118
Awaitu at Jimma	72.00	604.46	2.7168	8.6326	2.0	0.0010	0.0019	0.10	7.730
Bidru Awana Nr. Sokuru	39.72	1115.88	4.4640	4.5850	2.0	0.0020	0.0195	0.35	7.88
Bulbule Nr. Serbo	252.68	713.02	10.4316	7.2568	2.0	0.0020	0.0017	0.75	7.462
Dincha at Bonga	234.76	1299.08	64.0326	2.6066	2.0	0.0020	0.1374	0.25	7.227

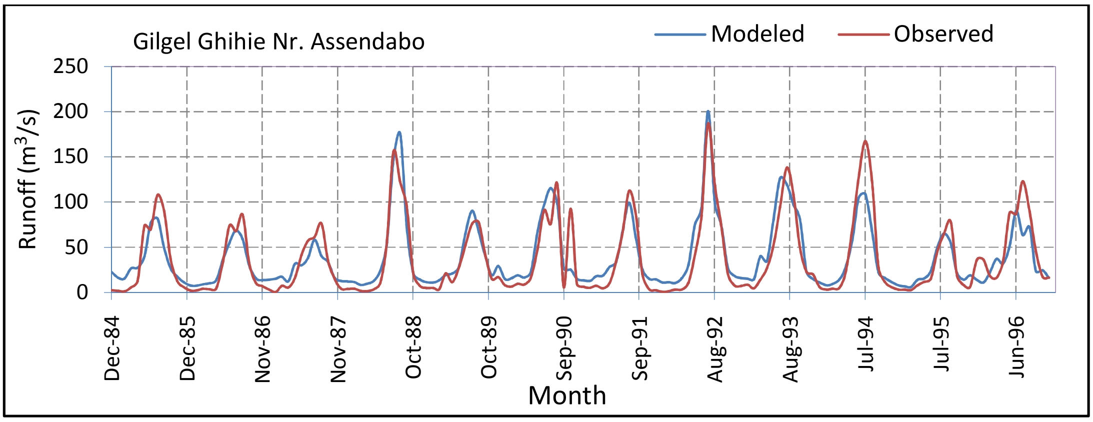
Gilgel ghibie Nr. Assendabo	2809.28	866.14	1.5574	5.6526	2.0	0.0030	0.0158	0.75	7.623
Ghibe Nr. Baco	282.44	2126.28	0.9667	4.7489	2.0	0.0020	0.0243	0.80	9.200
Ghibe Nr. Seka	280.40	1261.41	1.4680	5.0410	2.0	0.0010	0.0222	0.70	7.599
Gogeb Nr. Endeber	67.48	975.21	9.8434	3.0770	2.0	0.0150	0.0239	0.32	7.994
Gojeb Shebe	3241.68	1208.14	2.6731	5.5996	2.0	0.0010	0.0037	0.45	7.545
Gumma Nr. Andaracha	771.80	639.12	1.3490	5.3930	2.0	0.0032	0.0307	0.10	7.274
Kulti Nr. Wolkete	350.00	899.15	2.4501	4.4396	2.0	0.0020	0.0034	0.45	9.118
Megech Nr. Gubere	286.00	2659.36	0.5492	5.4878	2.0	0.1600	0.0353	0.75	8.088
Wabi Nr. Wolkite	1567.40	465.98	8.1920	2.6610	2.0	0.0100	0.0292	0.95	8.299
Walga Nr. Walkite	1884.32	1760.36	0.2600	4.7142	2.0	0.0020	0.0001	0.95	8.507
Werabessa Nr. Tolie	240.88	3426.09	0.4713	9.5878	2.0	0.1200	0.0006	0.10	8.621

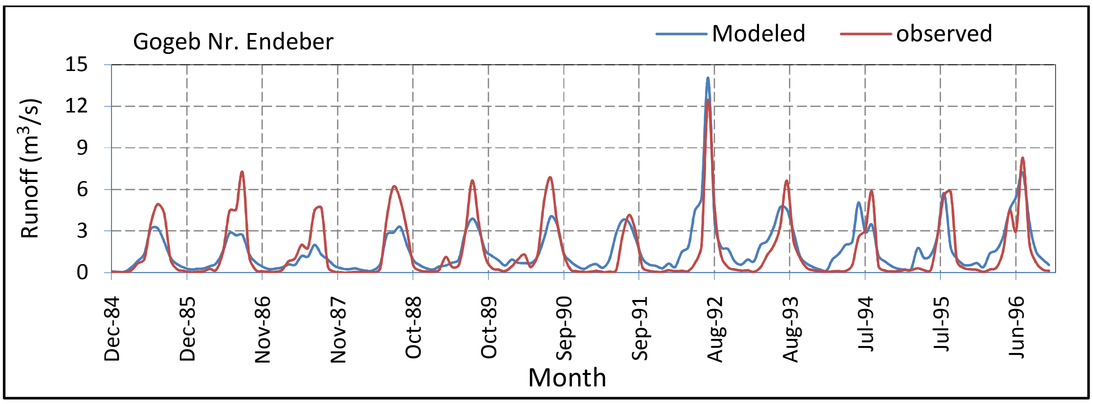
Table 6.2: Model Efficiencies during calibration and validation period

Sub-Catchments	Calibration			Validation		
	RVE	NS	r^2	RVE	NS	r^2
Amara Nr.Shebako	-0.90	0.62	0.79	-5.74	0.71	0.73
Awaitu at Jimma	4.68	0.64	0.80	1.07	0.68	0.68
Bidru Awana Nr. Sokuru	2.53	0.70	0.83	0.12	0.64	0.65
Bulbule Nr. Serbo	-4.58	0.62	0.80	-7.91	0.75	0.75
Dincha at Bonga	2.39	0.66	0.85	1.02	0.82	0.77
Gilgel ghibie Nr. Assendabo	4.13	0.81	0.90	-9.22	0.87	0.84
Ghibe Nr. Baco	5.09	0.61	0.78	-9.86	0.78	0.71
Ghibe Nr. Seka	4.89	0.65	0.80	-8.99	0.78	0.72
Gogeb Nr. Endeber	9.56	0.67	0.81	-4.35	0.75	0.82
Gojeb Shebe	7.35	0.64	0.80	-8.30	0.76	0.76
Gumma Nr. Andaracha	1.92	0.60	0.77	-5.86	0.67	0.65

Kulti Nr. Wolkete	8.78	0.75	0.86	8.07	0.77	0.81
Megech Nr. Gubere	2.62	0.60	0.77	-5.76	0.65	0.70
Wabi Nr. Wolkite	-8.43	0.74	0.87	3.77	0.77	0.82
Walga Nr. Walkite	4.88	0.71	0.84	5.21	0.66	0.75
Werabessa Nr. Tolie	9.87	0.63	0.79	-4.31	0.78	0.67

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 relatively accurately high dry season flows (See Figure 6.1). By taking three sub-catchments, the monthly observed and simulated flow hydrograph and scatter plot of calibration are presented in Figure 6.1 and Figure 6.2 respectively while the rest are attached in Appendix B1 and Appendix B3.





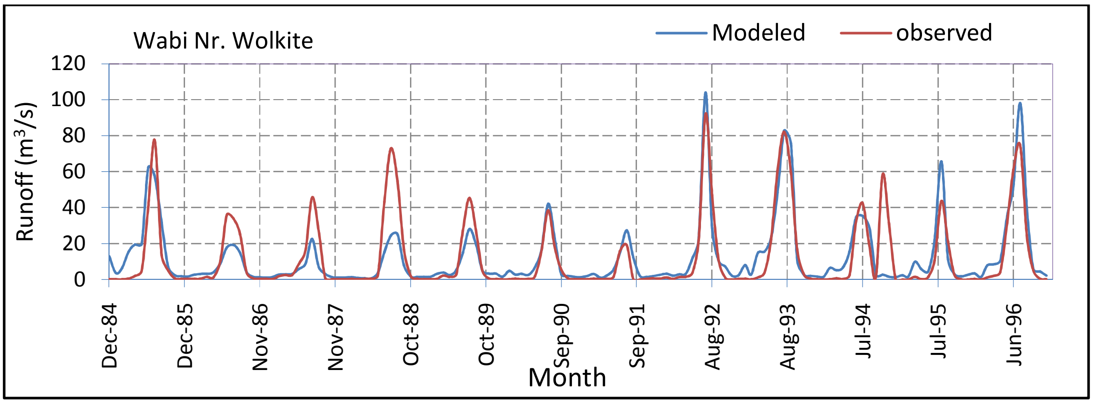


Figure 6.1: Observed and simulated monthly flow hydrograph of gauged catchments, calibration period (1985-1996)

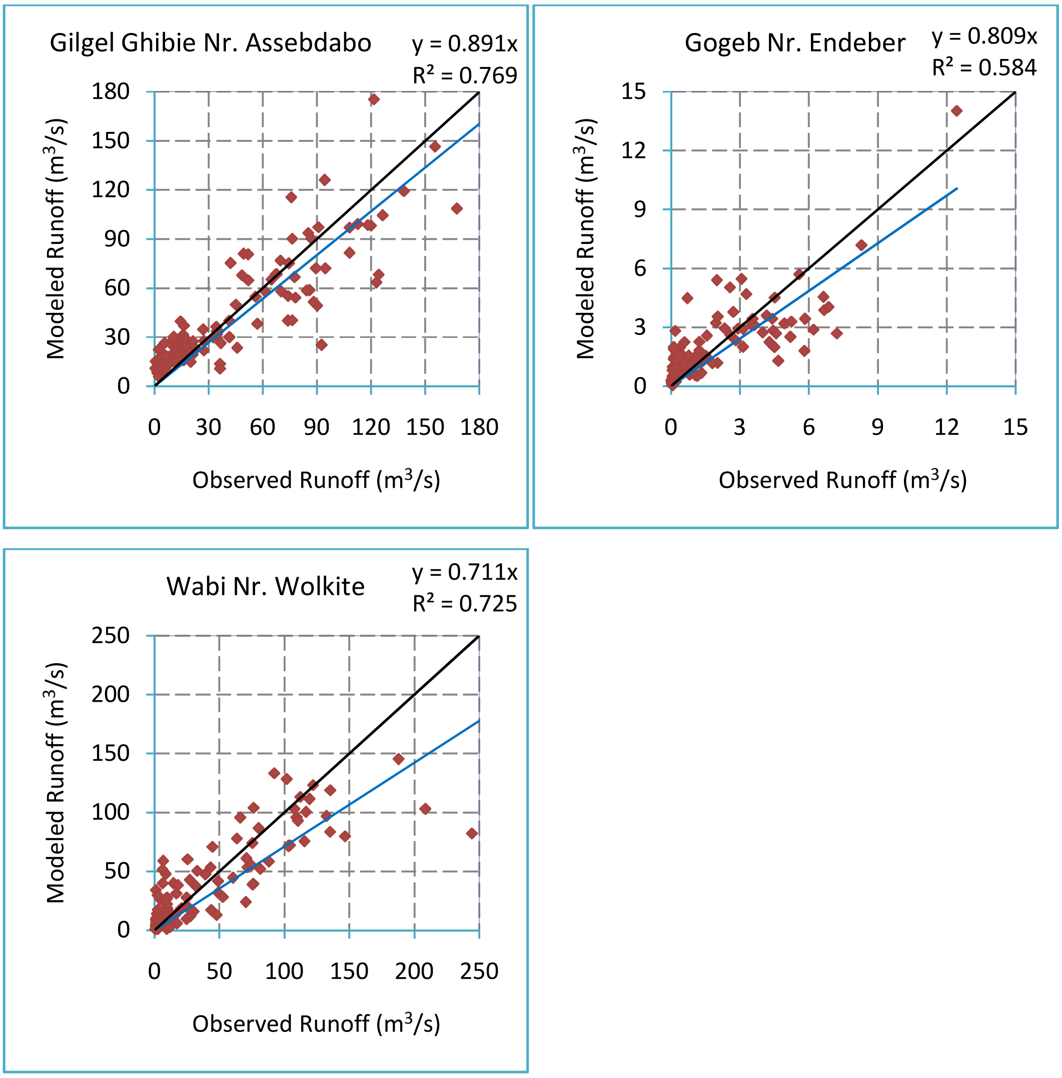


Figure 6.2: Scatter plot of observed and simulated discharge for gauged catchments, calibration Period (1985-1996)

In this study, the calibrated model is run for validation using the time series of hydro-meteorological data that were not used for calibration. All catchments that fulfilled the objective function during calibration resulted similar figures during validation period (See Table 6.2 above). The model validation period runs from 1997 to 2006. The monthly observed and simulated flow hydrograph and scatter plot are presented in Figure 6.3 and Figure 6.4 below respectively for selected three sub-catchments for validation period while the rest are attached in Appendix B2 and Appendix B3.

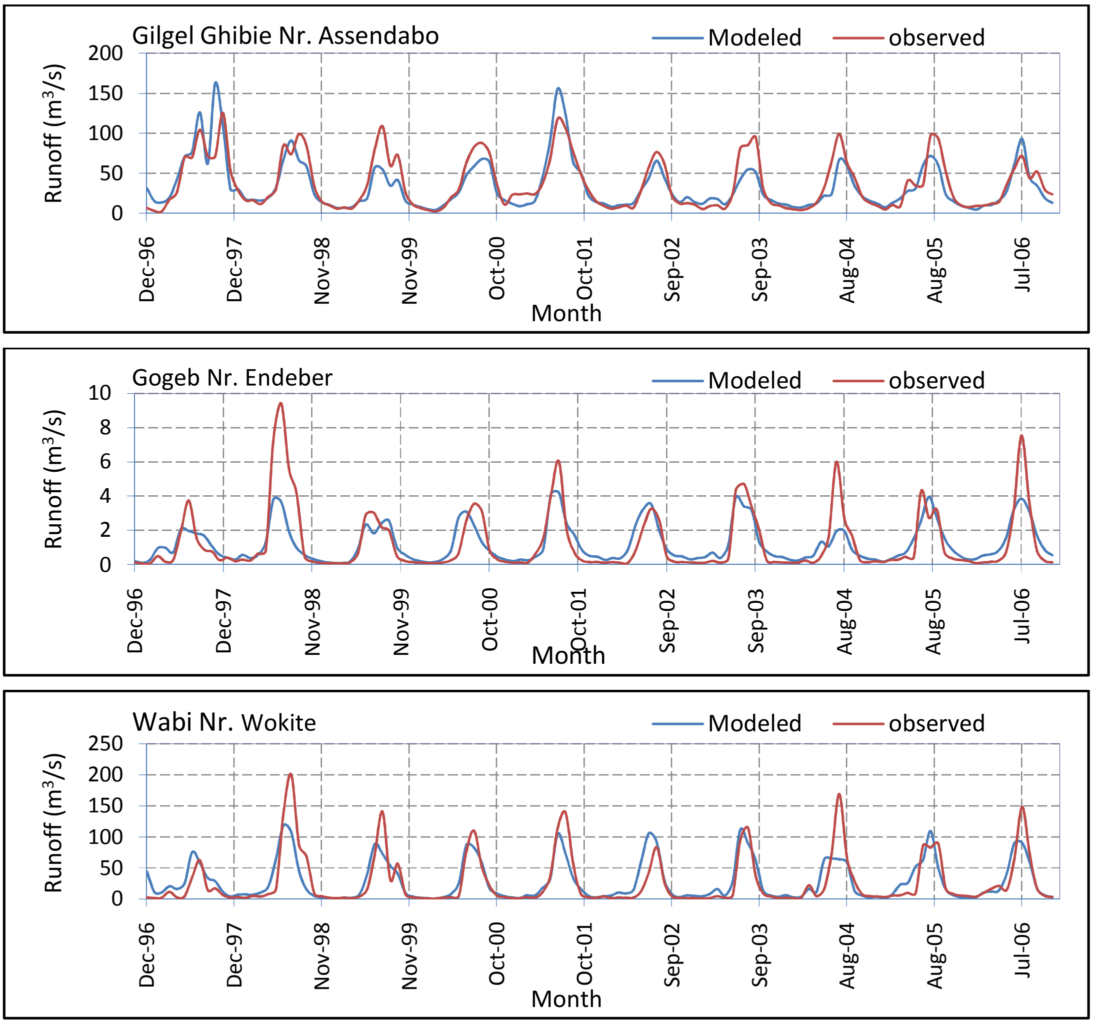


Figure 6.3: Observed and simulated monthly flow hydrograph of gauged catchments, validation period (1997-2006)

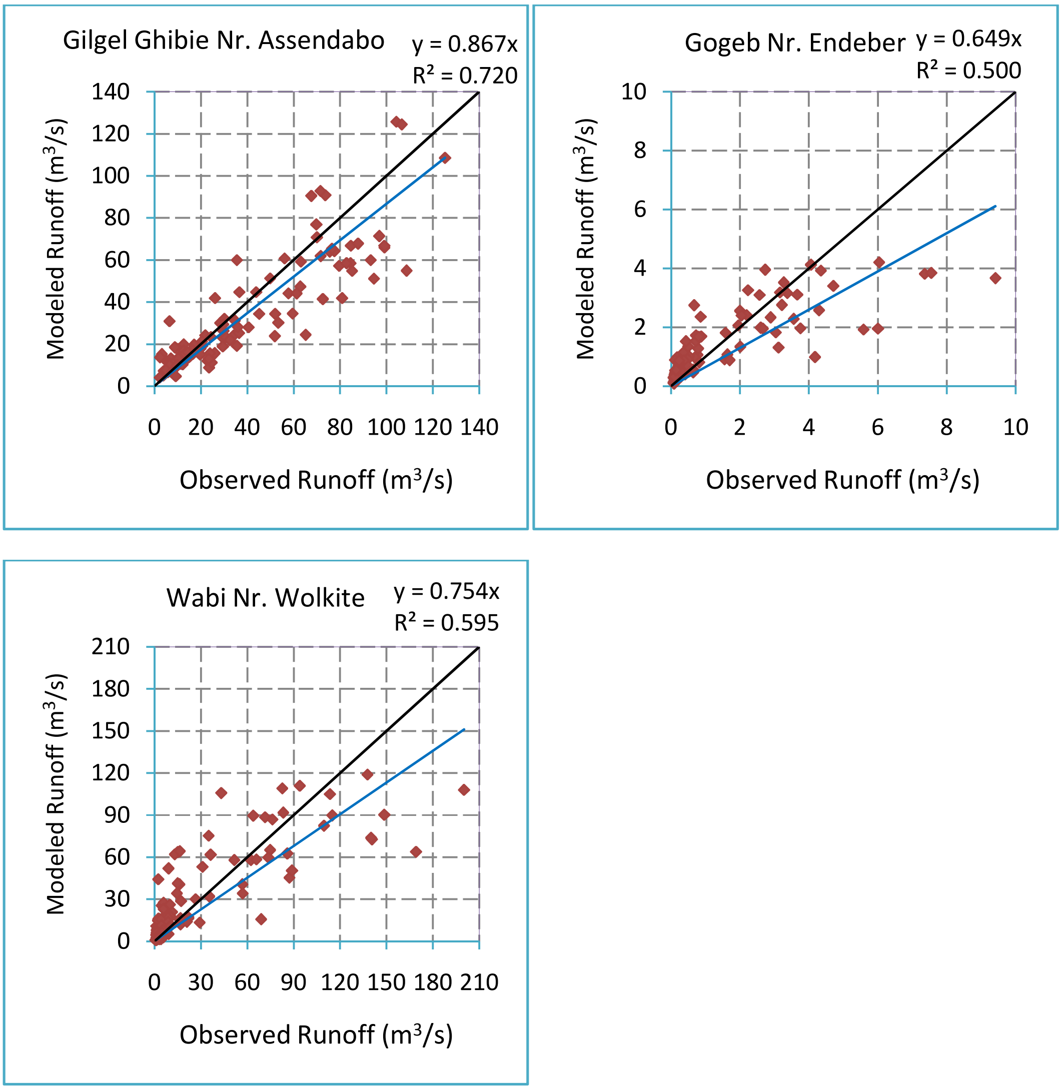


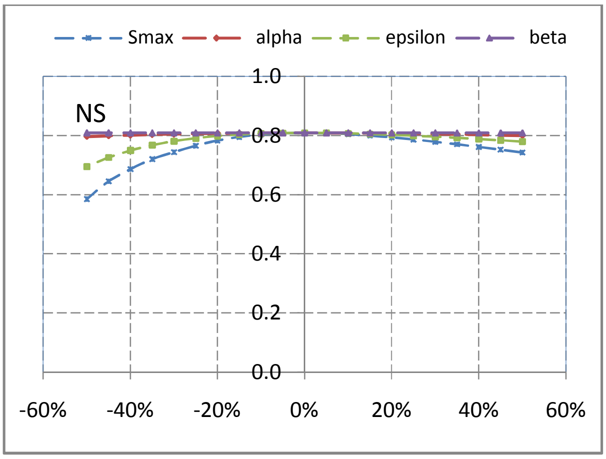
Figure 6.4: Scatter plot of observed and simulated discharge for gauged catchments, validation Period (1997-2006)

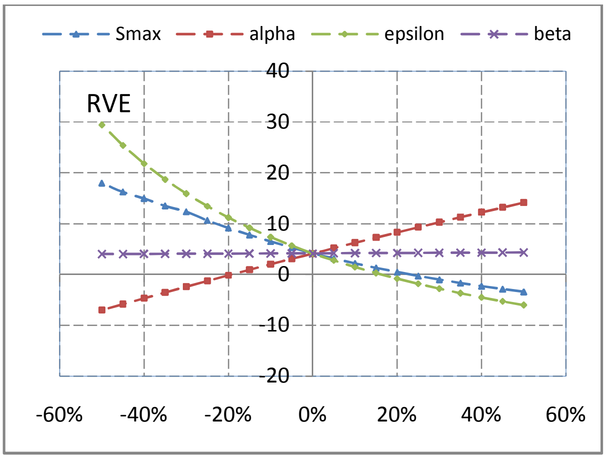
6.2. Sensitivity of model parameters

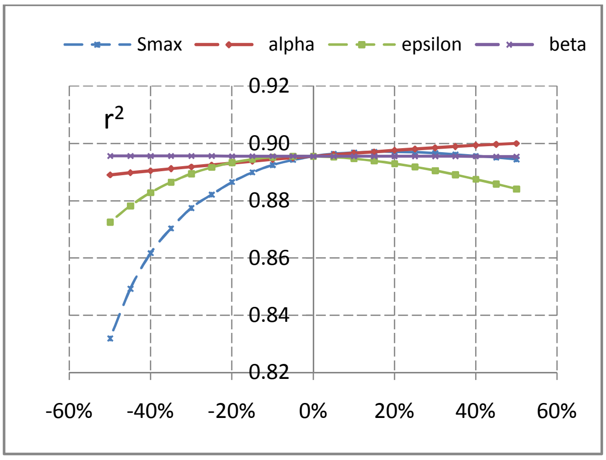
To get a clear understanding of the model behavior with respect to the model outcome (i.e. model hydrograph) a sensitivity analysis is performed. Each of the six model parameters contribute to conceptualizing the rainfall-runoff processes which all together result in simulating the hydrograph. Therefore if we change one of the model parameters the hydrograph will change. But every parameter does not contribute equal amount of change to the hydrograph. When trying to establish relationships between model parameters and PCCs, 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 within +50% to -50% of the optimum value for three randomly selected representative sub-catchments (Gilge Ghibie Nr. Assendabo,Wabi and Walga) and are shown in Figure 6.5.

As shown for selected three sub-catchments in Figure 6.5, S_{max} is the most sensitive model parameter and it varies non-linearly with respect to NS, RVE and 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.

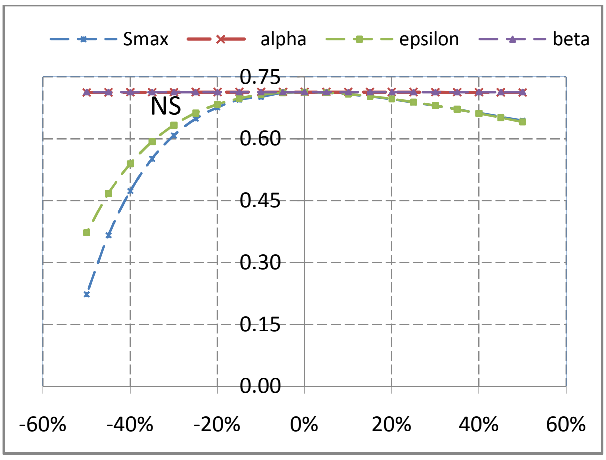
Gilgel Ghibie Nr. Assendabo sub- catchment

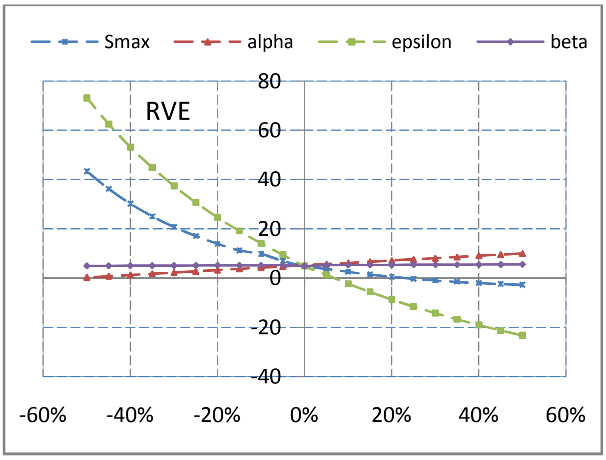


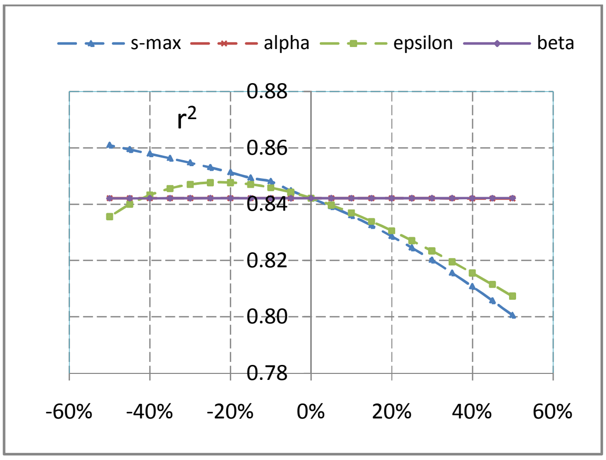




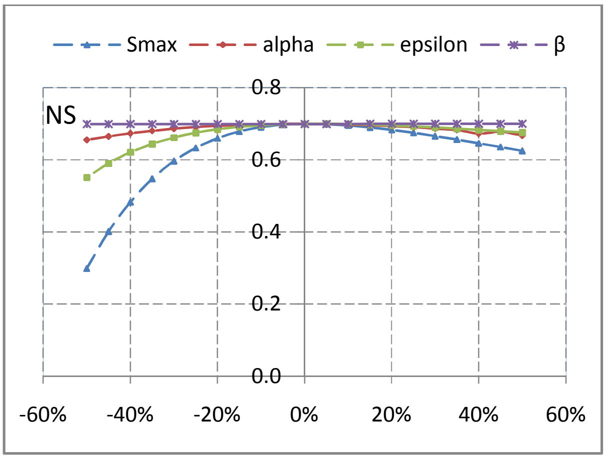
Walga sub-catchment

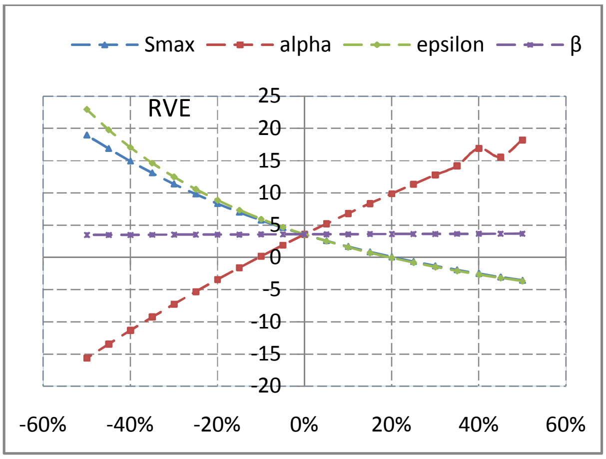






Bidru Awana sub-catchment





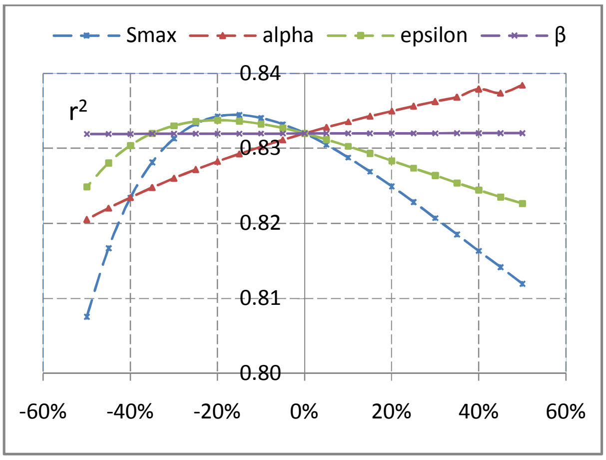


Figure 6.5: Sensitivity analysis of Gilgel Ghibie Nr. Assendabo, Walga and Bidru Awana sub-catchments

6.3. Results of regionalization

6.3.1. Multiple regression

The following generalized equations were 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 model to other measurable physical catchment characteristics given in Table 5.1. The general form of the equations is;

$$S_{max} = aA^b P^C PET^d S^e L^f El^g \qquad (6.1)$$

$$\alpha = hA^i P^j PET^k S^l L^m El^n \qquad (6.2)$$

$$\varepsilon = oA^p P^q PET^r S^s L^t El^u \qquad (6.3)$$

Where:

S_{max}	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	Mean annual precipitation (mm)
PET	Potential evapo-transpiration (mm)
S	Slope (%)
Lon	Longest flow path (m)

El Mean watershed elevation (m)

And a to u are coefficients to be derived by multiple regression techniques

Table 6.3: PCCs and MPs used in the multiple regressions

Sub-Catchments	Area	P	PET	Slope	Lon	El	S_{max}	Alpha	Epsilon
Amara Nr.Shebako	68.800	1232.091	961.593	10.869	13650.967	1809.000	785.315	9.522	4.937
Awaitu at Jimma	72.000	1502.079	1530.674	8.467	11029.646	2060.000	604.462	2.717	8.633
Bidru Awana Nr. Sokuru	39.720	1319.946	1572.010	11.531	11290.762	2070.333	1115.876	4.464	4.585
Bulbule Nr. Serbo	252.680	1663.901	1665.954	8.502	10212.578	2043.222	713.019	10.432	7.257
Dincha at Bonga	234.760	1759.982	1664.477	9.925	18505.382	2183.429	1299.076	64.033	2.607
Gilgel ghibie Nr. Assendabo	2809.280	1471.026	1504.362	6.654	10105.766	1955.524	866.140	1.557	5.653
Ghibe Nr. Baco	282.440	1232.091	1517.550	6.796	9825.031	2179.000	2126.284	0.967	4.749
Ghibe Nr. Seka	280.400	1526.436	1550.743	5.310	10341.233	2029.391	1261.405	1.468	5.041
Gogeb Nr. Endeber	67.480	1353.842	1355.513	3.059	14683.725	2080.333	975.207	9.843	3.077
Gojeb Shebe	3241.680	1643.365	1481.697	8.056	10185.494	2015.638	1208.143	2.673	5.600
Gumma Nr. Andaracha	771.800	1680.480	1682.553	7.816	9047.699	1845.923	639.116	1.349	5.393
Kulti Nr. Wolkete	350.000	1232.091	1233.611	10.869	14650.967	1809.000	899.145	2.450	4.440
Megech Nr. Gubere	286.000	1353.842	1355.513	4.218	13577.419	2479.320	2659.361	0.549	5.488
Wabi Nr. Wolkite	1567.400	1219.251	1220.755	7.080	13973.443	1959.027	465.981	8.192	2.661
Walga Nr. Walkite	1884.320	1240.696	1242.227	3.800	12560.846	2247.511	1760.356	0.260	4.714
Werabessa Nr. Tolie	240.880	1619.155	1621.152	4.758	10759.106	2680.273	3426.094	0.471	9.588

From relations in Equation 6.1 to 6.3 we observe that the numbers of independent parameters are six while the number of observations of the dependent variable in our case is twenty one. 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 we can proceed in the regression analyses.

The regional models for predicting the hydrological variables were developed by multiple linear regressions using the standard statistical package SPSS enter method in which all variables in the block are entered into the equation as a group (Appendix E).

A logarithmic transformation was used for both dependent and independent variables, since this improved the linear association between them. Variables in the multiple regression analysis were included according to standard statistical texts (Haan, 1977). The coefficient of determination R^2 is used as a measure of the association of the variables. The regional regression equations developed for each of the model parameters are given in the following along with the corresponding coefficient of determination R^2. The independent variables finally used and given in each of the following regression equations are the variables which play significant role (at the 95% confidence level) in explaining the spatial variation in the associated dependent variable.

The regression equations for model parameters found by the above mentioned method are:

$$S_{max} = 2.96 * 10^{-10} A^{0.018} P^{-0.404} PET^{-0.413} S^{0.112} L^{-0.302} El^{4.896}, \quad \text{with } R^2 = 0.72 \tag{6.4}$$

$$\alpha = 1.37 * 10^{-14} A^{-0.237} P^{3.618} PET^{1.653} S^{0.505} L^{4.718} El^{-6.449}, \quad \text{with } R^2 = 0.76 \tag{6.5}$$

$$\varepsilon = 70.96 * A^{-0.063} P^{1.391} PET^{-1.638} S^{0.226} L^{-1.725} El^{1.998}, \quad \text{with } R^2 = 0.76 \tag{6.6}$$

These equations contain six PCCs and their exponents indicate that, S_{max} increases with increasing A, S and El but decreases with increasing in P, PET and L. Alpha increases with increasing in P, PET, E and L and decreases with increasing A and El. The last parameter epsilon increases with increasing in P, S and El but decreases with increasing in A, PET and L. However, the last three PCCs in Table 6.1 are excluded in the regionalization process due to poor data quality. The developed regional equations show values of R^2 equal to 0.72, 0.76 and 0.76 for S_{max}, α and ε respectively while values of F_{cal} equal to 3.93, 4.66 and 4.84 for S_{max}, α and ε respectively from the ANOVA table (Appendix E). But value of F_{cr} from F-table is 3.37

which is less than all F_{cal} values. The above equations together with Table 6.1, that is the model parameter, form regional rainfall runoff model of Omo- Gibe river basin.

6.3.2. Validation 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 test catchments. In this study validation of the regional model is done using the validation period 1997 to 2006 of simulated gauged catchments.

The established regional model was used to estimate the model parameters of gauged catchment using their PCCs. Next the discharge was simulated based on the estimated parameter and the model performance with respect to NS, RVE and r^2 was evaluated. Table 6.4 shows the parameters derived from the regional model and the model performances and it indicates that the model performs reasonably with respect to RVE and NS.

Table 6.4: Validation of the regional model of gauged catchments from1997 to2006

Sub-Catchments	RVE	NS	r^2
Amara Nr.Shebako	-3.13	0.66	0.73
Awaitu at Jimma	8.56	0.75	0.7
Bidru Awana Nr. Sokuru	-9.07	0.63	0.65
Bulbule Nr. Serbo	-33.72	0.64	0.69
Dincha at Bonga	-1.16	0.82	0.77
Gilgel ghibie Nr. Assendabo	-8.3	0.87	0.85
Ghibe Nr. Baco	-9.46	0.55	0.64
Ghibe Nr. Seka	0.28	0.8	0.75
Gogeb Nr. Endeber	-21.58	0.7	0.82
Gojeb Shebe	5.86	0.66	0.75
Gumma Nr. Andaracha	6.51	0.69	0.66
Kulti Nr. Wolkete	8.16	0.31	0.8
Megech Nr. Gubere	4.67	0.65	0.7
Wabi Nr. Wolkite	-33.32	0.63	0.83
Walga Nr. Walkite	25.21	0.66	0.76
Werabessa Nr. Tolie	-1.46	0.78	0.67

6.3.3. Spatial proximity

The regression method is the most widely used regionalization technique but alternative methods are in use. The choice of catchments from which information is to be transferred is usually based on some sort of similarity measure, i.e. one tends to choose those catchments that are most similar to the site of interest. One common similarity measure is spatial proximity, based on the rationale that catchments that are close to each other will have a similar runoff regime as climate and catchment conditions will only vary smoothly in space. In this approach the complete set of model parameters is usually transferred from one or more gauged catchments to ungauged catchments, while in the regression the parameters are regionalized independently from each other. In this study parameter values derived for gauged catchment in upstream areas were transferred to downstream areas of ungauged catchment. Also catchments which are not gauged or failed to be simulated were given parameters from a neighboring catchment. Figure 6.6 shows the catchment relation layout based on the spatial proximity method.

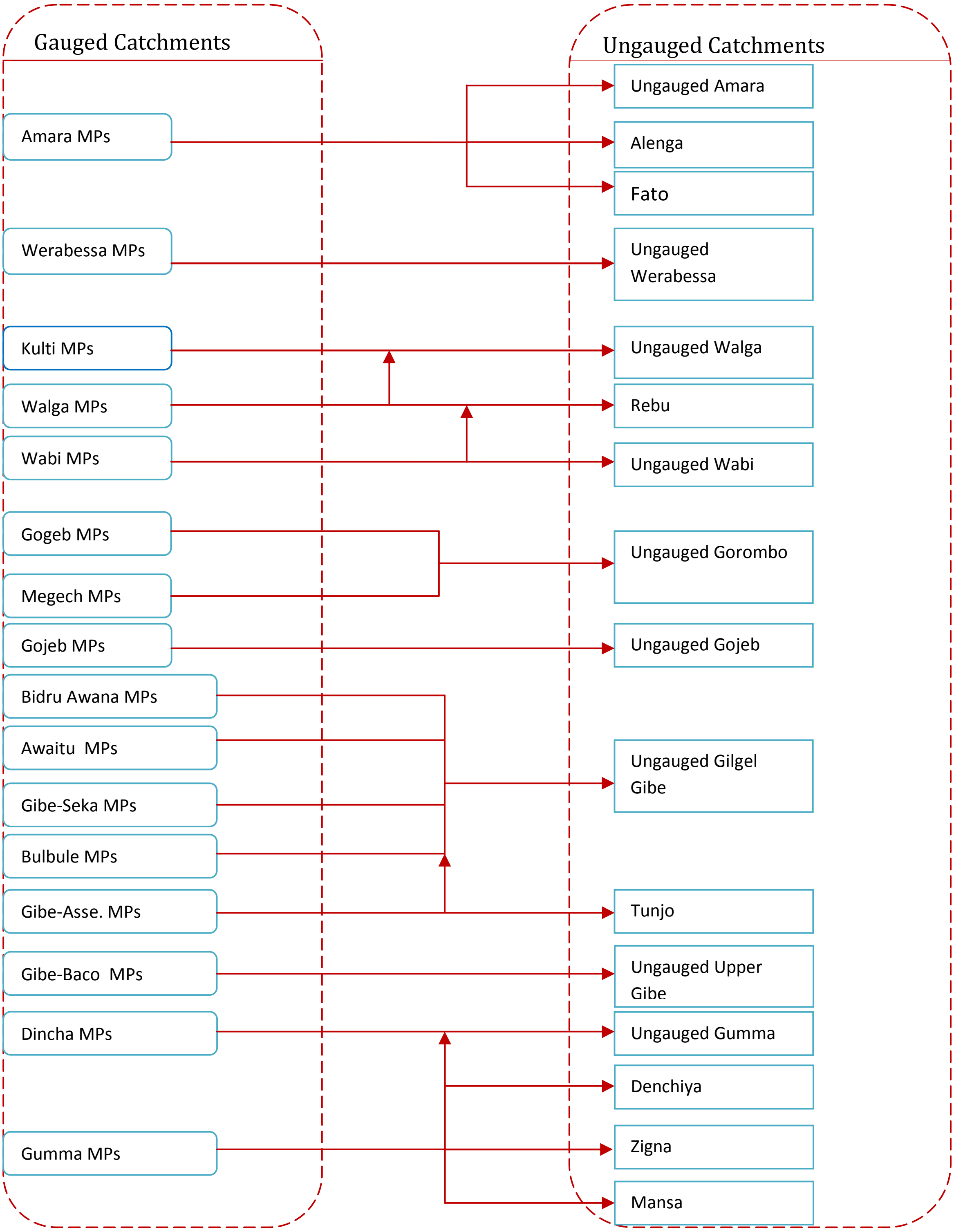


Figure 6.6: Catchments relation layout in spatial proximity method

6.3.4. Area ratio

This method considers only catchment areas by assuming that the catchment area is the dominant factor that controls the volume of water as produced by rainfall. The simulated annual average runoff in gauged catchments showed correlation with R^2 of 86.8% for catchment area (Figure 6.7).

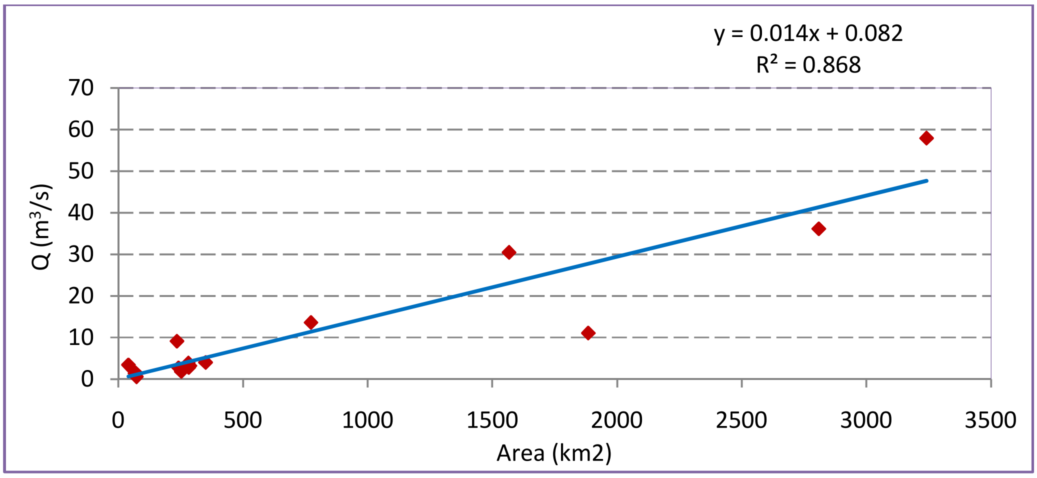


Figure 6.7: Annual average runoff with respect to catchment area for gauged catchment from 1985 to 2006

Hence parameter sets of gauged catchments were transferred to ungauged catchments of comparable area. Figure 6.8 shows the catchment relation layout based on the area ratio.

6.3.5. Sub-basin mean

The sub-basin mean represents the arithmetic mean (Kim and Kaluarachchi, 2008) of calibrated parameter set of 16 catchments to simulate the flow from ungauged catchments.

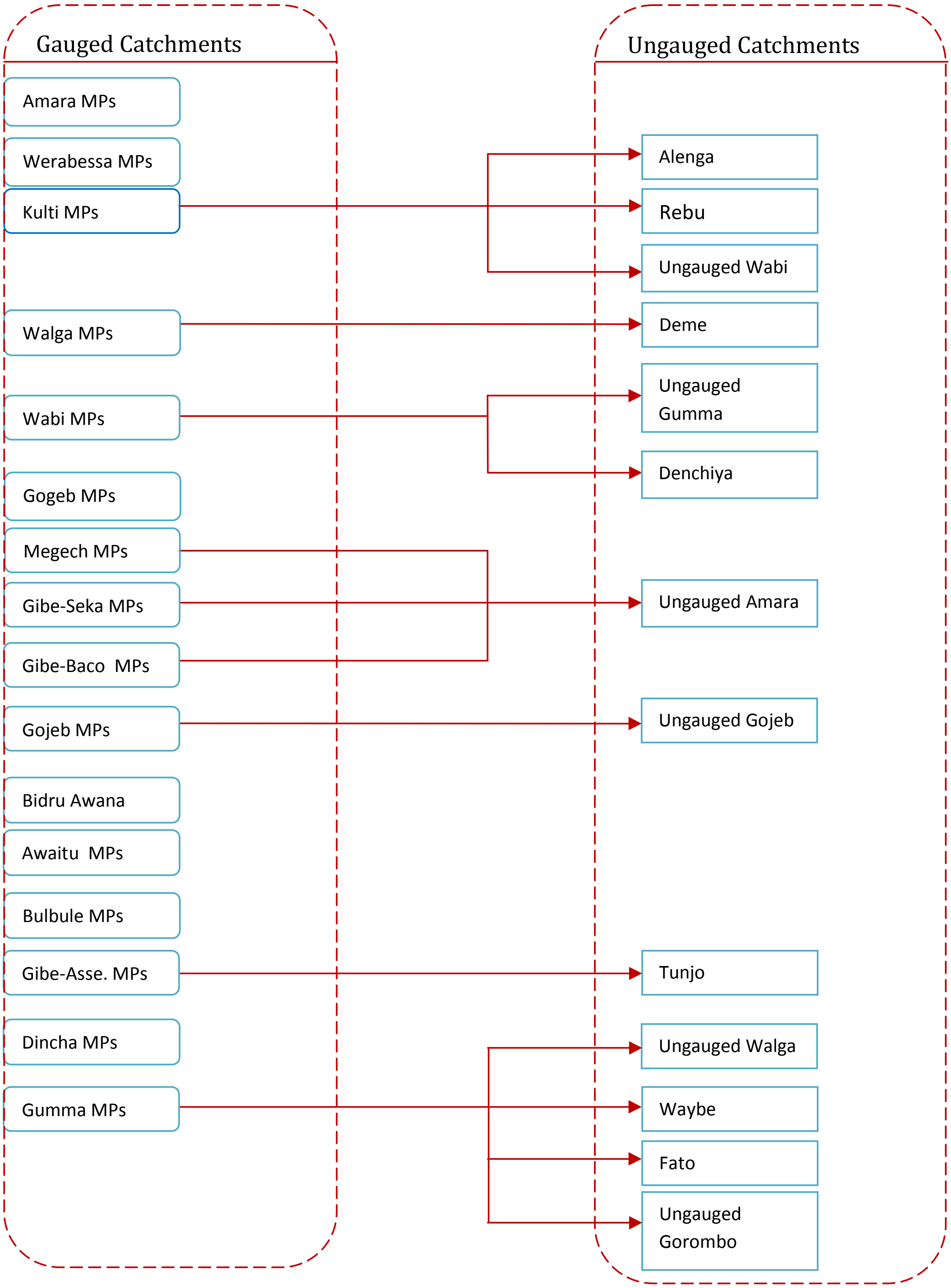


Figure 6.8: Catchment relation layout based on the area ratio

6.3.6. Performance of regionalization methods

The performance of the regionalization methods is presented in terms of their cumulative distribution functions (CDFs) where the NS values for the 16 catchments are summarized (Figure 6.9). The scatter plots in Figure 6.10 also compare the NS values between various regionalization methods and show the number of catchments where one regionalization method is significantly better than the other. The regionalization results are generally poorer than other similar studies, most likely because of the higher temporal and spatial variability in dataset used here.

The median NS values for the four regionalization methods show that multiple regression method (MR) performs best among the other regionalization methods. The area ratio method (AR) generally performs slightly better than the sub-basin mean (SM) while the spatial proximity method (SP) performs the least (Figure 6.9 and Figure 6.10).

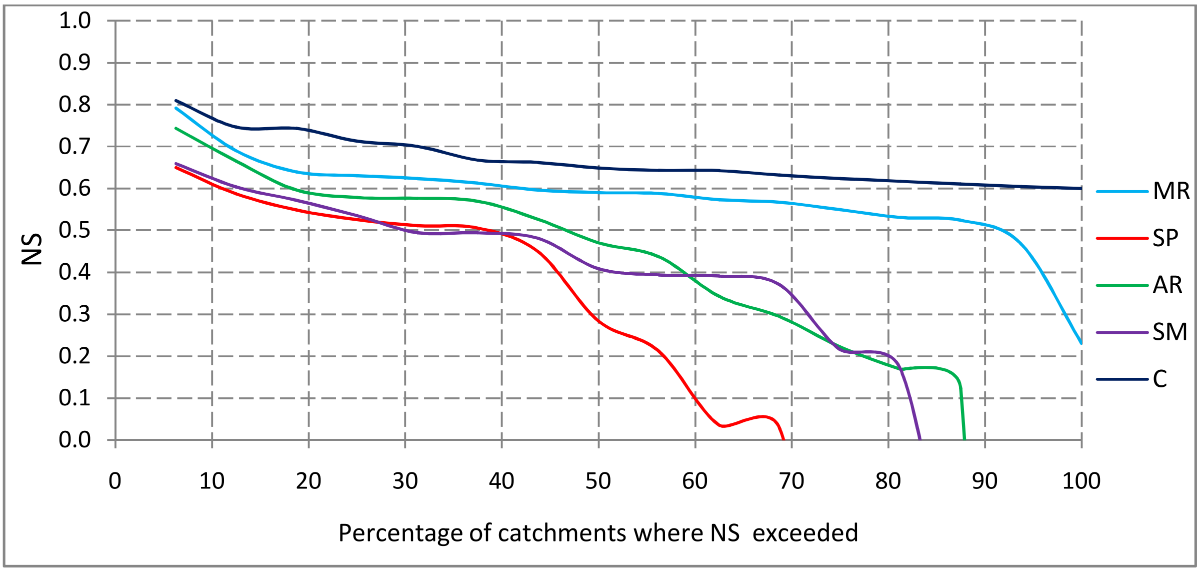


Figure 6.9: Accumulation curves summarizing the Nash-Sutcliffe Efficiency (NSE) for regionalization

(MR is multiple regression method, SP is spatial proximity method, AR is area ratio method, SM is sub-basin mean method, C is calibration)

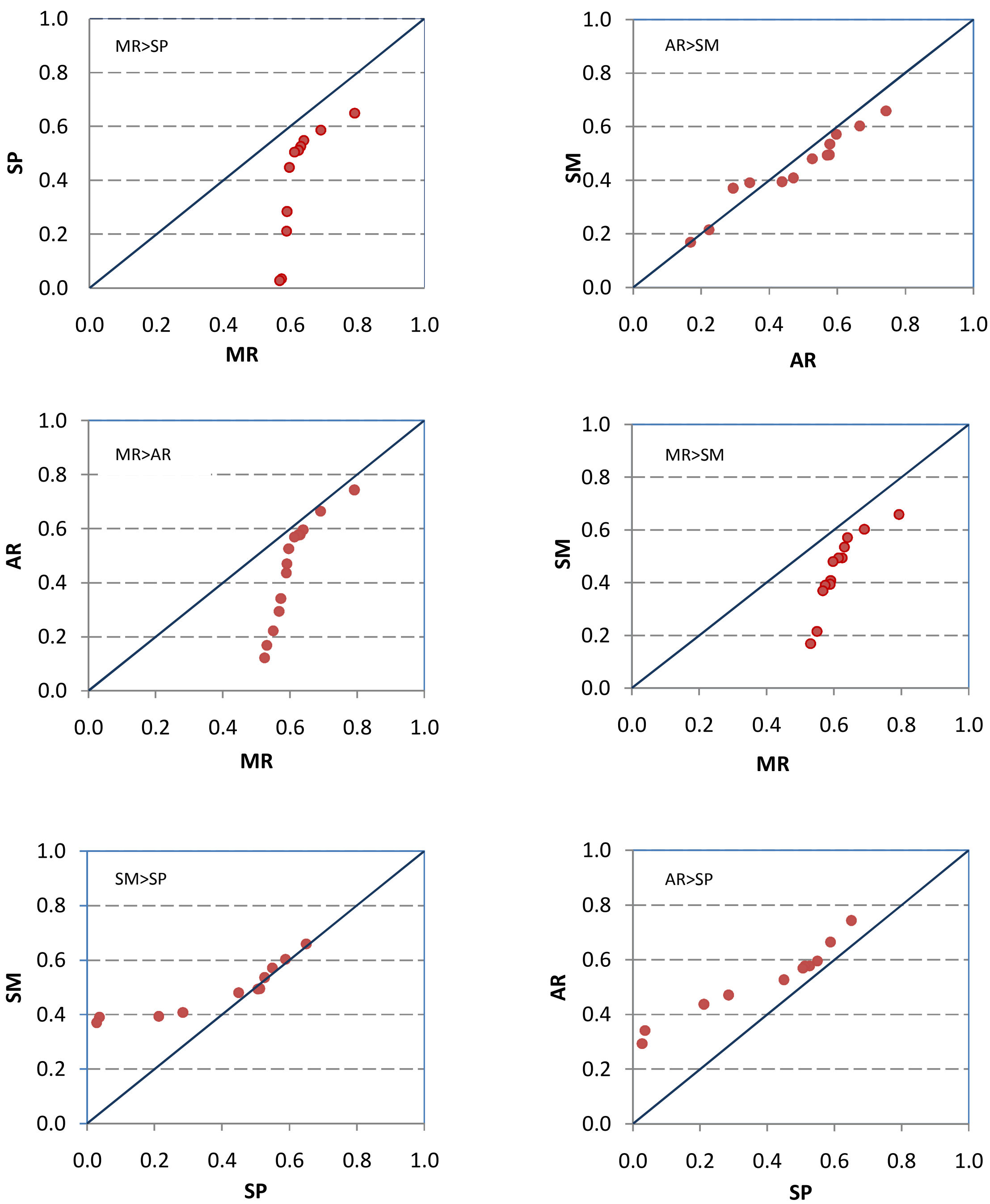


Figure 6.10: Comparisons of NS values between various regionalization methods

CHAPTER SEVEN

7. Conclusion and Recommendation

7.1. Conclusion

In this research, attempt is made to determine Model Parameters required for estimating monthly flow for gauged and ungauged watersheds in Omo-Gibe river 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. A relationship between gauged and ungauged catchments is also made using the methods of spatial proximity, area-ratio and sub-basin mean

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

- During model calibration and validation period, among the available 22 sub-catchments that are considered for the purpose of rainfall-runoff modeling, 16 sub-catchments fulfilled the set objective functions (See Sec. 5.2), but 6 sub-catchments failed. Thus, the model efficiency is reliable for 73% of the total sub-catchments considered in the study.
- The failure of some of the sub-catchments is expected to be due to quality of hydro-metrological and physiographic data in addition to equifinality problem.
- The sensitivity analysis of the model parameters indicates that maximum water holding capacity (S_{max}), sub-surface runoff parameter (α) and surface runoff parameter (ϵ) are the most sensitive parameters.
- The developed regional equations show values of R^2 equal to 0.72, 0.76, 0.76 and values of F_{cal} equal to 3.93, 4.66, 4.84 for S_{max}, α and ϵ respectively but value of F_{cr} is 3.37 which is less than all F_{cal} values. Thus the strength and overall significance of the regression equations are good.
- The validation of regional equation indicates that the model performs reasonably with respect to RVE and NS.
- The comparisons of the regionalization methods indicate that MR performs the best among other methods. The AR performs slightly better than the SM while SP performs the least.

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

7.2. Recommendation

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

- In order to deal with the problem of equifinality in other attempts of regionalizing the WATBAL model, the concept of a unique best-fit model could be abandoned.
- 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 39.7km^2 to 3241.68km^2, it is also recommended that the model be used within this range.
- The sub catchments used in the modeling work are found in the northern and north western parts of the basin; however, there are no representative sub-catchments in the southern and south western part of the basin yet. Further, there is considerable variation in PCCs from northwards to southwards. Hence, it is recommended that the developed regional equation be used in northern and north-western parts.
- 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 for each objective functions.
- A study of more advanced automatic model calibration techniques could be useful.

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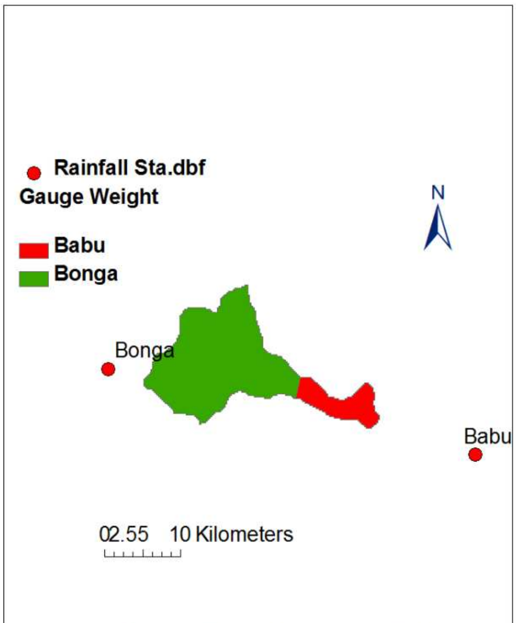
Appendices

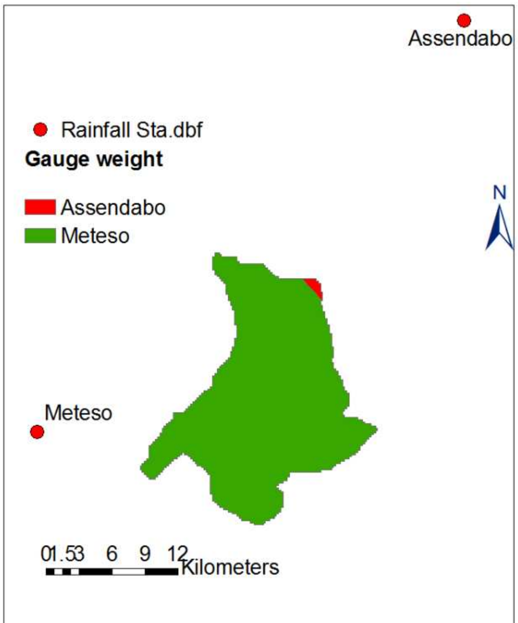
Appendix A: Thiessen Polygon Developed for Selected Sub Catchments

	Dincha Sub-catchment		
S.no	Rainfall stations	Area Weight (km^2)	Gauge Weight (%)
1	Bonga	36.26	18.266
2	Wushwush	198.50	84.555
	Total	234.8	

	Bulbul Sub-catchment		
S.no	Rainfall stations	Area Weight (km^2)	Gauge Weight (%)
1	Assendabo	1.476	0.584243699
2	Meteso	251.204	99.4157563
	Total	252.7	



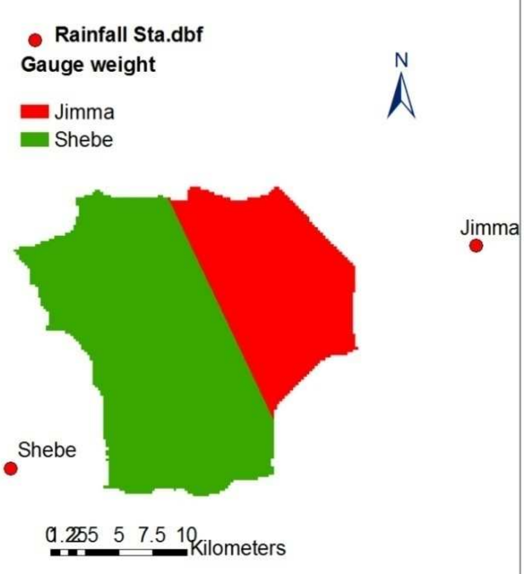
Developed Thiessen Polygon for Dincha sub-catchment



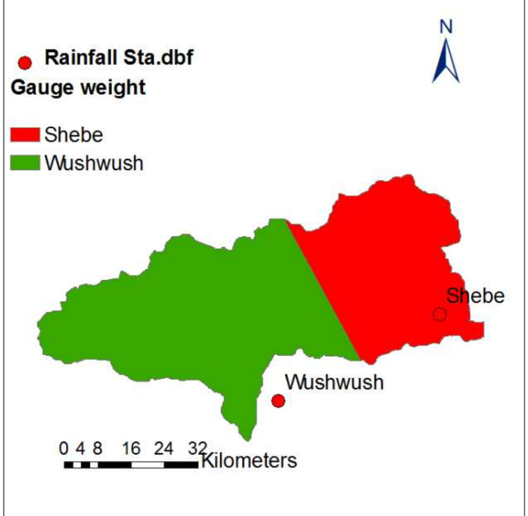
Developed Thiessen Polygon for Bulbul sub-catchment

	Gibe-Seka Sub-catchment		
S.no	Rainfall stations	Area Weight (km^2)	Gauge Weight (%)
1	Jimma	130.48	34.253
2	Shebe	250.44	65.747
	Total	380.9	

	Gojeb-shebe Sub-catchment		
S.no	Rainfall stations	Area Weight (km^2)	Gauge Weight (%)
1	Wushwush	1977.07	60.989
2	Shebe	1264.61	39.011
	Total	3241.7	



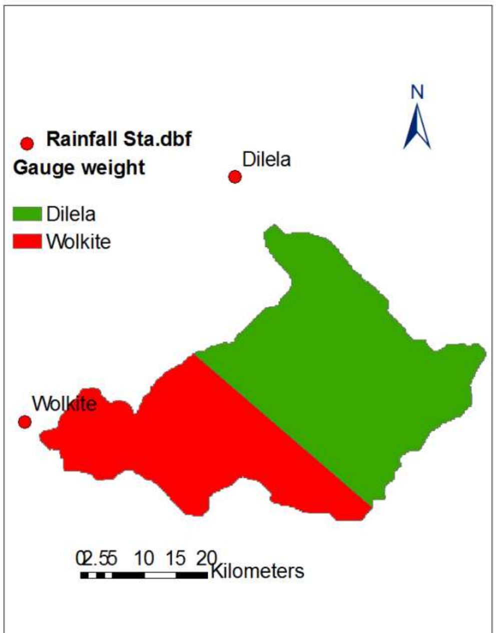
Developed Thiessen polygon for Gibe-seka sub catchment



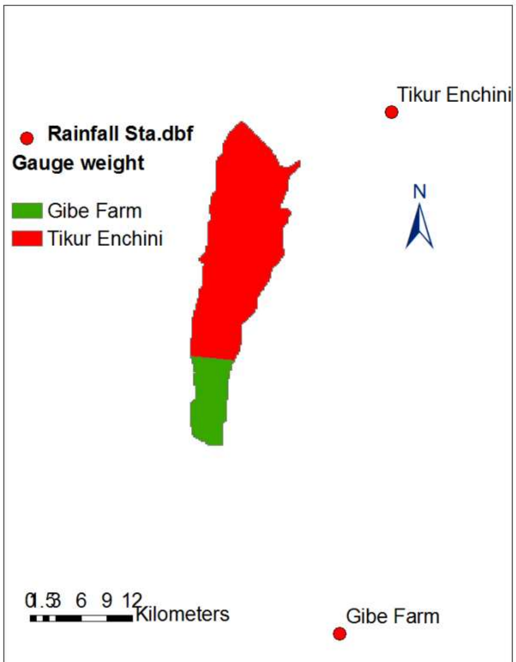
Developed Thiessen Polygon for Gojeb-shebe sub-catchment

	Wabi Sub-catchment		
S.no	Rainfall stations	Area Weight (km^2)	Gauge Weight (%)
1	Wolkite	640.79	40.882
2	Dilela	926.61	59.118
	Total	1567.4	

	Werabessa Sub-catchment		
S.no	Rainfall stations	Area Weight (km^2)	Gauge Weight (%)
1	Tikur Enchini	201.14	83.50
2	Gibe Farm	39.74	16.50
	Total	240.9	

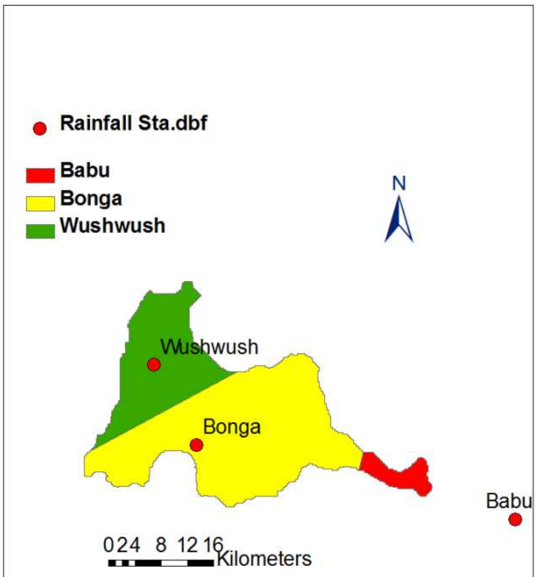


Developed Thiessen Polygon for Wabi sub-catchment



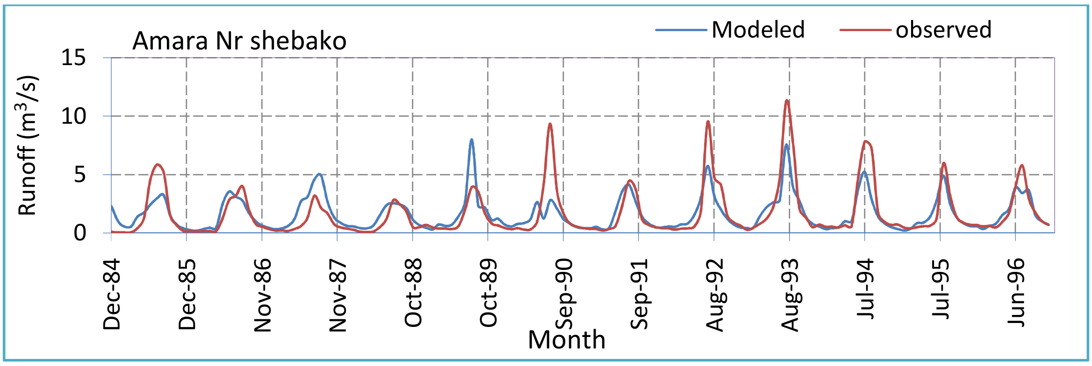
Developed Thiessen Polygon for Werabessa sub-catchment

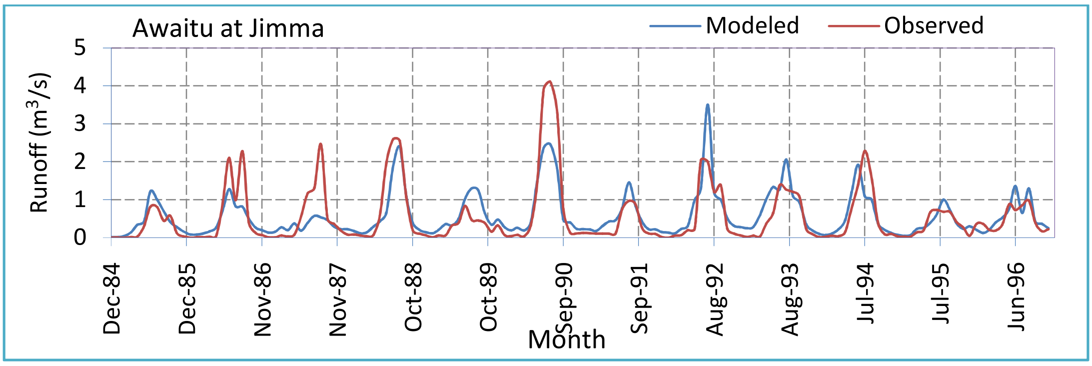
Gumma Sub-catchment			
S.no	Rainfall stations	Area Weight (km^2)	Gauge Weight (%)
1	Babu	36.26	4.70
2	Bonga	507.50	65.76
3	Wushwush	228.0	29.55
	Total	771.8	

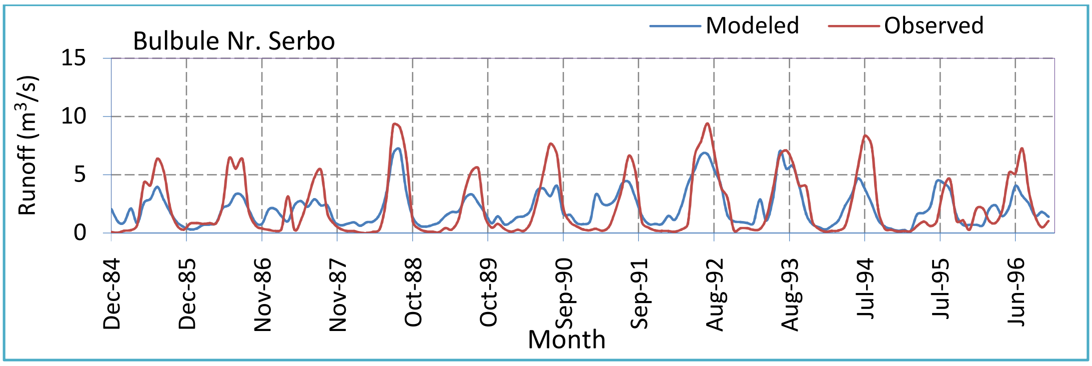


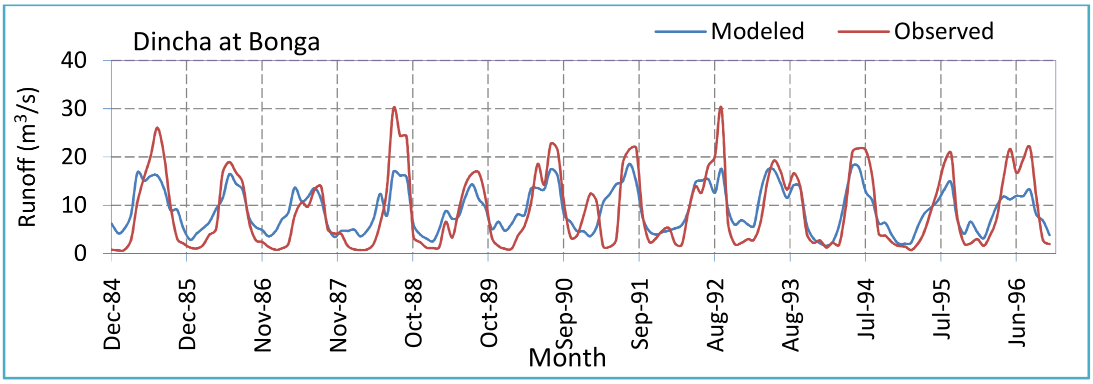
Developed Thiessen Polygon for Gumma sub-catchment

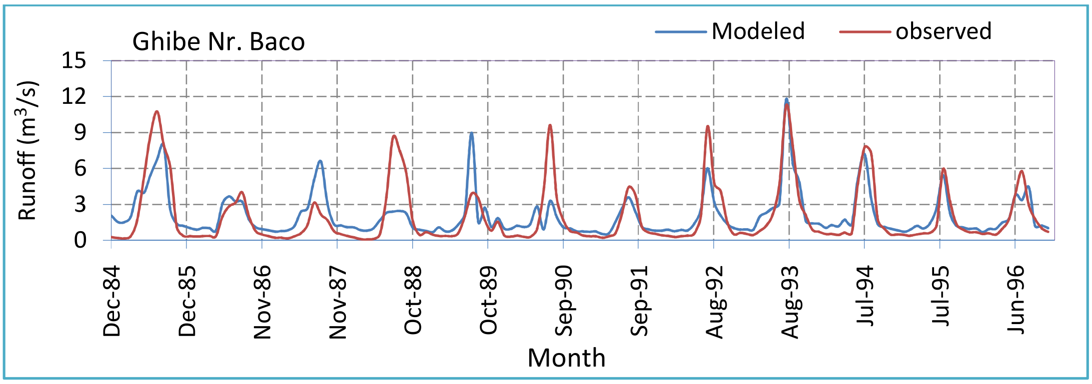
Appendix B1: Observed and simulated monthly flow hydrograph of gauged catchments, calibration period (1985-1996)

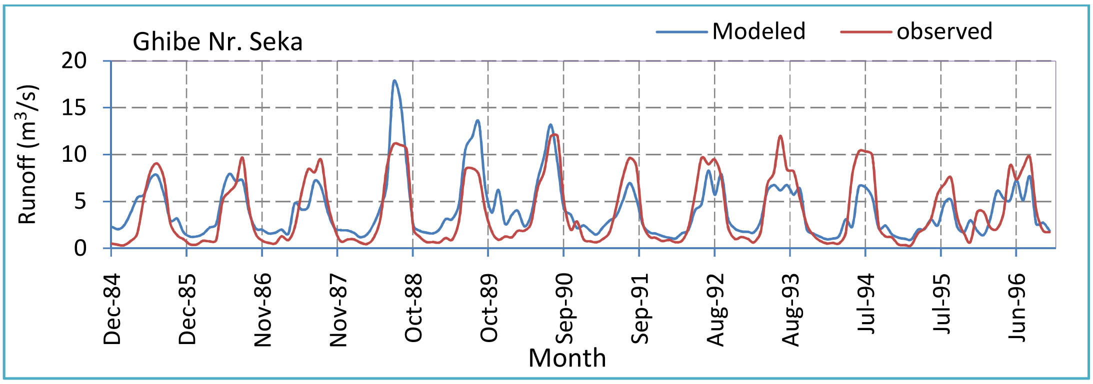


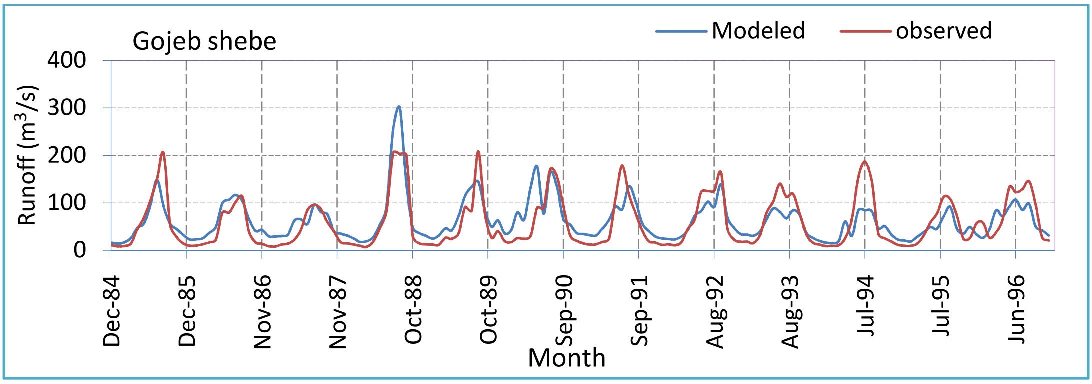


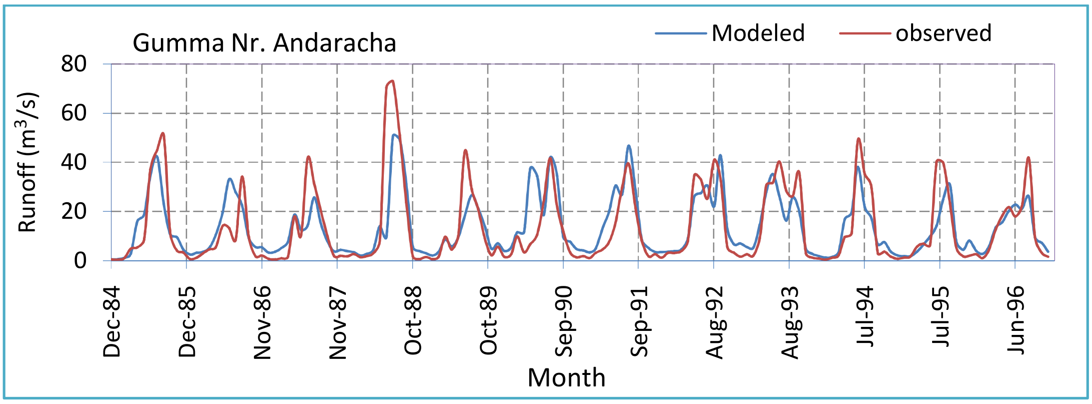


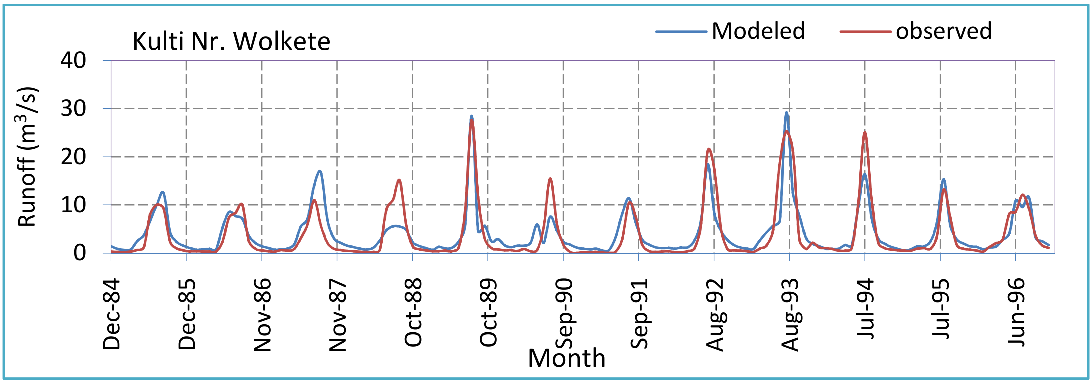


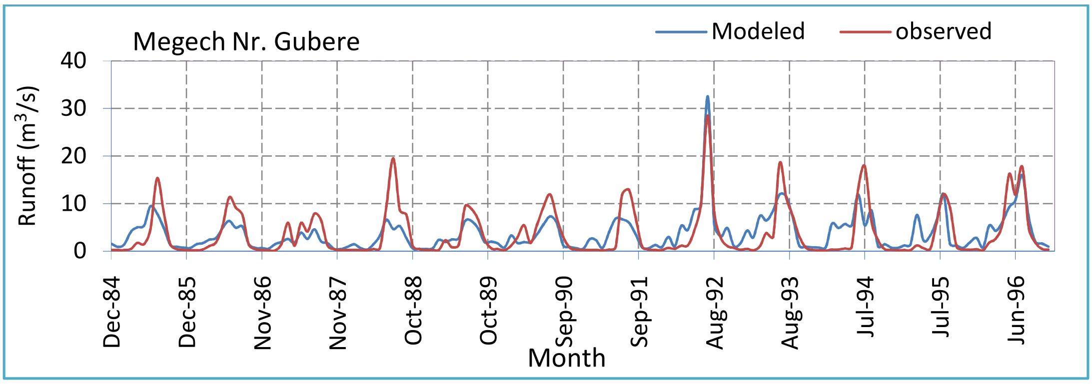

Ghibe Nr. Baco
Modeled
observed
Runoff (m3/s)
15
12
9
6
3
0
Dec-84
Dec-85
Nov-86
Nov-87
Oct-88
Oct-89
Sep-90
Sep-91
Aug-92
Aug-93
Jul-94
Jul-95
Jun-96
Month

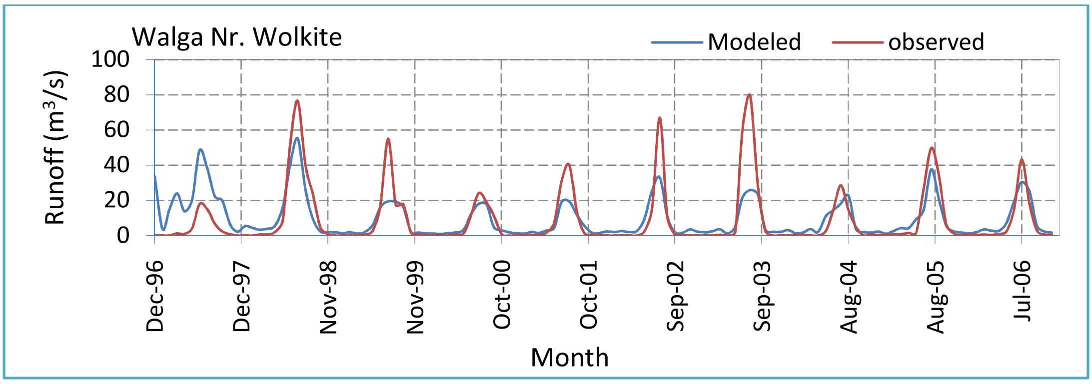

Ghibe Nr. Seka
Modeled
observed
Runoff (m3/s)
20
15
10
5
0
Dec-84
Dec-85
Nov-86
Nov-87
Oct-88
Oct-89
Sep-90
Sep-91
Aug-92
Aug-93
Jul-94
Jul-95
Jun-96
Month

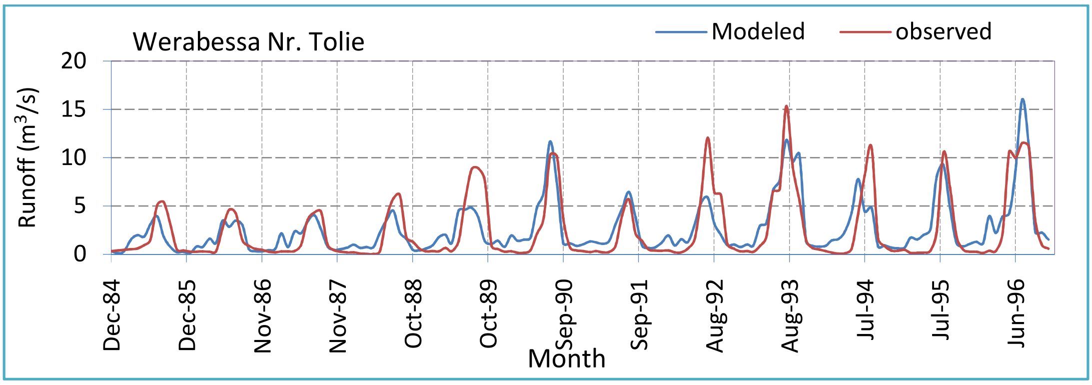

Gojeb shebe
Modeled
observed
Runoff (m3/s)
400
300
200
100
0
Dec-84
Dec-85
Nov-86
Nov-87
Oct-88
Oct-89
Sep-90
Sep-91
Aug-92
Aug-93
Jul-94
Jul-95
Jun-96
Month


Gumma Nr. Andaracha
Modeled
observed
Runoff (m3/s)
80
60
40
20
0
Dec-84
Dec-85
Nov-86
Nov-87
Oct-88
Oct-89
Sep-90
Sep-91
Aug-92
Aug-93
Jul-94
Jul-95
Jun-96
Month

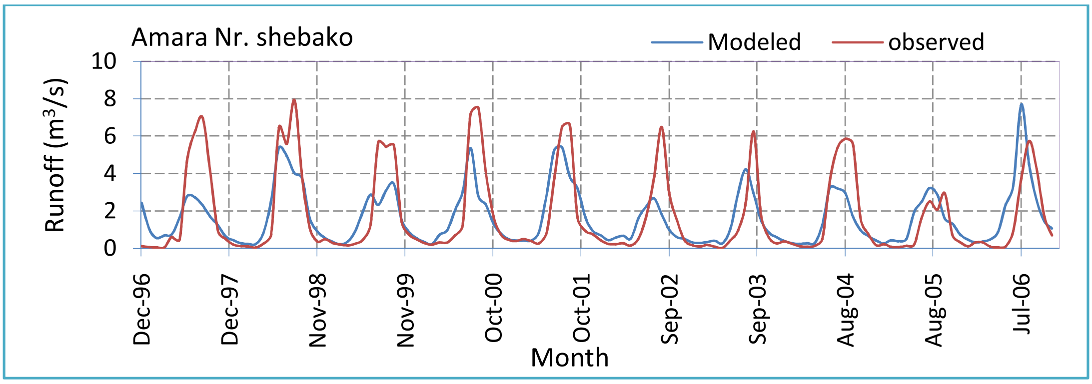

Kulti Nr. Wolkete
Modeled
observed
Runoff (m³/s)
40
30
20
10
0
Dec-84
Dec-85
Nov-86
Nov-87
Oct-88
Oct-89
Sep-90
Sep-91
Aug-92
Aug-93
Jul-94
Jul-95
Jun-96
Month

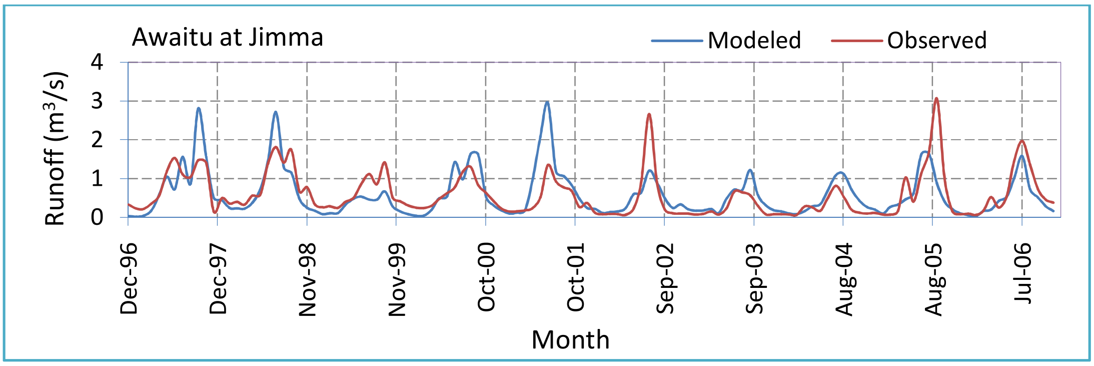

Megech Nr. Gubere
Modeled
observed
Runoff (m³/s)
40
30
20
10
0
Dec-84
Dec-85
Nov-86
Nov-87
Oct-88
Oct-89
Sep-90
Sep-91
Aug-92
Aug-93
Jul-94
Jul-95
Jun-96
Month

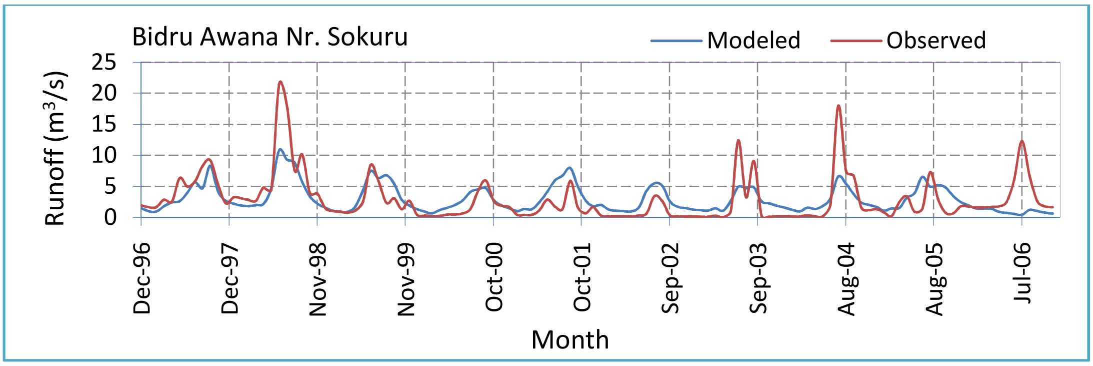

Walga Nr. Wolkite
Modeled
observed
Runoff (m³/s)
100
80
60
40
20
0
Dec-96
Dec-97
Nov-98
Nov-99
Oct-00
Oct-01
Sep-02
Sep-03
Aug-04
Aug-05
Jul-06
Month

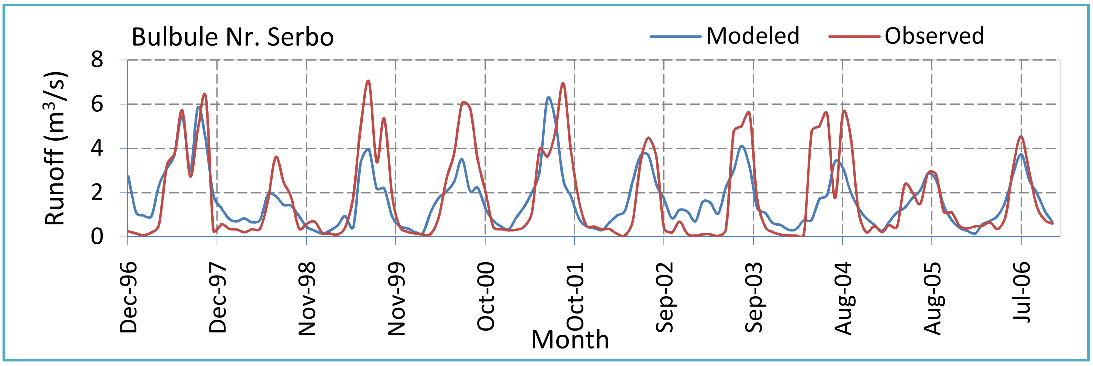

Werabessa Nr. Tolie
Modeled
observed
Runoff (m³/s)
20
15
10
5
0
Dec-84
Dec-85
Nov-86
Nov-87
Oct-88
Oct-89
Sep-90
Sep-91
Aug-92
Aug-93
Jul-94
Jul-95
Jun-96
Month

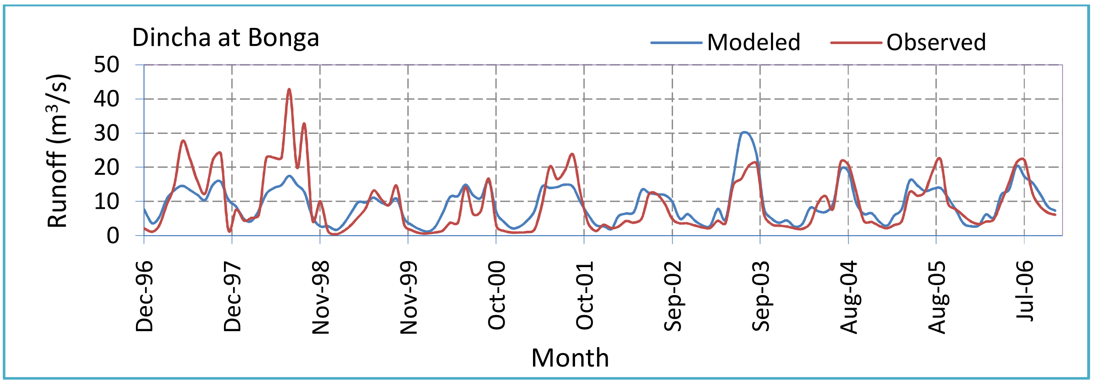
Appendix B2: Observed and simulated monthly flow hydrograph of gauged catchments, validation period (1997-2006)

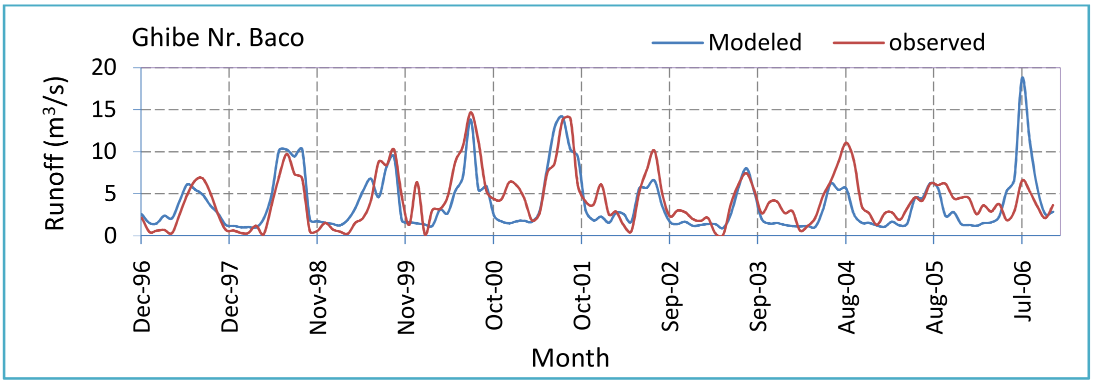


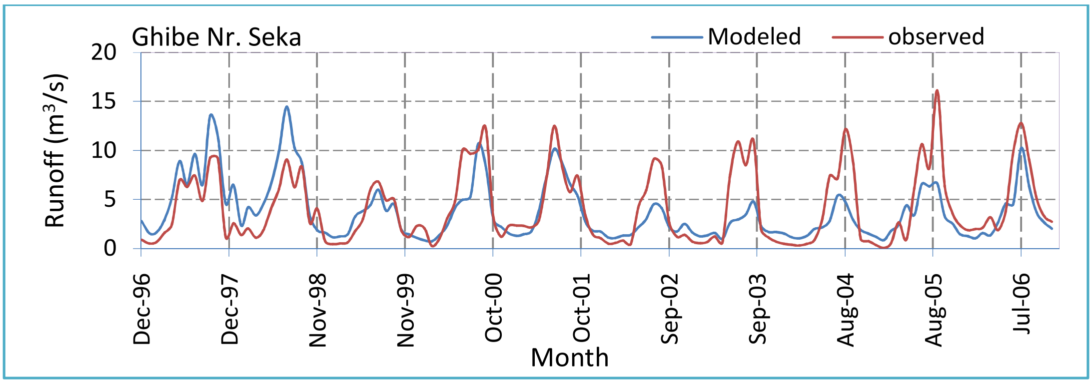


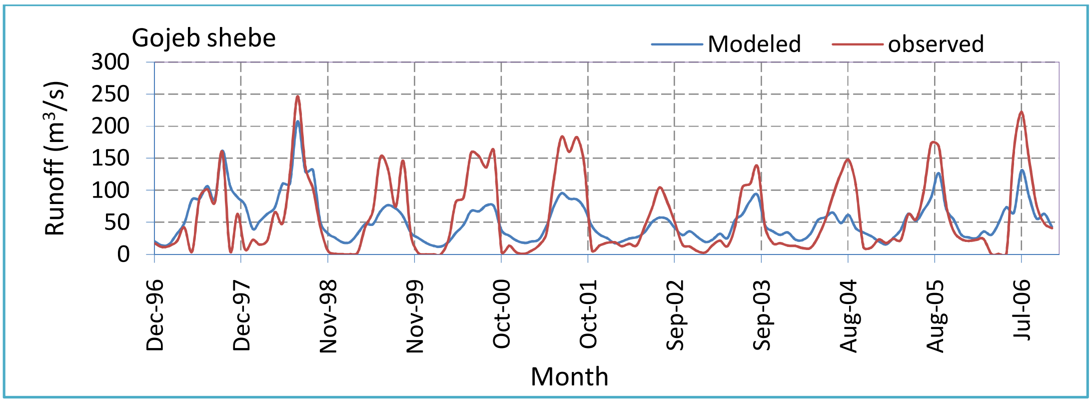


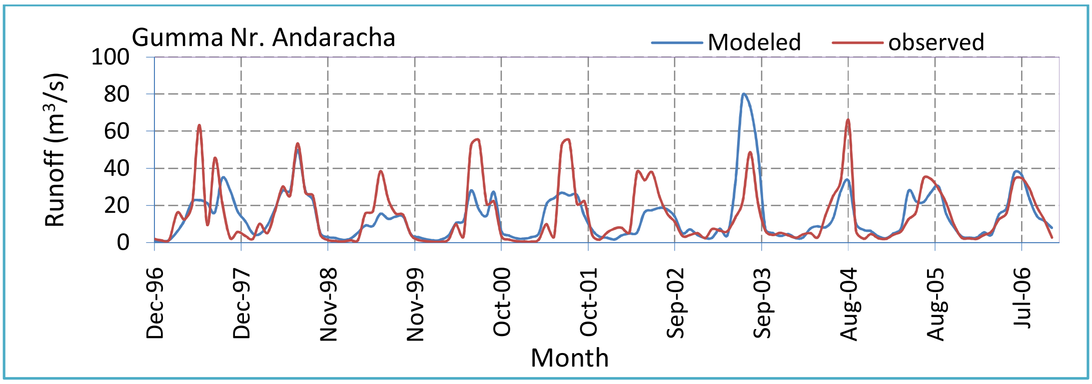


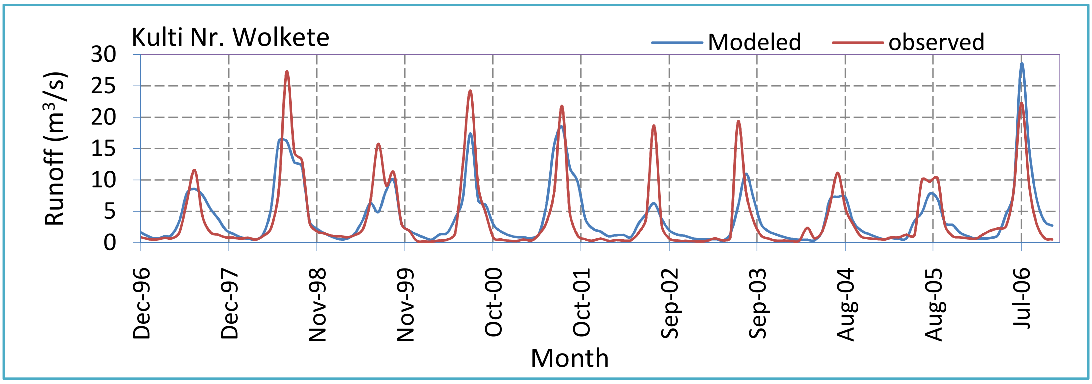

Dincha at Bonga
Modeled
Observed
Runoff (m3/s)
50
40
30
20
10
0
Dec-96
Dec-97
Nov-98
Nov-99
Oct-00
Oct-01
Sep-02
Sep-03
Aug-04
Aug-05
Jul-06
Month

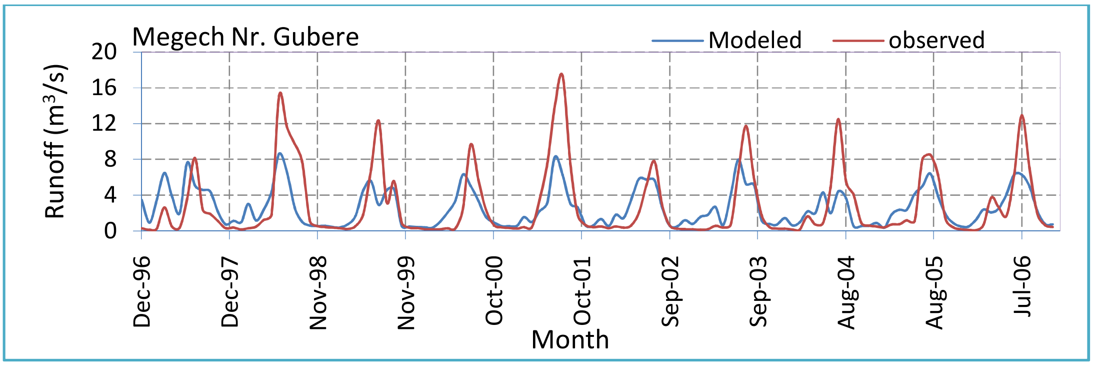

Ghibe Nr. Baco
Modeled
observed
Runoff (m3/s)
20
15
10
5
0
Dec-96
Dec-97
Nov-98
Nov-99
Oct-00
Oct-01
Sep-02
Sep-03
Aug-04
Aug-05
Jul-06
Month

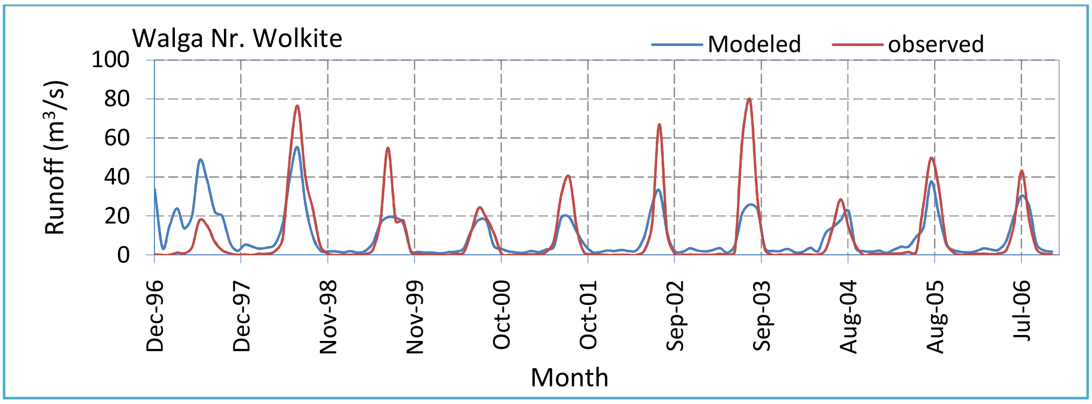

Ghibe Nr. Seka
Modeled
observed
Runoff (m3/s)
20
15
10
5
0
Dec-96
Dec-97
Nov-98
Nov-99
Oct-00
Oct-01
Sep-02
Sep-03
Aug-04
Aug-05
Jul-06
Month

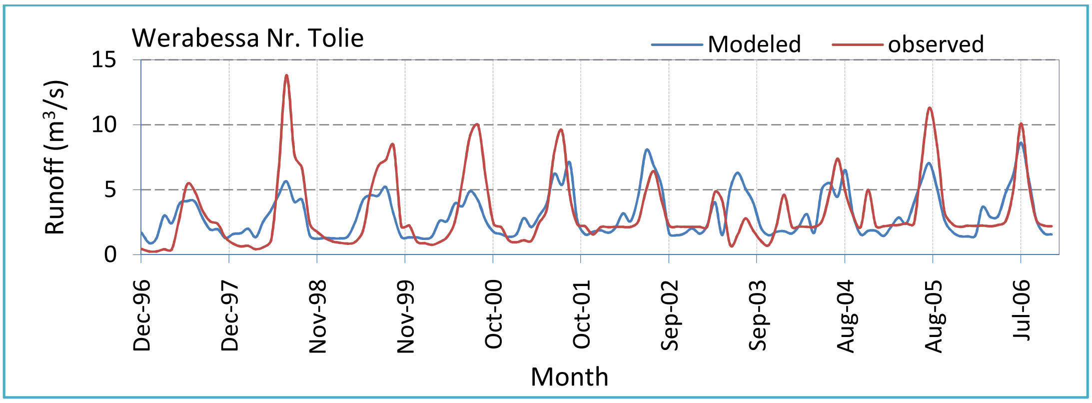

Gojeb shebe
Modeled
observed
Runoff (m3/s)
300
250
200
150
100
50
0
Dec-96
Dec-97
Nov-98
Nov-99
Oct-00
Oct-01
Sep-02
Sep-03
Aug-04
Aug-05
Jul-06
Month


Gumma Nr. Andaracha
Modeled
observed
Runoff (m³/s)
100
80
60
40
20
0
Dec-96
Dec-97
Nov-98
Nov-99
Oct-00
Oct-01
Sep-02
Sep-03
Aug-04
Aug-05
Jul-06
Month

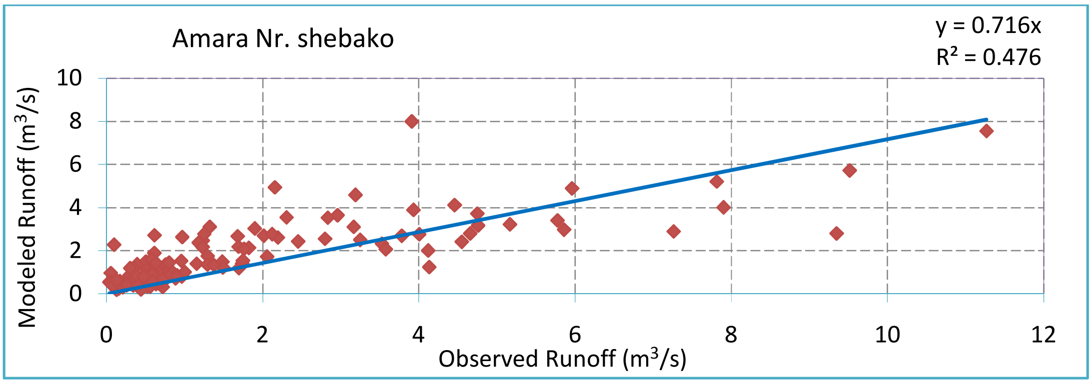

Kulti Nr. Wolkete
Modeled
observed
Runoff (m³/s)
30
25
20
15
10
5
0
Dec-96
Dec-97
Nov-98
Nov-99
Oct-00
Oct-01
Sep-02
Sep-03
Aug-04
Aug-05
Jul-06
Month

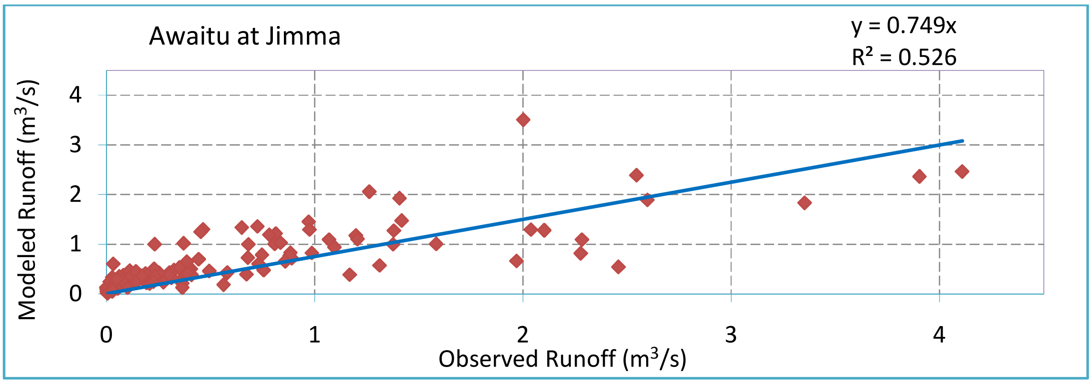

Megech Nr. Gubere
Modeled
observed
Runoff (m³/s)
20
16
12
8
4
0
Dec-96
Dec-97
Nov-98
Nov-99
Oct-00
Oct-01
Sep-02
Sep-03
Aug-04
Aug-05
Jul-06
Month

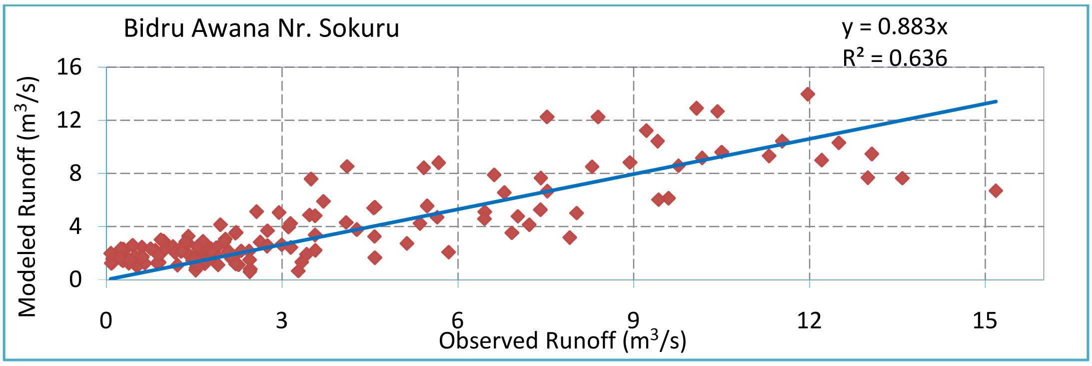

Walga Nr. Wolkite
Modeled
observed
Runoff (m³/s)
100
80
60
40
20
0
Dec-96
Dec-97
Nov-98
Nov-99
Oct-00
Oct-01
Sep-02
Sep-03
Aug-04
Aug-05
Jul-06
Month

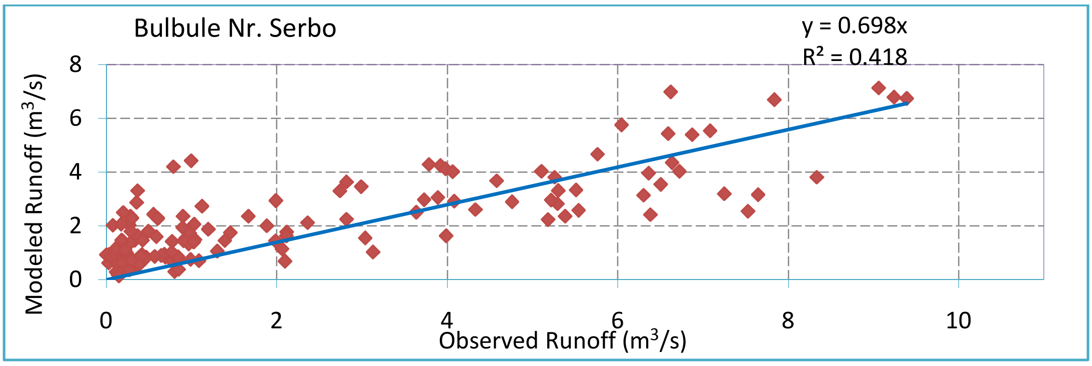


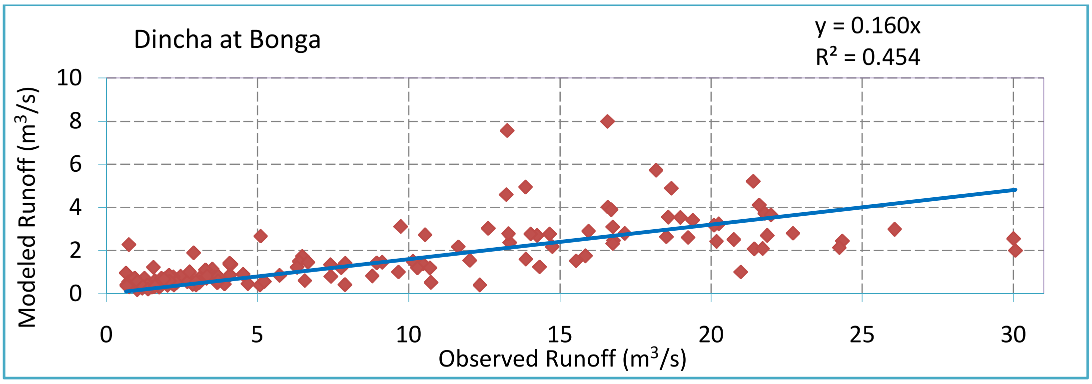
Appendix B3: Scatter plots of observed and simulated discharge for gauged catchments, calibration Period (1985-1996)

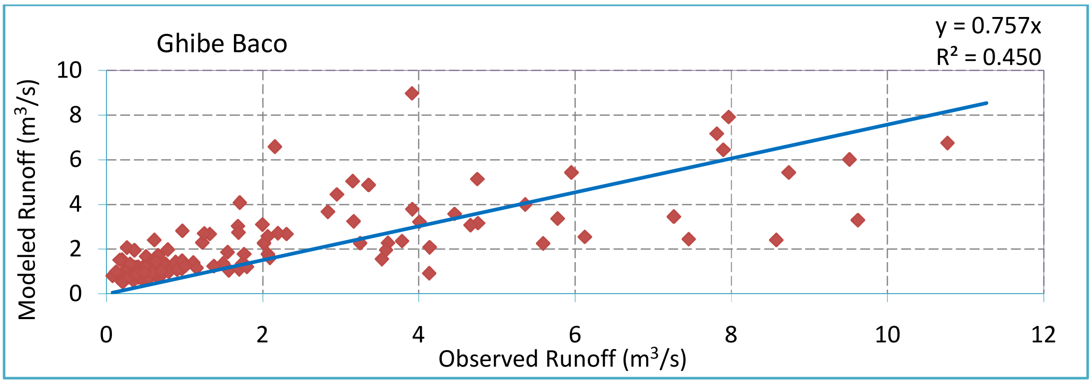


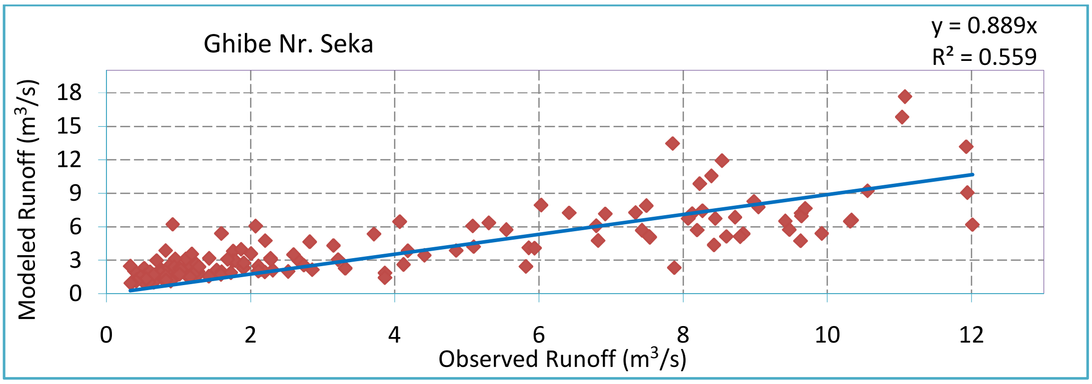


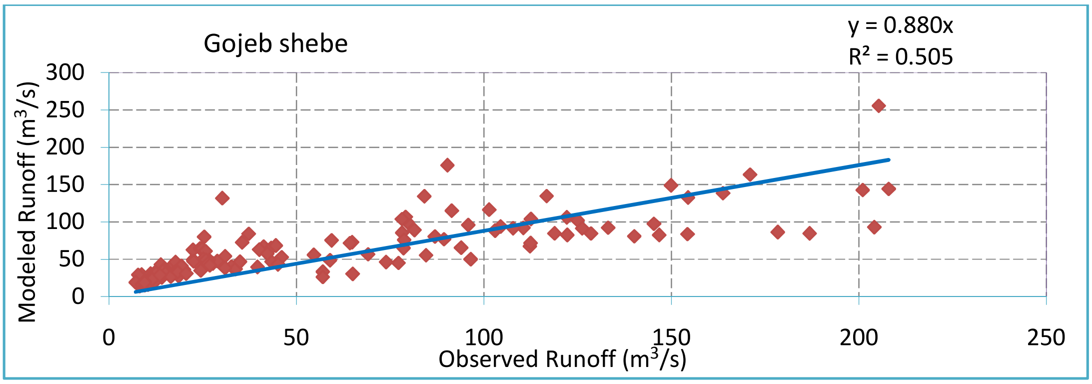

Bidru Awana Nr. Sokuru
y = 0.883x
R² = 0.636
Modeled Runoff (m³/s)
Observed Runoff (m³/s)
0
4
8
12
16
0
3
6
9
12
15

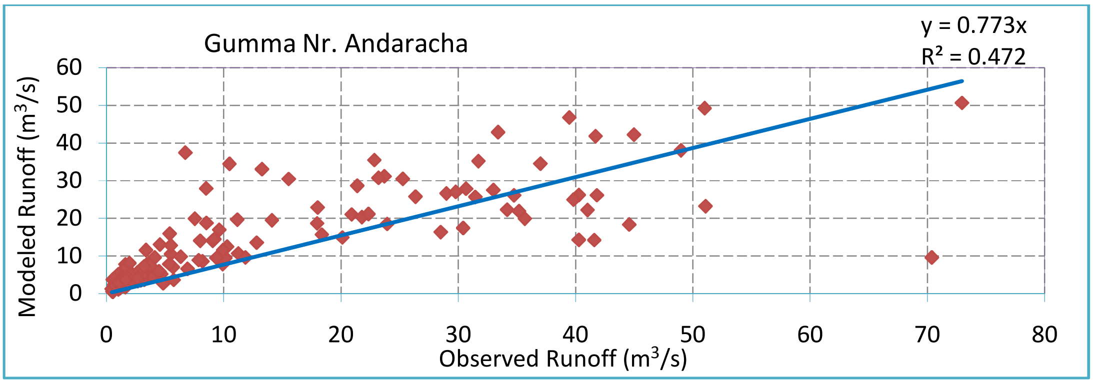

Bulbule Nr. Serbo
y = 0.698x
R² = 0.418
Modeled Runoff (m³/s)
Observed Runoff (m³/s)
0
2
4
6
8
0
2
4
6
8
10

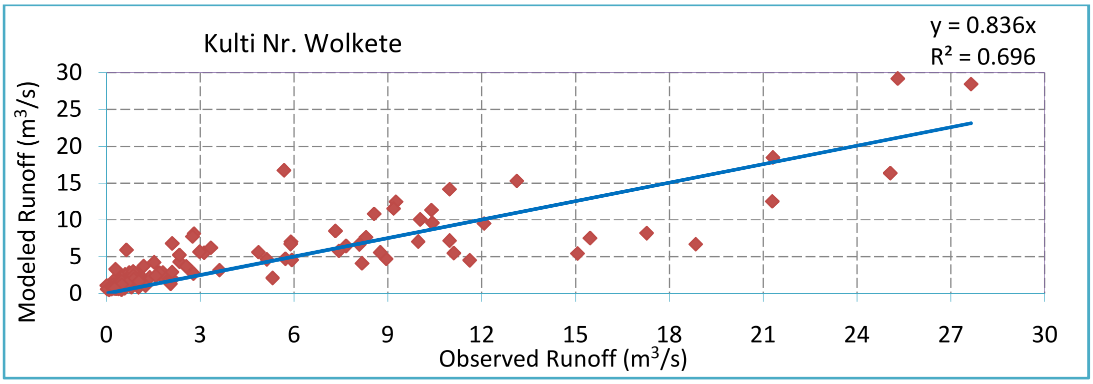

Dincha at Bonga
y = 0.160x
R² = 0.454
Modeled Runoff (m³/s)
Observed Runoff (m³/s)
0
2
4
6
8
10
0
5
10
15
20
25
30

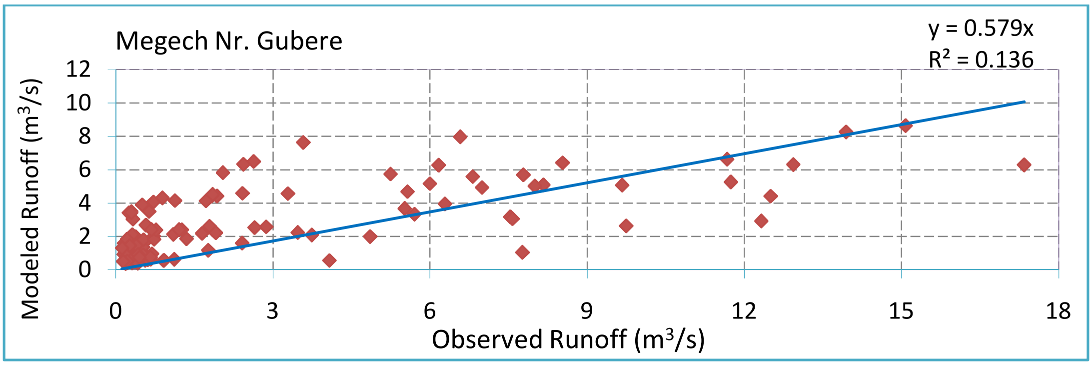

Ghibe Baco
y = 0.757x
R² = 0.450
Modeled Runoff (m³/s)
Observed Runoff (m³/s)
0
2
4
6
8
10
0
2
4
6
8
10
12

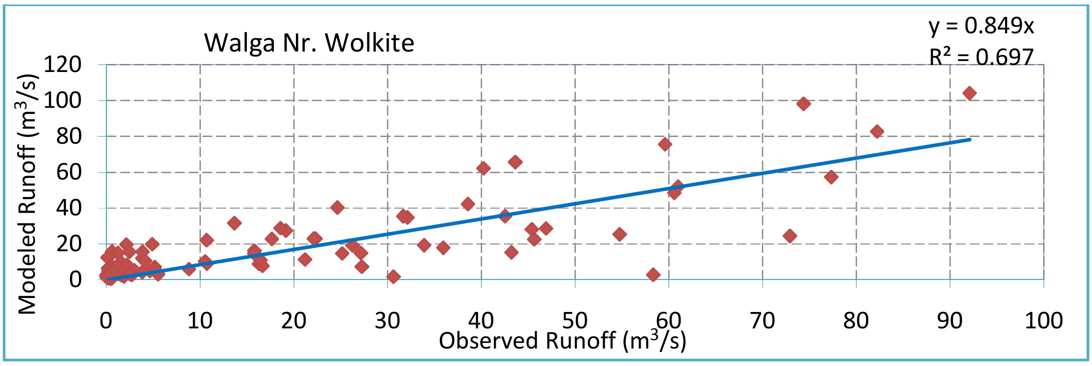

Ghibe Nr. Seka
y = 0.889x
R² = 0.559
Modeled Runoff (m3/s)
Observed Runoff (m3/s)

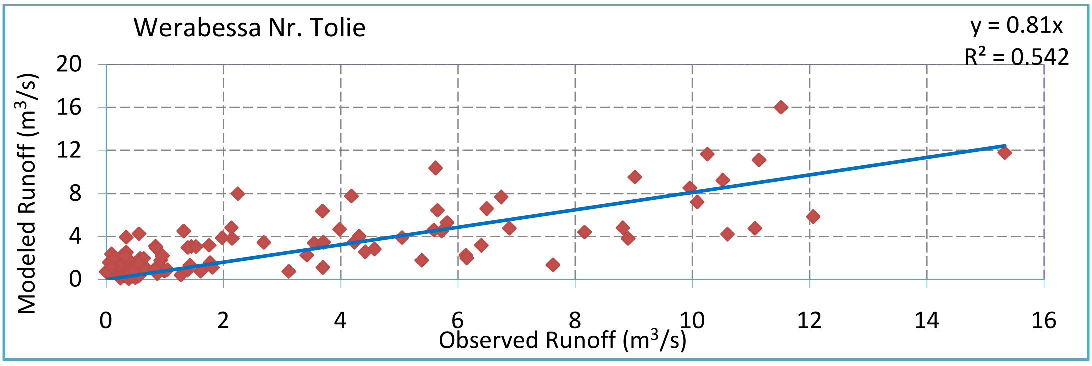

Gojeb shebe
y = 0.880x
R² = 0.505
Modeled Runoff (m3/s)
Observed Runoff (m3/s)


Gumma Nr. Andaracha
y = 0.773x
R² = 0.472
Modeled Runoff (m3/s)
Observed Runoff (m3/s)

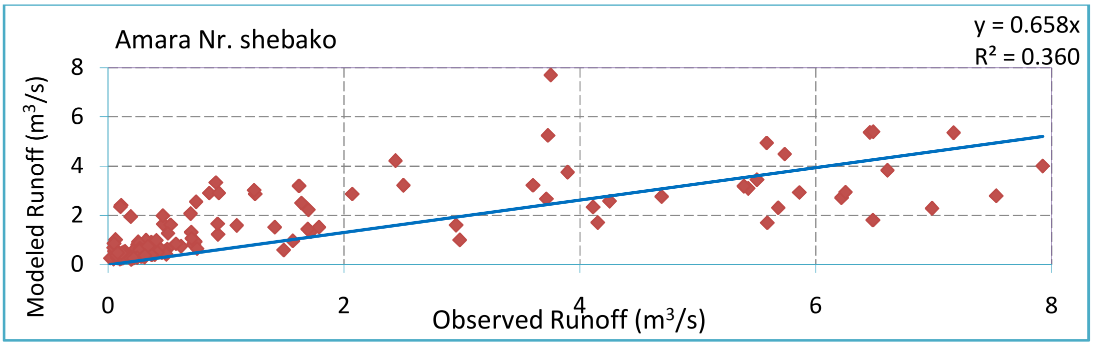

Kulti Nr. Wolkete
y = 0.836x
R² = 0.696
Modeled Runoff (m3/s)
Observed Runoff (m3/s)

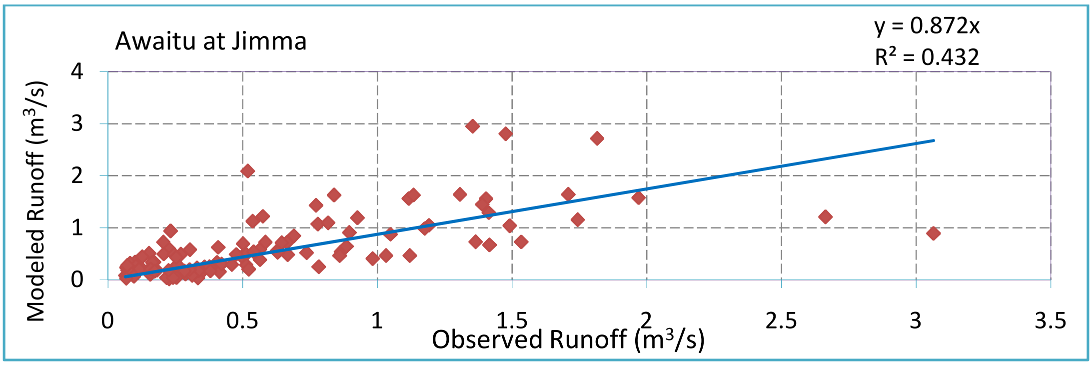


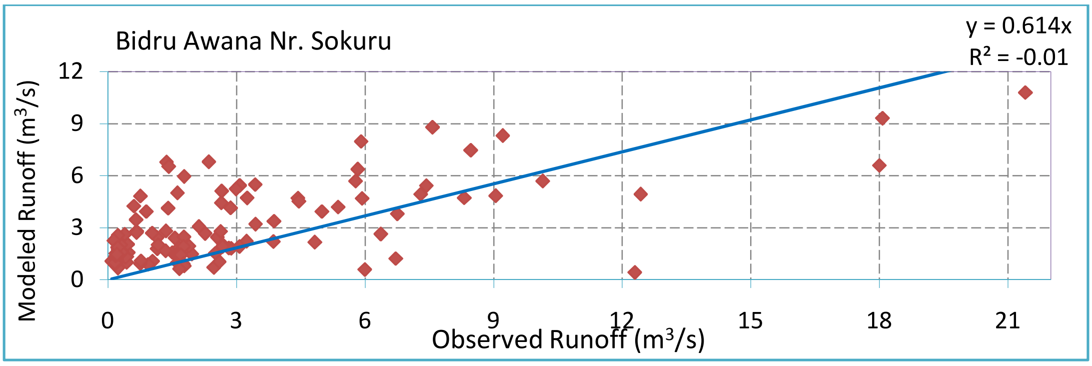


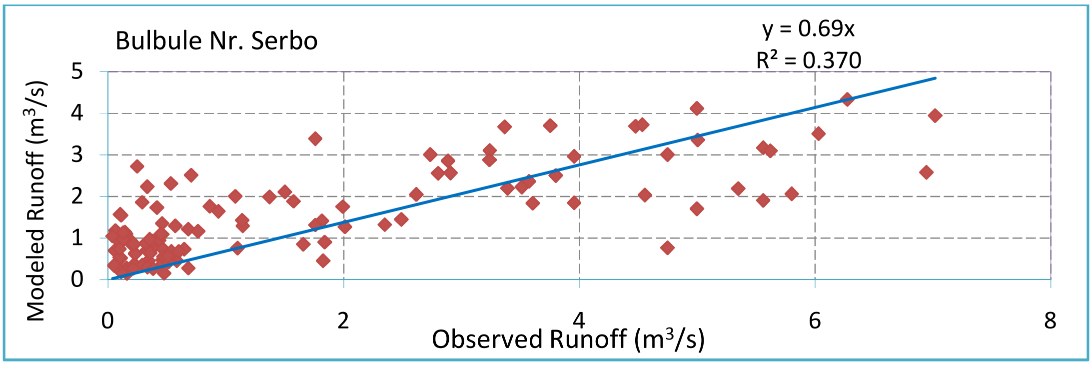


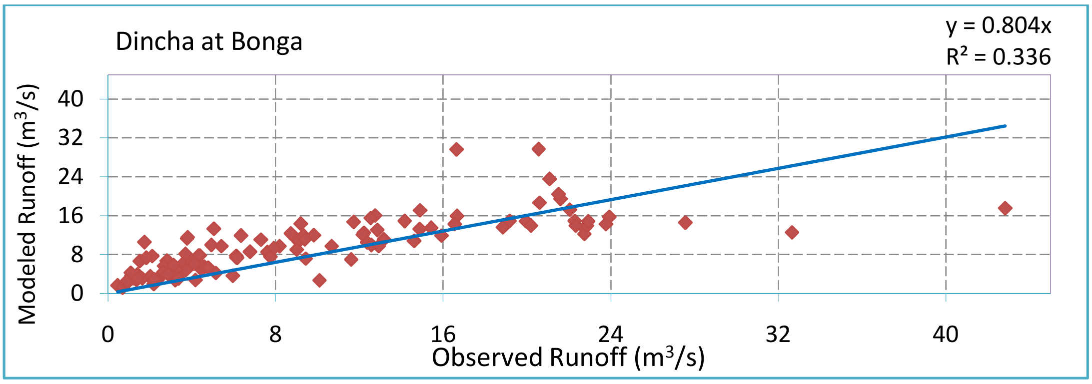
Appendix B4: Scatter plots of observed and simulated discharge for gauged catchments, validation Period (1997-2006)

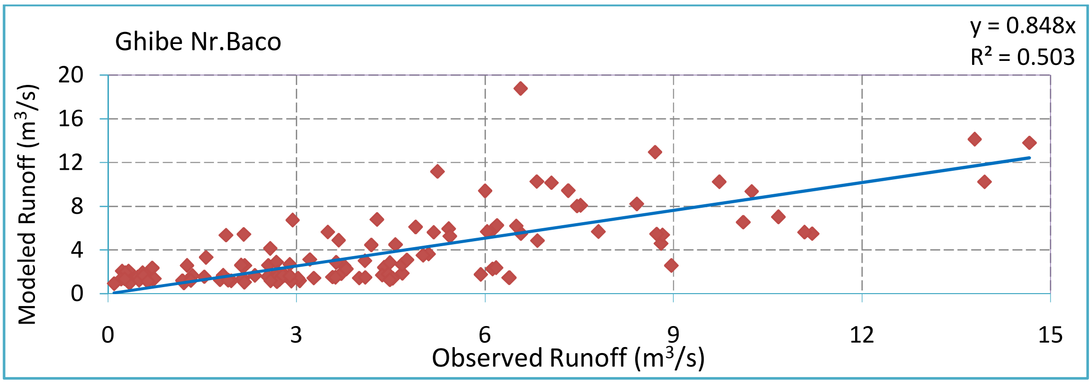


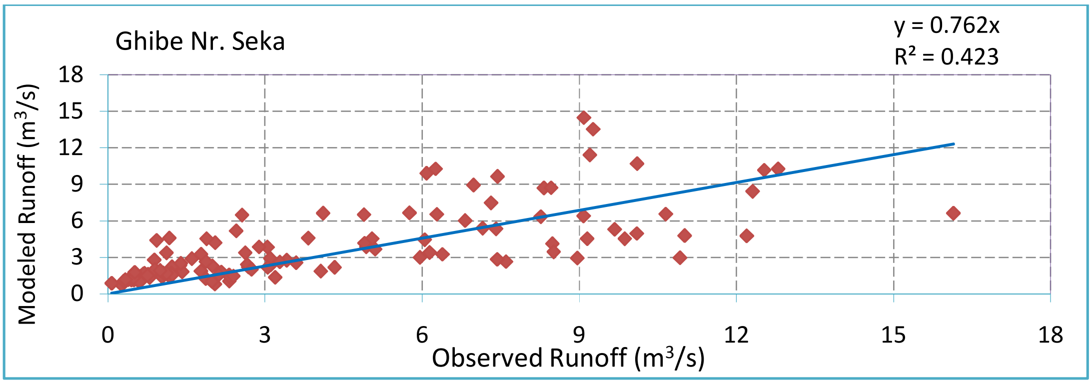

Awaitu at Jimma
y = 0.872x
R² = 0.432
Modeled Runoff (m³/s)
Observed Runoff (m³/s)

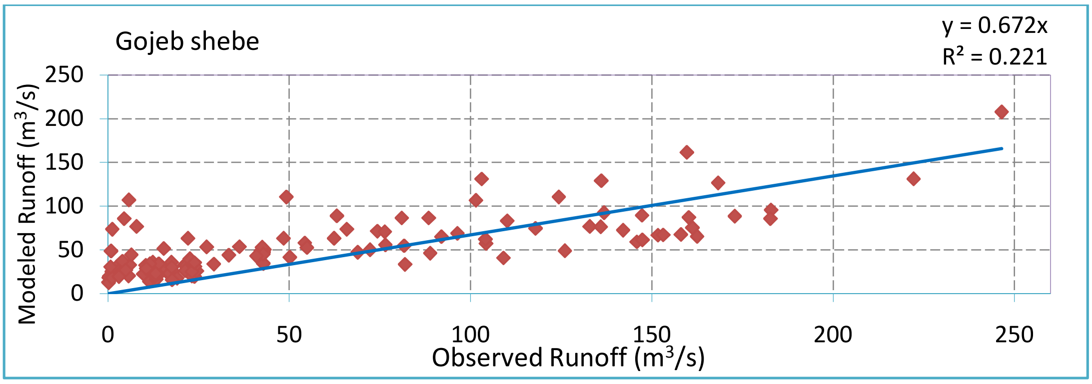

Bidru Awana Nr. Sokuru
y = 0.614x
R² = -0.01
Modeled Runoff (m³/s)
Observed Runoff (m³/s)

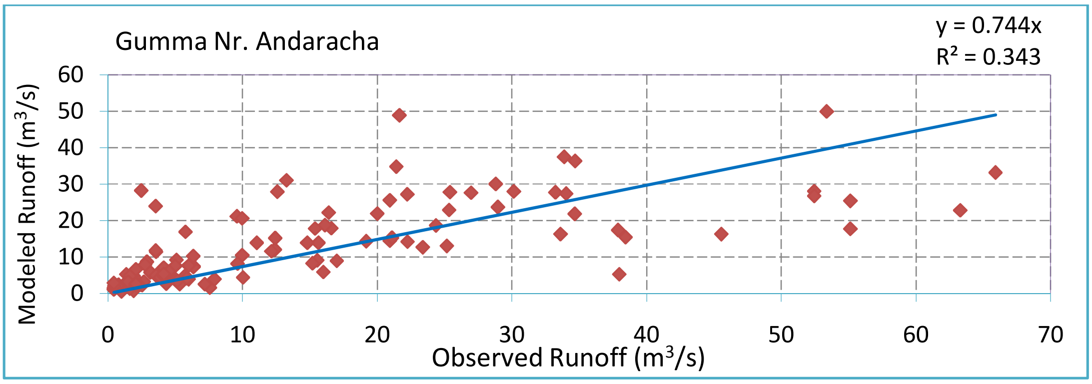

Bulbule Nr. Serbo
y = 0.69x
R² = 0.370
Modeled Runoff (m³/s)
Observed Runoff (m³/s)

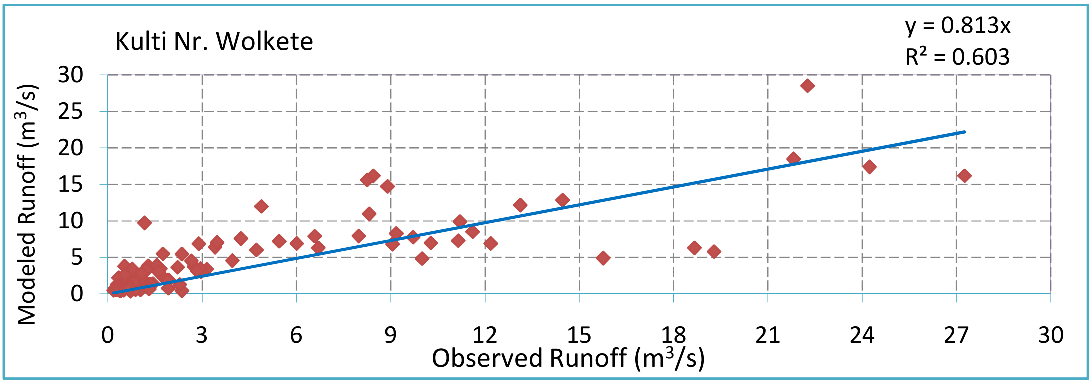

Dincha at Bonga
y = 0.804x
R² = 0.336
Modeled Runoff (m³/s)
Observed Runoff (m³/s)

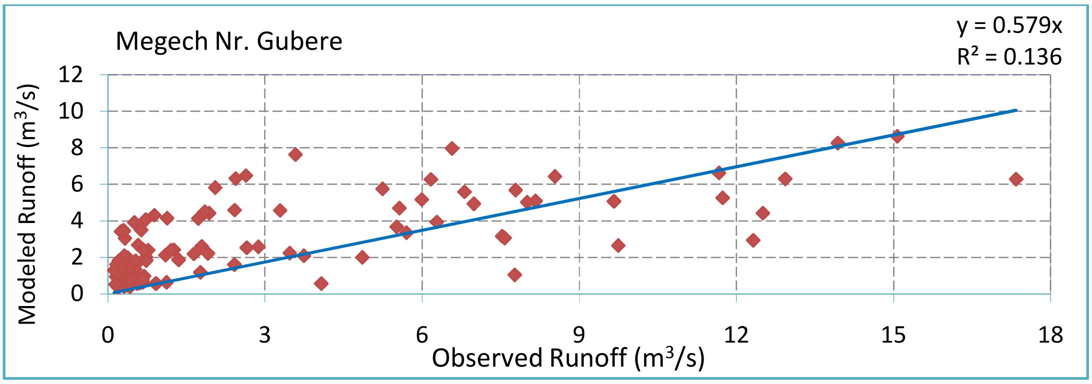

Ghibe Nr.Baco
y = 0.848x
R² = 0.503
Modeled Runoff (m3/s)
Observed Runoff (m3/s)

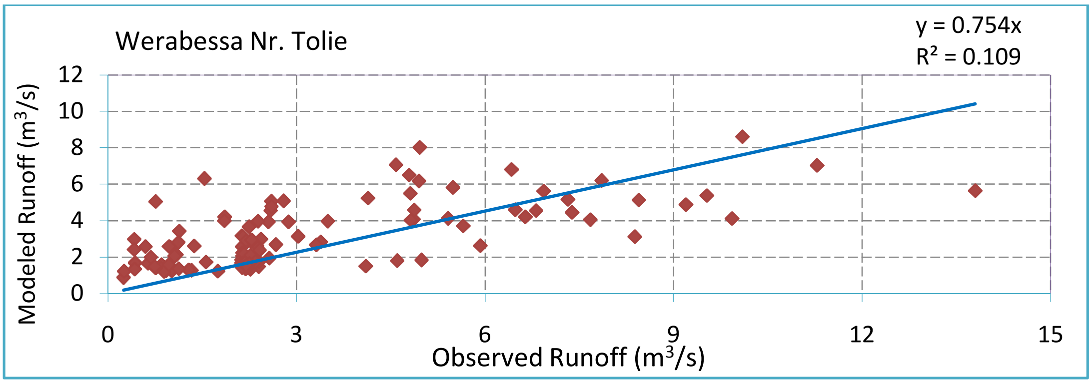

Ghibe Nr. Seka
y = 0.762x
R² = 0.423
Modeled Runoff (m3/s)
Observed Runoff (m3/s)


Gojeb shebe
y = 0.672x
R² = 0.221
Modeled Runoff (m3/s)
Observed Runoff (m3/s)

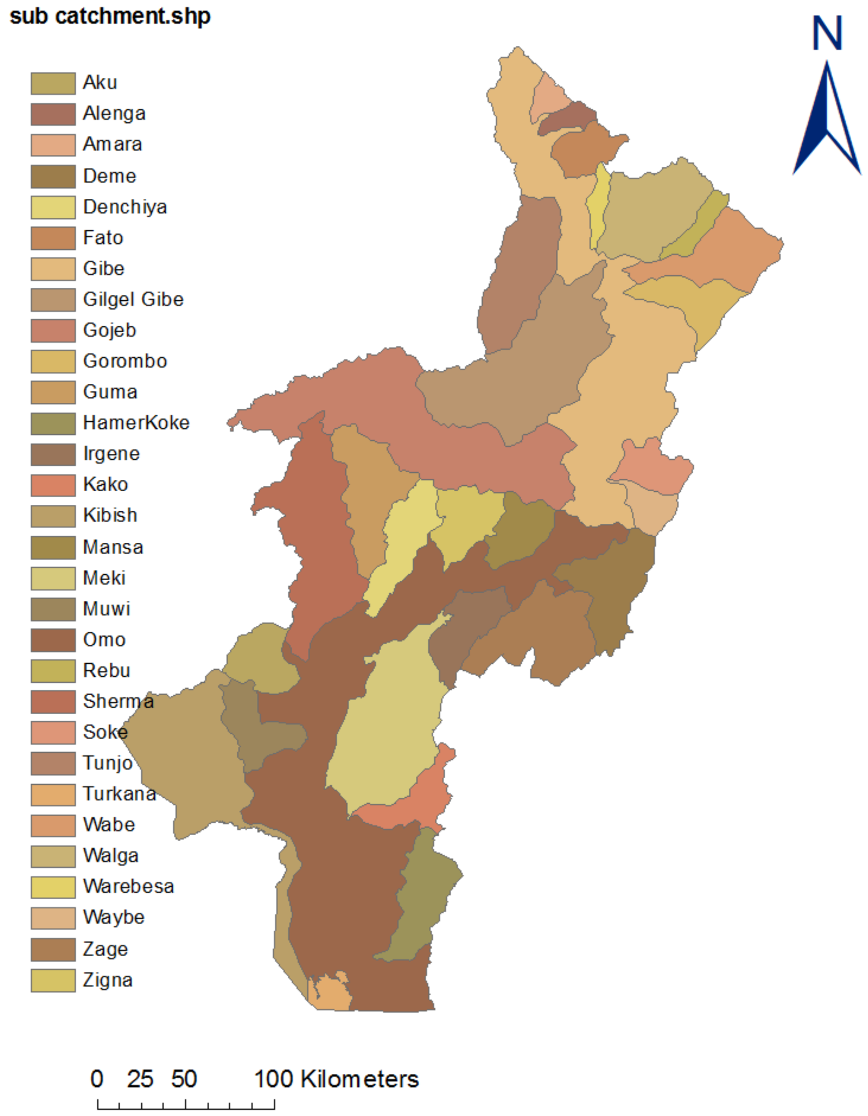

Gumma Nr. Andaracha
y = 0.744x
R² = 0.343
Modeled Runoff (m3/s)
Observed Runoff (m3/s)


Kulti Nr. Wolkete
y = 0.813x
R² = 0.603
Modeled Runoff (m3/s)
Observed Runoff (m3/s)
0
5
10
15
20
25
30
0
3
6
9
12
15
18
21
24
27
30

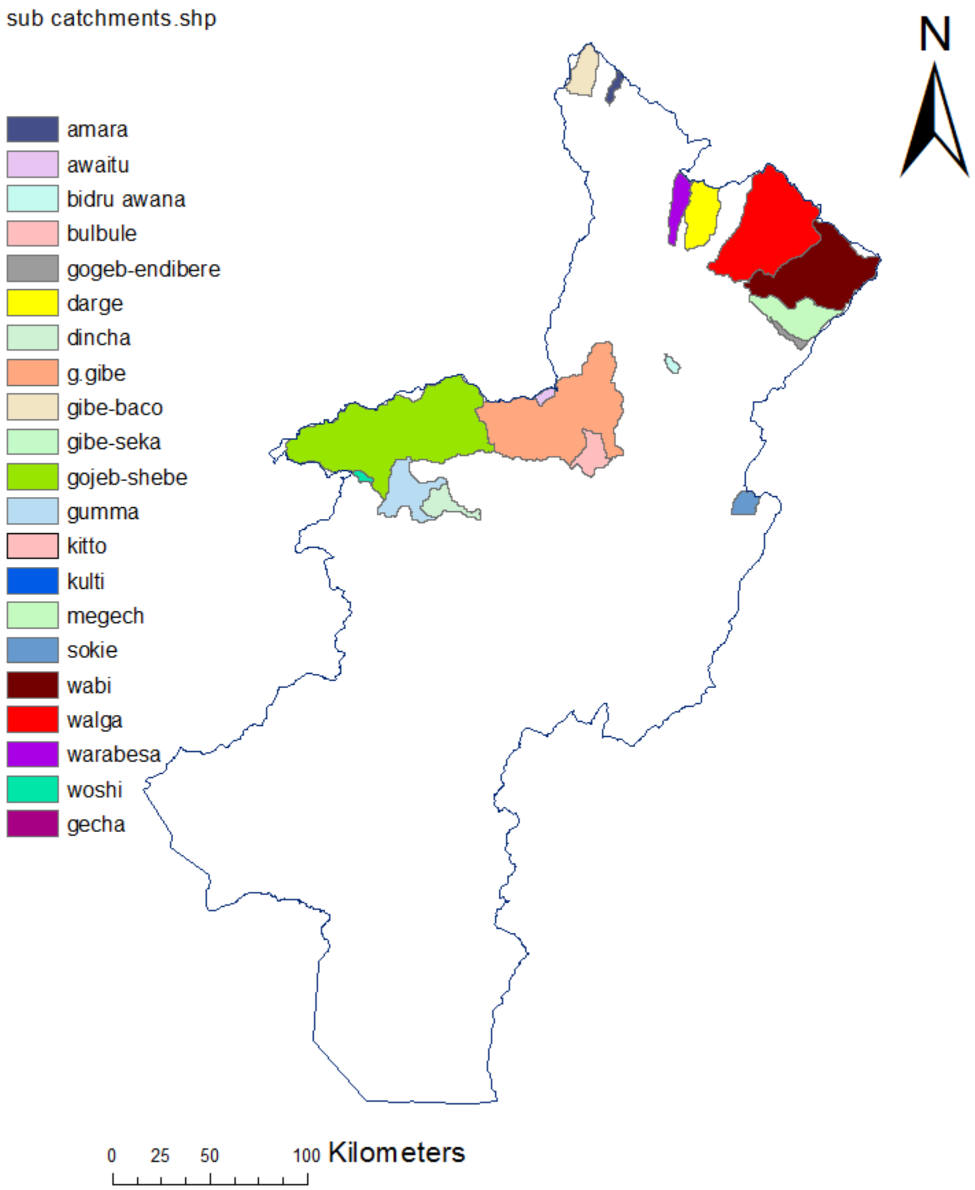

Megech Nr. Gubere
y = 0.579x
R² = 0.136
Modeled Runoff (m3/s)
Observed Runoff (m3/s)
0
2
4
6
8
10
12
0
3
6
9
12
15
18


Werabessa Nr. Tolie
y = 0.754x
R² = 0.109
Modeled Runoff (m3/s)
Observed Runoff (m3/s)
0
2
4
6
8
10
12
0
3
6
9
12
15

Appendix C: Main Sub basins of Omo-Gibe and selected sub-catchments in the modeling work



Main drainage sub basins of Omo-gibe



Sub catchments selected for Rainfall-Runoff modeling

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

Station Name: Amara Nr.Shebako

Station Number: 091021

Runoff (mm/day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.124	0.070	0.049	0.076	0.493	1.627	5.714	7.357	6.489	1.863	0.820	0.220
1986	0.198	0.162	0.203	0.213	0.181	1.548	3.559	3.976	5.029	2.583	0.979	0.683
1987	0.439	0.264	0.290	0.217	0.437	0.772	1.661	4.004	2.708	2.110	0.951	0.605
1988	0.465	0.325	0.136	0.100	0.158	0.635	1.481	3.515	3.082	2.291	0.642	0.635
1989	0.862	0.592	0.468	0.474	0.439	0.764	2.530	4.910	4.429	2.125	1.025	0.815
1990	0.518	0.408	0.513	0.368	0.382	1.219	5.190	11.740	4.493	2.130	1.001	0.686
1991	0.511	0.433	0.430	0.260	0.417	0.770	2.896	5.598	4.750	1.450	0.846	0.640
1992	0.535	0.488	0.360	0.457	0.496	0.727	2.385	11.951	5.976	5.173	1.874	1.113
1993	0.798	0.325	0.556	1.006	1.544	2.756	5.849	14.150	9.922	2.664	1.624	0.634
1994	0.903	0.657	0.671	0.580	0.832	0.745	5.963	9.813	9.121	2.184	1.211	0.865
1995	0.903	0.555	0.497	0.628	0.740	0.797	1.574	7.486	4.079	1.726	1.139	0.887
1996	0.866	0.704	0.744	0.604	1.203	2.212	4.937	7.253	3.716	2.194	1.260	0.900
1997	0.139	0.081	0.065	0.061	0.776	0.586	5.894	7.810	8.773	5.215	1.171	0.629
1998	0.247	0.156	0.127	0.061	0.315	0.937	8.109	7.011	9.951	4.892	1.368	0.461
1999	0.609	0.364	0.252	0.190	0.320	0.583	1.565	7.134	6.816	6.909	1.775	0.910
2000	0.583	0.350	0.246	0.401	0.403	0.879	1.557	9.002	9.457	5.166	2.157	0.915
2001	0.574	0.498	0.620	0.474	0.331	1.079	4.685	8.146	8.298	2.033	1.168	0.931
2002	0.543	0.290	0.271	0.339	0.182	0.668	2.131	4.668	8.143	3.746	1.871	0.526
2003	0.201	0.133	0.226	0.111	0.021	0.514	1.179	3.060	7.851	2.245	0.722	0.335
2004	0.465	0.313	0.137	0.099	0.157	0.635	4.525	6.770	7.361	7.019	1.968	0.948
2005	0.201	0.273	0.103	0.088	0.165	0.242	2.061	3.143	2.601	3.705	0.885	0.424
2006	0.141	0.388	0.391	0.102	0.064	0.132	1.149	4.713	7.204	5.342	2.127	0.888
Avg.	0.492	0.356	0.334	0.314	0.457	0.947	3.482	6.964	6.375	3.398	1.299	0.711

Precipitation (mm /day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.329	0.000	0.599	2.576	7.105	5.878	7.046	7.385	7.697	1.622	0.066	0.099
1986	0.000	0.266	2.125	2.536	1.132	10.819	7.977	5.365	4.954	1.901	0.253	0.250

1987	0.339	0.457	1.885	2.947	5.289	8.428	6.487	8.980	8.760	3.188	0.181	0.510
1988	0.595	1.391	0.697	1.250	3.184	6.405	6.569	5.286	4.753	3.980	0.214	0.072
1989	0.188	0.250	4.332	1.434	2.500	5.842	7.612	14.612	0.664	4.030	0.000	3.151
1990	0.112	1.007	3.135	2.786	4.095	8.184	0.000	8.204	3.365	0.668	0.799	0.000
1991	0.803	1.319	2.299	0.000	2.132	8.952	8.879	7.761	3.828	0.469	0.048	0.148
1992	1.082	2.350	1.497	3.132	2.612	6.010	8.155	11.105	4.289	2.322	0.842	0.000
1993	0.082	1.099	1.589	7.405	6.214	5.970	5.648	13.809	5.780	3.993	0.066	0.000
1994	0.457	0.000	1.878	2.207	4.803	2.632	11.204	9.799	3.707	0.164	0.039	0.000
1995	0.000	0.000	2.503	4.724	2.664	5.013	7.868	10.016	2.753	0.444	0.516	0.546
1996	1.477	0.000	3.201	3.280	5.829	5.668	9.109	5.855	6.888	0.000	0.789	0.497
1997	0.908	0.000	0.447	3.586	3.112	7.316	8.375	6.237	5.227	3.789	2.602	0.227
1998	0.211	0.000	0.618	0.980	5.461	9.280	11.276	8.224	6.559	6.641	0.000	0.000
1999	0.000	0.000	0.000	2.352	5.151	7.086	6.964	3.813	6.898	6.924	0.072	0.000
2000	0.000	0.000	0.000	5.247	3.556	7.112	7.207	10.477	3.359	3.951	0.743	0.115
2001	0.000	0.993	1.431	1.513	4.470	9.980	10.664	9.053	5.951	5.391	0.928	0.000
2002	0.865	0.095	2.526	2.553	0.941	7.359	5.865	5.836	2.421	0.181	0.000	0.954
2003	0.000	0.819	1.641	1.829	0.063	6.194	9.490	8.704	4.556	0.628	0.000	0.480
2004	0.237	0.309	0.602	1.352	1.026	7.507	9.497	6.026	5.385	1.543	0.164	0.474
2005	0.000	0.000	2.579	1.168	2.273	8.684	6.092	6.859	5.230	1.211	2.217	0.000
2006	0.000	0.148	1.691	2.316	4.115	8.438	7.595	13.546	6.770	3.023	0.730	1.342
Avg.	0.349	0.478	1.694	2.599	3.533	7.216	7.708	8.498	4.991	2.548	0.512	0.403

Temperature (˚C)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Avg.	19.30	21.10	21.70	22.10	21.00	19.60	18.50	18.50	18.90	19.00	19.20	19.10
Relative Humidity (%)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.56	0.62	0.59	0.59	0.72	0.80	0.85	0.87	0.86	0.88	0.65	0.62
Sunshine Hours (Hrs)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	8.52	8.88	6.36	7.68	5.64	5.88	4.80	3.72	5.64	6.96	8.40	9.00

Station Name: Awaitu at Jimma

Station Number: 091024

Runoff (mm/day)												
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.012	0.013	0.007	0.045	0.062	0.658	1.768	1.758	0.964	1.254	0.266	0.077
1986	0.004	0.028	0.028	0.054	0.075	1.935	4.574	2.146	4.954	0.883	0.278	0.146
1987	0.030	0.025	0.128	0.070	0.180	1.222	2.540	2.854	5.347	1.075	0.782	0.419
1988	0.181	0.176	0.121	0.081	0.147	1.264	4.283	5.650	5.537	2.326	0.415	0.228
1989	0.122	0.018	0.134	0.133	0.681	0.852	1.819	1.008	0.986	0.839	0.342	0.708
1990	0.146	0.090	0.168	0.075	0.659	3.083	8.490	8.938	7.292	1.644	0.296	0.247
1991	0.263	0.255	0.235	0.228	0.233	0.245	1.622	2.110	1.922	0.549	0.242	0.213
1992	0.039	0.002	0.120	0.152	0.435	0.505	4.435	4.353	2.605	2.995	0.497	0.235
1993	0.129	0.037	0.119	0.072	0.807	1.414	3.003	2.747	2.622	2.380	0.503	0.209
1994	0.032	0.052	0.112	0.088	0.311	1.700	3.060	4.966	3.445	0.819	0.198	0.220
1995	0.073	0.061	0.058	0.309	0.416	1.464	1.592	1.485	1.475	0.889	0.595	0.107
1996	0.793	0.793	0.452	0.407	0.761	1.912	1.577	1.868	2.122	0.850	0.373	0.491
1997	0.726	0.492	0.473	0.769	1.226	2.593	3.337	2.428	2.281	3.210	3.052	0.332
1998	1.080	0.781	0.878	0.719	1.226	1.271	3.023	3.950	3.075	3.791	1.452	1.703
1999	0.728	0.568	0.626	0.545	0.880	1.117	1.880	2.436	1.871	3.080	1.116	0.900
2000	0.678	0.554	0.526	0.658	1.036	1.365	1.681	2.558	2.840	1.825	1.372	0.917
2001	0.487	0.341	0.341	0.394	0.506	1.129	2.944	2.014	1.694	1.501	0.588	0.819
2002	0.268	0.176	0.193	0.187	0.148	0.490	1.926	5.792	1.949	0.450	0.239	0.220
2003	0.216	0.158	0.205	0.338	0.158	0.533	1.445	1.402	1.249	0.661	0.178	0.184
2004	0.175	0.158	0.140	0.617	0.562	0.373	1.091	1.778	1.170	0.446	0.277	0.225
2005	0.252	0.157	0.157	0.356	2.245	0.891	2.468	3.717	6.667	2.138	0.346	0.191
2006	0.209	0.148	0.376	1.138	0.549	1.178	3.244	4.284	2.969	1.604	1.000	0.826

Precipitation (mm /day)												
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.826	0.641	2.546	4.842	6.688	4.951	8.803	5.533	4.197	2.076	1.641	0.391
1986	0.000	1.586	2.688	3.776	4.957	8.424	7.648	4.401	5.365	2.914	0.457	1.559
1987	0.868	2.911	5.188	1.967	6.174	0.000	6.102	5.921	4.467	3.829	1.500	1.707
1988	2.674	1.941	1.016	2.865	5.980	5.431	6.072	9.671	9.602	5.655	0.049	0.000
1989	0.914	1.539	4.546	5.885	3.362	5.875	7.632	7.016	6.714	3.513	0.931	5.306
1990	0.809	1.513	4.372	1.842	6.368	10.530	9.197	9.217	8.046	0.753	3.043	0.615

1991	2.612	2.661	2.036	5.559	5.615	4.500	6.569	8.036	4.589	1.668	0.257	2.569
1992	0.934	1.855	1.839	5.319	4.720	9.441	6.980	11.711	5.763	5.921	2.293	1.171
1993	2.589	2.658	3.938	7.786	7.799	7.391	6.207	8.638	5.625	5.727	0.099	0.010
1994	0.030	0.928	3.174	5.046	6.990	9.026	8.401	5.237	5.826	0.365	0.595	0.345
1995	0.270	0.566	2.434	6.342	3.789	5.368	5.954	7.118	4.641	1.595	0.987	4.148
1996	1.342	0.770	4.457	6.681	5.750	6.464	7.615	2.993	8.161	0.786	3.063	1.329
1997	2.171	0.000	2.260	5.855	9.033	7.793	4.026	8.421	4.872	11.076	8.000	1.188
1998	3.372	0.737	3.174	3.066	6.039	7.322	8.171	10.089	6.576	6.602	1.530	0.046
1999	0.980	0.023	2.711	2.362	7.030	5.757	4.477	3.365	4.306	6.507	0.043	0.066
2000	0.000	0.033	1.293	6.405	7.819	5.056	8.747	5.220	8.395	8.026	1.539	0.819
2001	0.533	0.424	2.826	3.842	11.224	9.849	10.273	5.289	6.033	5.359	2.493	0.125
2002	2.266	0.164	3.000	2.951	4.516	7.947	4.924	7.727	5.438	2.618	0.266	4.553
2003	0.944	2.016	2.859	3.661	0.401	8.954	6.141	4.964	7.859	3.016	0.984	0.480
2004	1.678	0.934	1.516	4.306	5.326	4.224	7.115	7.217	6.612	4.382	2.214	0.000
2005	1.464	0.016	6.375	4.651	5.717	5.829	8.997	7.493	4.720	1.237	0.197	0.000
2006	0.105	0.000	5.980	3.628	6.957	5.354	7.434	7.901	3.720	3.360	0.986	0.352

Temperature (˚C)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	18.30	18.95	20.60	20.40	19.90	19.05	18.10	18.20	19.05	18.30	17.95	17.20
1986	17.75	20.50	19.20	19.95	20.40	19.15	18.75	18.85	18.85	18.40	17.85	17.80
1987	18.05	19.00	20.35	20.35	20.10	19.85	19.50	19.30	19.45	19.60	18.40	17.60
1988	18.60	20.35	20.10	20.40	21.00	19.75	18.75	19.20	19.45	19.15	16.75	16.40
1989	17.65	18.50	19.70	19.85	19.70	19.15	18.75	19.25	19.25	18.65	17.75	18.80
1990	17.45	19.40	20.05	20.40	20.00	19.65	18.80	19.15	19.40	18.50	18.35	17.05
1991	19.10	19.60	20.10	20.40	20.69	19.85	18.75	18.60	19.25	18.15	17.35	16.95
1992	18.20	20.05	20.45	20.45	20.40	19.80	18.50	19.00	19.40	19.40	17.70	18.50
1993	18.70	19.50	19.75	20.80	20.40	19.90	18.85	19.15	19.40	19.45	18.10	17.05
1994	17.85	20.15	21.60	20.70	20.20	19.60	18.60	19.25	19.35	18.70	19.00	17.50
1995	18.50	20.35	21.15	21.55	21.00	20.30	19.25	19.70	19.80	19.50	18.90	19.35
1996	19.05	20.00	21.10	21.05	20.55	19.95	19.10	19.45	19.90	19.05	17.90	17.65
1997	19.35	18.45	21.55	20.70	20.30	20.35	19.60	19.95	20.60	20.40	20.35	19.55
1998	20.40	20.85	21.90	22.55	21.75	20.55	19.70	19.95	20.50	20.60	17.85	16.65
1999	18.15	18.80	21.05	21.35	20.70	20.05	19.05	19.05	20.30	19.95	17.55	17.75
2000	17.85	19.00	21.30	21.60	21.20	19.85	19.30	19.45	20.40	20.35	19.10	18.10

2001	19.05	20.15	20.90	21.45	21.20	20.15	19.40	19.80	20.40	20.60	19.20	18.85
2002	19.15	19.55	21.55	21.00	21.40	20.00	20.00	19.80	20.25	19.80	18.75	19.75
2003	18.20	20.30	21.15	20.90	21.45	20.35	19.40	19.85	20.15	19.45	19.25	18.00
2004	19.95	20.05	21.00	21.55	21.25	20.05	19.35	19.75	20.00	19.20	18.85	17.20
2005	18.40	19.55	21.35	21.25	20.70	19.75	19.65	20.10	19.76	19.36	18.35	17.92
2006	18.56	19.67	21.55	21.30	20.90	19.86	19.10	19.50	19.76	19.36	18.35	17.92

Relative Humidity (%)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.64	0.70	0.72	0.74	0.79	0.83	0.79	0.87	0.90	0.84	0.78	0.71
Sunshine Hours (Hrs)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	7.42	7.10	6.70	6.18	6.36	5.33	3.74	4.07	5.38	6.97	7.69	7.77

Station Name: Bidru Awana Nr. Sokuru

Station Number: 091019

Runoff (mm/day)												
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.039	0.524	0.521	0.574	0.833	1.024	1.559	3.565	2.400	0.478	0.101	0.569
1986	0.175	0.190	0.223	0.297	0.331	3.055	3.338	2.834	2.870	1.186	0.334	0.208
1987	0.026	0.037	0.099	0.083	0.318	1.007	1.567	3.151	1.939	1.218	0.474	0.286
1988	0.197	0.168	0.131	0.096	0.088	0.153	1.267	3.476	3.944	2.323	0.752	0.575
1989	0.609	0.477	0.439	0.898	0.788	2.367	3.281	4.174	3.223	1.064	0.462	0.666
1990	0.439	0.388	0.400	0.436	0.541	0.876	2.262	3.867	1.195	0.758	0.258	0.080
1991	0.030	0.029	0.513	0.137	0.538	1.074	1.852	4.467	1.871	2.704	1.997	1.567
1992	0.837	0.728	0.309	0.504	0.713	1.931	4.645	3.443	2.534	2.209	0.695	0.610
1993	0.599	0.638	0.514	0.940	1.218	2.207	3.216	4.093	3.592	1.405	0.940	0.531
1994	0.739	0.652	0.771	0.754	1.169	1.754	2.534	5.190	1.829	0.642	0.512	0.414
1995	0.840	0.835	1.120	1.140	1.219	1.077	1.564	2.469	2.744	0.564	0.305	0.209
1996	0.604	0.527	0.615	0.688	1.399	2.574	2.572	4.274	4.443	1.462	0.937	0.209
1997	0.668	0.555	0.567	0.984	0.873	2.177	1.707	1.975	2.842	3.149	1.836	0.776
1998	1.105	1.048	0.963	0.918	1.649	1.516	7.321	6.180	2.590	3.469	1.324	1.320
1999	0.513	0.355	0.321	0.258	0.392	0.906	2.894	1.992	0.804	1.051	0.462	0.914
2000	0.150	0.103	0.079	0.096	0.162	0.156	0.228	0.480	1.523	2.027	0.899	0.646
2001	0.579	0.149	0.138	0.142	0.391	0.979	0.607	0.466	2.019	0.553	0.227	0.569

2002	0.102	0.072	0.074	0.070	0.063	0.107	0.207	1.175	0.907	0.135	0.083	0.061
2003	0.061	0.041	0.037	0.096	0.030	0.352	4.250	1.112	3.093	0.078	0.048	0.074
2004	0.078	0.061	0.054	0.109	0.063	0.080	0.724	6.154	2.538	2.308	0.535	0.400
2005	0.459	0.263	0.072	0.857	1.177	0.307	0.485	2.495	1.020	0.259	0.224	0.607
2006	0.604	0.545	0.560	0.582	0.603	0.844	2.050	4.205	2.296	0.888	0.609	0.568

Precipitation (mm /day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.957	0.069	0.934	4.461	6.059	4.753	8.240	11.632	1.447	1.207	0.260	0.204
1986	0.171	2.352	2.809	2.589	5.822	13.115	7.224	6.316	9.253	1.451	0.000	1.563
1987	1.434	1.280	5.248	3.734	5.261	7.533	5.586	10.234	6.362	2.286	0.007	1.178
1988	0.661	3.030	0.793	3.299	3.049	6.056	9.086	8.957	8.280	4.286	0.451	0.013
1989	2.724	1.793	4.507	4.757	2.066	6.263	7.934	8.454	4.122	2.141	1.375	5.770
1990	0.046	3.487	2.240	3.388	3.457	8.984	8.398	7.645	5.510	0.401	0.171	0.099
1991	0.691	2.319	4.405	2.089	4.718	7.490	9.533	7.658	3.076	0.592	0.076	0.905
1992	1.734	2.938	1.628	3.099	5.171	8.707	8.487	10.293	4.697	2.974	0.569	0.454
1993	0.454	3.822	1.868	6.054	5.773	6.407	10.541	9.974	6.036	6.112	0.046	0.000
1994	0.000	0.000	2.297	2.708	5.297	5.433	8.007	7.029	2.601	0.000	0.000	0.000
1995	0.191	0.424	2.046	5.431	6.003	4.023	5.109	5.497	6.033	1.313	0.000	2.178
1996	2.036	0.161	6.388	5.668	7.013	8.046	10.342	6.875	4.961	0.637	0.395	0.079
1997	1.655	0.043	2.039	5.826	5.224	4.033	5.984	6.947	4.329	9.046	2.091	0.470
1998	1.593	2.043	2.823	3.671	3.820	8.452	11.078	6.839	6.484	3.668	0.921	0.000
1999	0.299	0.000	1.257	2.168	5.898	9.092	8.704	5.158	5.990	4.454	0.000	0.000
2000	0.000	0.000	0.612	4.921	4.069	4.355	4.941	6.171	5.457	5.342	1.132	0.411
2001	0.816	0.059	3.852	2.493	6.438	7.303	7.138	6.408	7.171	3.378	0.030	0.010
2002	2.957	0.220	1.418	1.783	1.941	5.056	8.836	6.770	5.010	0.293	0.000	1.589
2003	1.247	1.678	2.082	4.089	0.921	7.635	7.859	4.852	4.977	0.411	2.036	1.605
2004	1.612	0.862	1.227	4.921	2.076	4.286	5.980	9.178	5.013	2.701	0.566	0.757
2005	1.313	0.046	3.901	3.178	7.553	5.776	7.799	3.822	4.082	3.362	1.115	0.000
2006	0.142	0.000	2.482	2.681	0.000	0.000	0.000	0.000	5.595	1.006	0.000	0.000

Temperature (˚C)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	18.3	18.95	20.6	20.4	19.9	19.05	18.1	18.2	19.05	18.3	17.95	17.2
1986	17.75	20.5	19.2	19.95	20.4	19.15	18.75	18.85	18.85	18.4	17.85	17.8

1987	18.05	19	20.35	20.35	20.1	19.85	19.5	19.3	19.45	19.6	18.4	17.6
1988	18.6	20.35	20.1	20.4	21	19.75	18.75	19.2	19.45	19.15	16.75	16.4
1989	17.65	18.5	19.7	19.85	19.7	19.15	18.75	19.25	19.25	18.65	17.75	18.8
1990	17.45	19.4	20.05	20.4	20	19.65	18.8	19.15	19.4	18.5	18.35	17.05
1991	19.1	19.6	20.1	20.4	20.4	19.85	18.75	18.6	19.25	18.15	17.35	16.95
1992	18.2	20.05	20.45	20.45	20.4	19.8	18.5	19	19.4	19.4	17.7	18.5
1993	18.7	19.5	19.75	20.8	20.4	19.9	18.85	19.15	19.4	19.45	18.1	17.05
1994	17.85	20.15	21.6	20.7	20.2	19.6	18.6	19.25	19.35	18.7	19	17.5
1995	18.5	20.35	21.15	21.55	21	20.3	19.25	19.7	19.8	19.5	18.9	19.35
1996	19.05	20	21.1	21.05	20.55	19.95	19.1	19.45	19.9	19.05	17.9	17.65
1997	19.35	18.45	21.55	20.7	20.3	20.35	19.6	19.95	20.6	20.4	20.35	19.55
1998	20.4	20.85	21.9	22.55	21.75	20.55	19.7	19.95	20.5	20.6	17.85	16.65
1999	18.15	18.8	21.05	21.35	20.7	20.05	19.05	19.05	20.3	19.95	17.55	17.75
2000	17.85	19	21.3	21.6	21.2	19.85	19.3	19.45	20.4	20.35	19.1	18.1
2001	19.05	20.15	20.9	21.45	21.2	20.15	19.4	19.8	20.4	20.6	19.2	18.85
2002	19.15	19.55	21.55	21	21.4	20	20	19.8	20.25	19.8	18.75	19.75
2003	18.2	20.3	21.15	20.9	21.45	20.35	19.4	19.85	20.15	19.45	19.25	18
2004	19.95	20.05	21	21.55	21.25	20.05	19.35	19.75	20	19.2	18.85	17.921
2005	18.4	19.55	21.35	21.25	20.7	19.75	19.65	20.1	19.758	19.36	18.345	17.921
2006	18.557	19.669	21.55	21.3	20.9	19.862	19.102	19.5	19.758	19.36	18.345	17.921

Relative Humidity (%)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.64	0.70	0.72	0.74	0.79	0.83	0.79	0.87	0.90	0.84	0.78	0.71
Sunshine Hours (Hrs)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	7.42	7.10	6.70	6.18	6.36	5.33	3.74	4.07	5.38	6.97	7.69	7.77

Station Name: Bulbule Nr.Serbo

Station Number: 091032

Runoff (mm/day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.093	0.030	0.247	0.309	0.828	5.196	4.900	7.636	6.352	2.540	0.816	0.338
1986	0.959	1.019	0.929	1.017	1.009	2.834	7.662	6.610	7.563	2.258	0.770	0.467

1987	0.324	0.205	0.396	3.753	0.340	1.347	3.383	5.712	6.459	2.000	0.923	0.421
1988	0.216	0.204	0.033	0.002	0.127	0.439	3.587	11.090	10.875	7.805	1.157	0.433
1989	0.167	0.133	0.069	0.508	0.349	1.434	4.471	6.363	6.646	1.745	0.558	0.926
1990	0.378	0.129	0.334	0.227	1.074	3.383	6.309	9.175	8.067	2.535	1.120	0.680
1991	0.355	0.285	0.440	0.238	0.661	2.387	4.705	7.961	6.260	1.089	0.540	0.267
1992	0.221	0.209	0.126	0.361	0.943	7.911	9.407	11.269	8.249	4.774	3.643	0.267
1993	0.500	0.488	0.317	0.426	1.563	4.665	7.945	8.501	7.250	4.878	4.783	1.183
1994	0.395	0.137	0.218	0.265	0.710	3.290	6.913	10.003	9.033	2.474	0.461	0.324
1995	0.157	0.190	0.175	0.700	1.175	0.724	1.193	4.543	5.496	1.245	1.302	0.351
1996	2.511	2.511	1.236	1.080	2.382	6.217	6.127	8.701	4.363	1.665	0.595	1.230
1997	0.296	0.186	0.092	0.233	0.641	3.886	4.502	6.863	3.282	5.770	7.527	0.350
1998	0.686	0.434	0.395	0.256	0.417	0.460	1.890	4.324	2.987	2.177	0.458	0.701
1999	0.817	0.193	0.189	0.129	0.521	2.191	6.005	8.422	4.068	6.417	2.206	0.555
2000	0.270	0.185	0.132	0.173	1.037	3.139	4.561	7.234	6.961	4.215	2.413	0.559
2001	0.412	0.349	0.384	0.551	1.296	4.745	4.362	5.675	8.331	4.745	1.988	0.628
2002	0.559	0.402	0.428	0.159	0.077	0.847	4.039	5.371	4.287	0.499	0.243	0.818
2003	0.156	0.069	0.124	0.134	0.047	0.400	5.697	5.996	6.671	2.110	0.552	0.274
2004	0.121	0.089	0.062	0.116	5.697	5.996	6.671	2.110	6.746	5.466	1.372	0.258
2005	0.566	0.257	0.646	0.539	2.818	2.391	1.802	3.462	3.362	1.368	1.319	0.617
2006	0.460	0.571	0.610	0.777	0.426	1.124	3.885	5.439	3.489	1.646	0.916	0.721

Precipitation (mm /day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.741	0.511	3.170	8.161	0.036	9.654	6.550	8.857	5.254	2.994	1.039	0.603
1986	0.128	2.274	3.845	2.941	3.443	8.093	5.850	8.090	6.747	3.509	0.292	2.370
1987	7.853	5.353	3.144	2.297	8.718	6.741	4.289	7.197	4.945	5.885	0.386	1.091
1988	2.975	3.526	1.508	4.203	3.499	5.959	9.648	13.194	12.580	5.882	0.039	0.072
1989	1.614	3.145	3.718	5.883	5.563	4.877	7.897	7.328	5.123	3.308	0.482	5.498
1990	0.406	3.892	5.221	4.503	6.183	9.809	7.634	5.968	9.086	1.133	4.086	0.904
1991	2.244	3.961	11.558	5.263	4.971	7.192	9.302	8.480	5.301	1.504	0.744	2.513
1992	2.532	6.147	2.916	8.186	10.870	10.777	11.611	11.581	9.821	7.910	0.465	1.660
1993	2.737	2.687	2.819	10.892	0.025	10.297	15.205	9.719	10.745	7.539	0.902	0.088
1994	0.882	0.469	4.076	5.119	8.345	8.372	9.736	7.017	4.466	0.737	0.336	0.624
1995	0.051	1.815	0.243	9.813	5.104	6.477	10.585	8.312	7.307	0.898	0.280	2.498
1996	2.342	2.506	8.874	6.518	2.503	6.882	9.864	5.951	5.024	2.271	5.434	2.943

1997	3.252	0.131	2.985	3.139	8.758	7.906	7.943	10.962	4.864	12.848	8.168	1.474
1998	2.391	1.509	2.402	3.453	2.007	3.057	7.302	4.496	3.300	4.114	1.761	0.015
1999	0.410	0.059	2.479	3.431	4.706	0.044	12.876	8.495	3.272	5.589	0.000	0.291
2000	1.079	0.193	1.133	7.502	6.297	5.613	6.223	8.439	3.245	5.975	1.782	0.903
2001	0.712	1.155	5.190	5.453	6.656	8.004	12.710	9.444	3.526	3.761	0.391	0.446
2002	1.273	1.070	4.131	4.413	4.299	8.468	8.673	7.516	4.049	3.645	0.547	4.651
2003	3.079	1.286	6.924	4.474	2.224	7.927	7.397	9.175	6.165	0.738	2.770	0.742
2004	1.682	0.533	1.903	4.443	2.925	6.901	4.920	9.146	6.636	3.727	2.186	1.009
2005	0.918	0.062	4.493	4.931	4.567	5.523	5.516	7.381	4.759	1.244	0.199	0.000
2006	0.106	0.000	4.524	3.448	4.032	5.401	7.498	8.451	3.738	3.387	0.994	0.357

Temperature (˚C)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	18.45	19.37	20.69	20.57	19.99	19.15	18.27	18.32	18.74	18.39	17.88	17.40
1986	18.06	20.47	19.69	20.26	20.34	19.22	18.74	18.78	18.60	18.46	17.81	17.83
1987	18.27	19.41	20.51	20.54	20.13	19.72	19.27	19.10	19.03	19.31	18.20	17.69
1988	18.66	20.36	20.33	20.57	20.77	19.65	18.74	19.03	19.03	18.99	17.03	16.84
1989	17.98	19.05	20.05	20.18	19.85	19.22	18.74	19.06	18.89	18.64	17.74	18.54
1990	17.84	19.69	20.30	20.57	20.06	19.58	18.77	18.99	18.99	18.53	18.16	17.30
1991	19.01	19.83	20.33	20.57	5.88	19.72	18.74	18.60	18.89	18.28	17.45	17.23
1992	18.37	20.15	20.58	20.61	20.34	19.68	18.56	18.88	18.99	19.17	17.70	18.33
1993	18.73	19.76	20.08	20.86	20.34	19.75	18.81	18.99	18.99	19.20	17.98	17.30
1994	18.13	20.22	21.40	20.79	20.20	19.54	18.63	19.06	18.96	18.67	18.62	17.62
1995	18.59	20.36	21.08	21.39	20.77	20.04	19.09	19.38	19.28	19.24	18.55	18.93
1996	18.98	20.12	21.04	21.04	20.45	19.79	18.98	19.20	19.35	18.92	17.84	17.72
1997	19.19	19.02	21.36	20.79	20.27	20.07	19.34	19.56	19.84	19.88	19.58	19.07
1998	19.93	20.72	21.61	22.10	21.30	20.22	19.41	19.56	19.77	20.02	17.81	17.01
1999	18.34	19.27	21.01	21.25	20.55	19.86	18.95	18.92	19.63	19.56	17.59	17.79
2000	18.13	19.41	21.18	21.43	20.91	19.72	19.13	19.20	19.70	19.84	18.69	18.04
2001	18.98	20.22	20.90	21.32	20.91	19.93	19.20	19.45	19.70	20.02	18.76	18.57
2002	19.05	19.80	21.36	21.00	21.05	19.83	19.62	19.45	19.60	19.45	18.44	19.21
2003	18.37	20.33	21.08	20.93	21.09	20.07	19.20	19.49	19.52	19.20	18.80	17.97
2004	19.62	20.15	20.97	21.39	20.94	19.86	19.16	19.42	19.42	19.03	18.52	5.21
2005	18.52	19.80	21.22	21.18	20.55	19.65	19.37	19.66	5.24	5.41	5.15	5.21
2006	5.47	5.94	21.36	21.21	20.70	5.65	5.44	19.24	5.24	5.41	5.15	5.21

Relative Humidity (%)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.65	0.72	0.75	0.77	0.82	0.84	0.80	0.88	0.90	0.85	0.80	0.72
Sunshine Hours (Hrs)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	7.53	6.99	6.67	6.23	6.32	5.21	3.56	3.97	5.28	7.00	7.68	7.88

Station Name: Dincha at Bonga

Station Number: 092005

Runoff (mm/day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.275	0.238	0.268	1.029	3.856	5.830	7.425	9.593	7.452	3.729	1.134	0.745
1986	0.436	0.375	0.646	1.438	1.870	6.170	6.985	6.163	5.395	2.385	1.013	0.878
1987	0.489	0.277	0.378	0.741	2.859	3.878	3.582	4.868	5.101	1.876	1.517	1.504
1988	0.592	0.308	0.246	0.312	0.755	2.346	4.910	11.043	8.959	8.922	1.290	0.869
1989	0.450	0.410	0.464	2.414	1.220	3.357	5.242	6.100	6.164	4.284	1.206	0.573
1990	0.347	0.379	1.315	2.108	3.787	6.816	5.274	8.357	7.884	3.938	1.231	1.351
1991	2.905	4.544	3.952	0.554	0.499	1.061	6.837	7.946	8.045	2.907	0.902	1.133
1992	1.720	1.924	0.726	0.673	3.236	5.105	4.648	6.690	7.396	11.065	2.322	0.722
1993	0.803	1.094	1.050	2.451	5.430	7.079	6.307	4.879	6.105	5.161	1.503	0.815
1994	0.985	0.443	0.823	0.676	3.557	7.723	8.013	7.874	5.867	1.503	1.360	0.852
1995	0.576	0.509	0.251	0.756	1.665	3.291	4.893	6.877	7.637	2.725	0.763	0.767
1996	1.091	0.591	1.363	2.735	5.715	7.986	6.144	7.138	8.090	4.424	1.013	0.704
1997	0.779	0.419	1.088	3.351	5.477	10.146	8.372	5.861	4.555	8.203	8.809	0.642
1998	2.803	1.647	1.895	2.252	8.369	8.412	8.435	15.764	7.344	12.019	1.691	3.713
1999	0.503	0.170	0.443	1.070	1.991	3.013	4.848	3.926	3.316	5.381	1.156	0.600
2000	0.287	0.256	0.352	0.560	1.389	1.400	5.213	2.339	2.686	6.133	1.034	0.521
2001	0.334	0.341	0.399	0.671	3.389	7.428	6.092	7.057	8.751	4.628	1.360	0.521
2002	1.181	0.807	0.984	1.580	1.409	1.860	4.500	4.475	3.434	1.814	1.336	1.335
2003	1.075	0.880	0.847	1.613	1.368	5.482	6.124	7.565	7.758	2.254	1.208	1.071
2004	0.972	0.792	0.743	1.361	3.476	4.271	2.909	7.950	7.584	4.756	1.587	1.483
2005	1.050	0.812	1.152	1.594	4.694	4.319	4.734	6.937	8.216	3.457	2.856	2.192
2006	1.538	1.238	1.516	1.763	3.619	5.677	7.916	8.114	4.616	3.213	2.496	2.273

Precipitation (mm /day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	1.549	1.462	3.451	5.562	9.972	6.862	7.529	7.469	5.970	3.627	4.683	1.376
1986	0.310	3.348	3.625	4.332	5.785	6.270	8.499	6.424	6.135	2.452	2.236	2.351
1987	1.366	3.303	4.846	5.183	7.978	4.741	5.792	6.759	5.048	1.434	0.748	3.318
1988	2.652	2.943	1.446	3.531	5.041	7.493	2.614	9.878	7.581	7.623	0.705	1.174
1989	1.301	1.201	4.446	6.220	3.374	4.241	6.747	7.283	4.972	4.492	1.181	4.150
1990	1.810	4.096	5.101	4.345	7.993	6.578	6.180	8.739	7.401	2.449	2.886	1.813
1991	2.502	1.605	4.130	7.233	6.609	7.262	7.037	9.062	6.545	2.061	1.447	1.830
1992	2.790	2.970	3.269	3.750	5.740	8.371	7.078	7.190	5.595	9.236	2.946	1.742
1993	3.969	2.945	3.132	8.661	9.034	8.139	6.304	4.848	6.936	6.232	0.462	0.075
1994	0.388	0.328	2.438	5.459	8.063	9.028	7.644	5.138	4.550	1.529	3.141	0.679
1995	0.021	1.322	1.773	5.416	5.346	5.255	5.585	6.808	7.358	1.787	0.965	4.722
1996	1.528	1.168	5.284	6.400	6.403	5.381	5.817	5.672	6.710	2.966	3.150	0.753
1997	2.813	0.337	4.011	7.399	7.172	7.214	6.025	5.372	4.868	8.251	7.756	4.195
1998	3.779	1.400	2.217	5.490	7.546	7.091	7.066	8.489	6.692	5.834	0.766	0.000
1999	1.736	0.167	3.213	5.364	6.192	4.916	5.708	4.385	4.429	6.052	0.663	0.761
2000	0.175	0.139	2.986	6.027	7.208	5.790	7.596	5.065	5.331	8.696	1.243	0.977
2001	0.059	2.065	3.704	5.412	8.849	6.657	6.688	7.098	6.779	4.168	2.064	0.287
2002	1.383	0.617	5.586	4.048	3.981	8.222	5.759	5.715	5.826	4.680	0.937	4.034
2003	1.523	0.944	1.864	6.663	1.575	11.329	14.134	12.933	10.152	1.013	1.559	1.601
2004	2.909	0.508	2.836	6.496	3.627	3.591	5.330	10.849	8.654	3.200	2.336	3.276
2005	1.102	1.114	4.916	5.083	9.700	6.780	5.785	6.563	6.338	4.563	2.530	0.000
2006	0.887	1.905	5.142	2.775	8.133	6.439	9.832	7.463	6.591	5.019	3.013	3.087

Temperature (˚C)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	19.97	20.60	20.83	20.65	20.23	19.28	18.50	19.03	18.77	19.33	19.46	19.66
Relative Humidity (%)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RH	0.70	0.72	0.75	0.80	0.84	0.90	0.91	0.91	0.88	0.84	0.85	0.79
Sunshine Hours (Hrs)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	7.56	6.72	6.36	6.60	6.00	4.92	3.24	3.48	4.92	6.84	7.56	8.04

Station Name: Gilgel Ghibie Nr. Assendabo

Station Number: 091008

Runoff (mm/day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.078	0.051	0.038	0.171	0.395	2.275	2.147	3.325	2.772	1.131	0.390	0.184
1986	0.065	0.079	0.125	0.110	0.134	1.051	2.280	2.086	2.642	1.013	0.315	0.215
1987	0.100	0.016	0.227	0.168	0.491	1.274	1.757	1.885	2.349	1.091	0.466	0.124
1988	0.119	0.132	0.051	0.044	0.105	0.329	1.724	4.782	3.742	2.914	0.630	0.226
1989	0.149	0.153	0.108	0.650	0.350	0.839	1.603	2.347	2.389	1.278	0.459	0.526
1990	0.250	0.198	0.295	0.273	0.501	1.494	2.797	2.333	3.691	0.178	2.846	0.291
1991	0.191	0.161	0.228	0.141	0.323	1.066	2.063	3.465	2.592	0.623	0.104	0.075
1992	0.020	0.044	0.096	0.099	0.329	1.298	2.619	5.744	3.633	2.292	0.611	0.237
1993	0.222	0.262	0.140	0.440	0.832	1.598	2.904	4.250	3.326	1.520	0.704	0.617
1994	0.179	0.097	0.132	0.152	0.657	2.156	3.888	5.152	3.819	0.838	0.347	0.178
1995	0.099	0.093	0.076	0.247	0.357	0.465	1.390	1.994	2.404	0.574	0.243	0.190
1996	1.119	1.119	0.570	0.503	1.064	2.714	2.675	3.783	2.755	1.410	0.527	0.503
1997	0.200	0.099	0.074	0.525	0.805	2.155	2.147	3.206	2.203	2.189	3.853	1.643
1998	0.874	0.495	0.500	0.360	0.633	0.927	2.605	2.266	3.050	2.599	1.050	0.458
1999	0.310	0.181	0.225	0.186	0.510	1.093	2.448	3.343	1.832	2.232	0.800	0.339
2000	0.196	0.118	0.073	0.224	0.612	0.916	1.935	2.546	2.701	2.321	1.123	0.339
2001	0.706	0.725	0.759	0.737	1.124	2.081	3.615	3.277	2.383	1.533	0.916	0.473
2002	0.301	0.181	0.222	0.299	0.219	0.913	1.777	2.350	1.883	0.674	0.376	0.388
2003	0.327	0.162	0.277	0.308	0.177	0.747	2.490	2.619	2.909	0.947	0.392	0.304
2004	0.199	0.152	0.127	0.206	0.413	1.003	2.005	3.047	1.941	1.391	0.629	0.406
2005	0.282	0.149	0.316	0.270	1.251	1.067	1.091	2.982	2.867	1.596	0.606	0.304
2006	0.237	0.284	0.301	0.373	0.443	1.105	1.724	2.199	1.349	1.600	0.908	0.722

Precipitation (mm /day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.682	0.929	2.722	5.978	4.744	5.867	7.535	6.518	4.111	2.127	1.453	0.435
1986	0.076	2.084	3.281	3.394	4.359	7.889	6.744	6.445	5.342	2.591	0.396	1.644
1987	2.850	3.535	4.164	1.974	7.502	4.667	5.067	6.403	4.126	3.943	0.718	1.159
1988	2.252	2.577	1.206	3.277	4.378	6.268	7.713	10.518	10.063	4.914	0.066	0.050
1989	1.110	2.365	3.935	5.258	4.391	5.074	7.754	7.547	5.467	3.608	0.865	4.562
1990	0.742	2.998	4.365	3.184	4.971	9.006	7.839	7.752	6.783	1.061	2.718	0.846

1991	1.865	2.682	4.852	4.121	5.239	5.114	7.258	7.636	4.663	1.614	0.467	2.190
1992	1.359	2.770	2.551	5.127	6.835	8.859	7.351	11.001	6.146	5.647	1.304	1.088
1993	2.025	2.781	3.134	8.048	4.880	8.199	8.469	7.319	6.406	5.979	0.430	0.064
1994	0.423	0.505	3.156	4.996	6.658	7.810	8.286	7.240	4.918	0.488	0.860	0.652
1995	0.212	1.175	1.595	6.557	4.145	5.323	7.096	6.510	5.049	1.030	0.643	3.801
1996	1.703	1.622	6.333	6.949	4.604	6.463	7.735	5.033	6.162	1.125	3.044	1.421
1997	2.189	0.044	2.109	4.940	7.554	7.735	6.381	8.516	4.551	10.599	7.121	1.292
1998	3.021	1.285	2.995	3.243	4.416	6.076	7.675	7.496	5.426	5.397	1.449	0.020
1999	0.731	0.036	2.338	2.917	6.135	4.715	8.432	5.702	3.423	5.160	0.112	0.167
2000	0.298	0.066	0.932	6.002	6.123	5.685	6.587	6.055	6.263	5.811	1.458	0.706
2001	0.702	0.785	3.682	4.787	8.528	8.876	9.605	7.306	4.344	4.391	1.168	0.313
2002	1.610	0.519	3.389	3.345	4.040	6.974	6.241	6.767	4.248	2.089	0.485	4.217
2003	1.609	1.925	5.073	3.740	1.153	6.014	6.510	6.112	5.175	1.641	1.419	1.011
2004	1.737	0.666	1.918	4.161	3.894	5.814	4.226	8.254	5.757	3.211	1.698	0.828
2005	1.061	0.053	4.991	5.182	5.851	4.801	6.898	6.373	5.256	1.366	0.599	0.007
2006	0.239	0.157	5.346	3.508	5.301	6.202	7.642	7.791	3.585	3.419	1.201	0.655

Temperature (˚C)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	17.95	18.86	19.96	20.54	19.92	19.14	18.19	18.28	18.62	18.46	18.08	17.77
1986	18.47	20.53	18.37	18.83	18.86	19.21	18.66	18.71	18.51	18.51	18.04	18.03
1987	18.53	19.65	20.51	20.62	20.14	19.66	19.20	19.01	18.90	19.28	18.32	18.01
1988	18.90	20.52	20.66	20.69	20.69	19.64	18.66	18.87	18.89	18.95	17.48	17.41
1989	18.40	19.30	20.19	20.21	19.91	19.20	18.61	18.95	18.74	18.80	18.14	16.38
1990	18.32	19.73	20.28	20.63	20.14	19.54	18.73	18.80	18.90	18.70	18.34	17.62
1991	19.15	19.98	20.49	20.62	8.97	19.78	16.61	16.49	18.80	18.40	17.78	17.66
1992	18.67	20.23	20.67	20.74	20.29	19.64	18.61	18.82	18.88	19.10	17.89	18.49
1993	18.92	19.89	20.20	18.51	18.03	17.48	16.66	16.80	16.75	16.97	15.92	15.41
1994	16.14	17.94	18.92	18.45	17.92	17.32	16.53	16.86	16.72	16.55	16.43	15.66
1995	16.51	18.06	18.67	18.93	18.37	17.71	16.89	17.11	16.97	16.99	16.37	16.69
1996	16.81	19.99	20.82	20.83	20.13	19.60	19.05	19.29	19.39	18.20	17.35	18.30
1997	19.52	19.77	21.61	20.90	20.38	20.07	19.35	19.53	19.77	19.78	19.46	19.15
1998	19.90	20.73	21.49	21.96	21.17	20.12	19.28	19.35	19.53	19.82	17.96	17.40
1999	18.66	19.72	21.04	21.16	20.41	19.70	18.83	18.84	19.38	19.06	17.60	17.91
2000	18.32	19.42	20.88	18.96	18.48	19.60	16.92	16.97	17.31	17.47	16.48	15.99

2001	16.81	17.94	18.53	18.87	18.48	19.66	19.02	17.16	17.31	17.61	16.54	16.41
2002	18.84	19.66	20.80	20.46	20.38	19.29	18.53	18.43	18.59	18.55	17.72	18.26
2003	16.34	18.03	18.67	18.57	18.62	17.74	16.97	17.19	17.17	16.97	16.57	15.93
2004	17.31	17.89	18.59	18.93	18.50	17.57	16.94	17.13	17.09	16.83	16.34	5.91
2005	16.45	17.61	18.78	18.76	18.20	17.40	17.11	17.33	17.72	17.67	16.89	16.20
2006	18.04	19.31	21.19	21.04	20.60	19.00	18.07	18.09	17.72	17.67	16.89	16.20

Relative Humidity (%)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.62	0.67	0.68	0.71	0.76	0.81	0.79	0.87	0.89	0.83	0.76	0.69
Sunshine Hours (Hrs)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	7.55	6.99	6.68	6.25	6.34	5.22	3.56	3.97	5.28	7.02	7.70	7.90

Station Name: Ghibie Nr. Baco

Station Number: 091020

Runoff (mm/day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.081	0.061	0.053	0.110	0.522	1.640	2.672	3.294	2.437	1.874	0.340	0.117
1986	0.109	0.095	0.111	0.115	0.102	0.612	0.867	0.969	1.226	0.632	0.238	0.152
1987	0.107	0.064	0.071	0.053	0.106	0.188	0.405	0.965	0.660	0.515	0.232	0.166
1988	0.113	0.076	0.033	0.024	0.038	0.155	1.102	2.623	2.280	1.710	0.479	0.147
1989	0.211	0.144	0.114	0.116	0.107	0.186	0.617	1.196	1.079	0.518	0.250	0.475
1990	0.126	0.099	0.125	0.090	0.093	0.297	1.264	2.943	1.095	0.519	0.244	0.199
1991	0.124	0.106	0.105	0.063	0.105	0.188	0.706	1.364	1.157	0.353	0.206	0.167
1992	0.130	0.115	0.088	0.110	0.121	0.177	0.633	2.910	1.456	1.266	0.457	0.156
1993	0.194	0.165	0.136	0.241	0.376	0.672	1.425	3.447	2.416	1.027	0.640	0.271
1994	0.221	0.160	0.164	0.141	0.203	0.181	1.453	2.391	2.222	0.533	0.295	0.146
1995	0.154	0.135	0.121	0.153	0.180	0.194	0.384	1.821	0.994	0.421	0.278	0.209
1996	0.211	0.166	0.181	0.147	0.296	0.539	1.198	1.767	0.903	0.550	0.308	0.216
1997	0.666	0.146	0.187	0.215	0.101	0.789	1.498	2.010	2.091	1.561	0.780	0.219
1998	0.191	0.103	0.108	0.370	0.068	1.123	2.158	2.976	2.240	2.088	0.168	0.184
1999	0.468	0.226	0.152	0.084	0.478	0.661	1.310	2.692	2.574	3.133	1.433	0.411
2000	1.951	0.064	0.933	0.982	1.432	2.700	3.264	4.486	3.428	1.659	1.345	1.336
2001	1.954	1.814	1.364	0.561	0.820	2.301	2.663	4.218	4.267	1.835	1.250	1.136

2002	1.873	0.778	0.885	0.385	0.173	1.585	2.388	3.092	1.534	0.715	0.925	0.861
2003	0.600	0.545	0.657	0.082	0.031	1.149	1.872	2.282	1.665	0.825	1.224	1.251
2004	0.835	0.892	0.194	0.362	0.664	1.455	1.987	2.671	3.391	2.742	1.093	0.821
2005	0.403	0.823	0.852	0.586	1.002	1.400	1.282	1.894	1.847	1.888	1.371	1.385
2006	1.373	0.791	1.108	0.886	1.160	0.575	0.898	2.008	1.604	1.071	0.649	1.112

Precipitation (mm /day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.329	0.000	0.599	2.576	7.105	5.878	7.046	7.385	7.697	1.622	0.066	0.099
1986	0.000	0.266	2.125	2.536	1.132	10.819	7.977	5.365	4.954	1.901	0.253	0.250
1987	0.339	0.457	1.885	2.947	5.289	8.428	6.487	8.980	8.760	3.188	0.181	0.510
1988	0.595	1.391	0.697	1.250	3.184	6.405	6.569	5.286	4.753	3.980	0.214	0.072
1989	0.188	0.250	4.332	1.434	2.500	5.842	7.612	14.612	0.664	4.030	0.000	3.151
1990	0.112	1.007	3.135	2.786	4.095	8.184	0.000	8.204	3.365	0.668	0.799	0.000
1991	0.803	1.319	2.299	0.000	2.132	8.952	8.879	7.761	3.828	0.469	0.048	0.148
1992	1.082	2.350	1.497	3.132	2.612	6.010	8.155	11.105	4.289	2.322	0.842	0.000
1993	0.082	1.099	1.589	7.405	6.214	5.970	5.648	13.809	5.780	3.993	0.066	0.000
1994	0.457	0.000	1.878	2.207	4.803	2.632	11.204	9.799	3.707	0.164	0.039	0.000
1995	0.000	0.000	2.503	4.724	2.664	5.013	7.868	10.016	2.753	0.444	0.516	0.546
1996	1.477	0.000	3.201	3.280	5.829	5.668	9.109	5.855	6.888	0.000	0.789	0.497
1997	0.908	0.000	0.447	3.586	3.112	7.316	8.375	6.237	5.227	3.789	2.602	0.227
1998	0.211	0.000	0.618	0.980	5.461	9.280	11.276	8.224	6.559	6.641	0.000	0.000
1999	0.000	0.000	0.000	2.352	5.151	7.086	6.964	3.813	6.898	6.924	0.072	0.000
2000	0.000	0.000	0.000	5.247	3.556	7.112	7.207	10.477	3.359	3.951	0.743	0.115
2001	0.000	0.993	1.431	1.513	4.470	9.980	10.664	9.053	5.951	5.391	0.928	0.000
2002	0.865	0.095	2.526	2.553	0.941	7.359	5.865	5.836	2.421	0.181	0.000	0.954
2003	0.000	0.819	1.641	1.829	0.063	6.194	9.490	8.704	4.556	0.628	0.000	0.480
2004	0.237	0.309	0.602	1.352	1.026	7.507	9.497	6.026	5.385	1.543	0.164	0.474
2005	0.000	0.000	2.579	1.168	2.273	8.684	6.092	6.859	5.230	1.211	2.217	0.000
2006	0.000	0.148	1.691	2.316	4.115	8.438	7.595	13.546	6.770	3.023	0.730	1.342

Temperature (˚C)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	19.30	21.10	21.70	22.10	21.00	19.60	18.50	18.50	18.90	19.00	19.20	19.10
Relative Humidity (%)												

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.56	0.62	0.59	0.59	0.72	0.80	0.85	0.87	0.86	0.88	0.65	0.62
Sunshine Hours (Hrs)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	8.52	8.88	6.36	7.68	5.64	5.88	4.80	3.72	5.64	6.96	8.40	9.00

Station Name: Ghibie Nr. Seka

Station Number: 091017

Runoff (mm/day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.162	0.120	0.103	0.253	0.491	1.709	2.547	2.787	2.289	0.823	0.439	0.306
1986	0.131	0.132	0.247	0.233	0.273	1.565	1.858	2.132	2.969	1.288	0.472	0.251
1987	0.176	0.167	0.391	0.274	0.680	1.805	2.596	2.503	2.901	1.495	0.661	0.234
1988	0.290	0.296	0.189	0.146	0.352	0.970	2.686	3.412	3.400	3.253	0.649	0.371
1989	0.207	0.205	0.186	0.340	0.294	0.869	2.585	2.631	2.420	1.254	0.542	0.283
1990	0.385	0.365	0.576	0.586	0.800	1.978	2.536	3.675	3.680	1.569	0.617	0.880
1991	0.291	0.233	0.201	0.313	0.540	1.359	2.322	2.971	2.722	0.844	0.392	0.347
1992	0.244	0.276	0.203	0.253	0.678	1.830	2.966	2.767	2.919	2.308	0.701	0.318
1993	0.376	0.314	0.202	0.551	2.094	2.487	3.701	2.602	2.525	1.634	0.777	0.438
1994	0.254	0.165	0.182	0.170	0.518	2.427	3.185	3.180	3.057	0.711	0.396	0.359
1995	0.128	0.108	0.104	0.492	0.650	0.990	1.793	2.101	2.319	1.021	0.490	0.215
1996	1.190	1.190	0.703	0.638	1.144	2.709	2.262	2.650	2.987	1.269	0.587	0.532
1997	0.273	0.155	0.207	0.492	0.755	2.151	1.936	2.293	1.505	2.855	2.834	0.360
1998	0.789	0.424	0.631	0.345	0.580	1.266	1.874	2.800	1.928	2.565	0.808	1.251
1999	0.236	0.137	0.160	0.192	0.548	0.938	1.864	2.102	1.518	1.554	0.549	0.363
2000	0.714	0.629	0.081	0.319	0.957	1.510	3.111	2.981	3.114	3.793	0.954	0.377
2001	0.713	0.723	0.715	0.667	0.888	2.254	3.860	2.608	1.774	2.284	1.051	0.437
2002	0.327	0.152	0.178	0.245	0.149	1.334	1.835	2.820	2.614	0.826	0.374	0.428
2003	0.220	0.168	0.206	0.379	0.187	2.342	3.366	2.622	3.394	0.613	0.345	0.214
2004	0.146	0.119	0.094	0.151	0.278	0.941	2.291	2.204	3.759	2.761	0.307	0.234
2005	0.103	0.022	0.158	0.819	0.286	1.893	3.282	2.548	4.974	1.968	1.106	0.738
2006	0.575	0.613	0.652	0.984	0.577	1.178	3.039	3.943	2.798	1.573	1.011	0.845

Precipitation (mm /day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC

1985	0.919	1.537	3.740	6.252	7.001	6.088	6.690	6.305	4.593	1.989	3.402	0.688
1986	0.125	2.096	3.585	5.171	4.734	8.727	7.700	5.976	6.036	2.923	0.937	1.801
1987	1.416	2.911	4.247	2.551	9.176	5.426	5.016	7.348	5.972	3.347	1.126	1.763
1988	2.581	2.326	1.112	3.910	6.629	7.360	7.796	12.219	9.477	5.851	0.244	0.177
1989	1.077	2.130	4.181	6.278	4.999	6.474	9.723	8.500	8.747	4.296	2.538	5.479
1990	1.300	4.087	4.982	2.136	5.296	8.549	8.257	8.936	6.110	2.708	2.961	1.154
1991	2.995	2.082	1.710	5.194	5.423	5.374	6.399	7.084	4.987	1.655	0.700	1.557
1992	1.300	1.689	1.992	5.224	5.051	7.886	6.184	8.272	5.082	7.141	1.990	1.095
1993	1.436	2.446	2.912	6.350	8.794	7.045	5.448	5.775	4.965	5.859	0.153	0.220
1994	0.386	0.365	2.673	4.283	8.104	3.814	8.996	6.509	5.064	0.705	2.823	0.715
1995	0.222	1.210	2.015	6.965	4.657	6.052	3.363	6.976	6.142	1.526	1.218	5.301
1996	1.954	1.339	6.789	8.803	5.945	5.179	6.728	4.328	7.045	1.178	2.587	1.392
1997	1.974	0.045	2.277	6.201	8.014	9.106	5.415	7.617	5.075	10.005	7.678	2.684
1998	5.450	0.758	5.287	3.994	5.858	7.203	8.229	9.585	6.723	6.174	1.724	0.016
1999	0.773	0.081	2.516	3.936	7.921	6.170	5.612	6.529	3.681	5.077	0.486	0.384
2000	0.000	0.011	1.215	6.243	6.876	7.666	6.280	5.673	9.409	6.655	1.310	1.178
2001	0.459	0.879	3.094	4.378	7.997	9.122	8.491	6.432	5.057	4.473	1.687	0.616
2002	1.685	0.056	1.676	3.736	3.472	5.577	5.536	6.475	4.847	1.611	1.259	4.263
2003	1.470	1.058	2.796	4.025	0.613	7.749	5.354	5.187	6.451	1.907	1.200	2.325
2004	2.329	1.107	1.860	3.899	5.750	4.566	5.137	7.647	5.462	2.853	1.299	1.138
2005	0.750	0.081	6.388	5.999	7.769	4.372	7.505	5.975	6.048	2.438	2.149	0.042
2006	0.672	0.930	4.903	2.917	6.853	7.662	5.302	9.389	5.217	2.715	1.865	1.378

Temperature (˚C)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	15.67	16.08	16.71	20.19	19.57	18.96	17.63	17.99	18.54	18.69	19.09	19.08
1986	19.87	20.85	12.00	12.32	12.60	19.08	18.37	18.55	18.51	18.66	19.12	18.90
1987	19.36	20.14	20.32	20.72	20.17	19.62	19.27	18.96	18.97	19.60	19.20	19.32
1988	19.89	21.16	21.75	20.94	20.72	19.77	18.37	18.45	18.91	19.04	19.08	19.28
1989	19.72	19.63	20.33	19.90	20.05	19.02	18.13	18.77	18.67	19.55	19.96	7.50
1990	19.84	19.48	19.90	20.67	20.47	19.50	18.63	18.25	19.10	19.41	19.39	18.70
1991	19.90	20.30	20.88	20.61	14.12	20.26	17.98	18.30	19.00	18.76	19.08	19.18
1992	19.74	20.44	20.89	21.08	20.20	19.67	18.78	18.75	19.01	19.18	18.77	19.48
1993	19.74	20.09	20.23	19.98	19.52	19.33	18.02	18.47	18.84	18.37	18.28	18.36
1994	19.20	20.18	20.15	19.95	19.46	19.24	17.94	18.50	18.82	18.14	18.56	18.50

1995	19.40	20.24	20.02	20.21	19.71	19.45	18.14	18.64	18.96	18.38	18.53	19.07
1996	19.57	19.30	19.98	20.00	18.95	19.02	19.54	20.04	20.40	15.30	15.36	20.73
1997	21.21	22.21	22.95	21.31	20.96	20.47	19.81	19.98	20.53	20.15	20.04	20.22
1998	20.45	20.98	21.43	22.03	21.28	20.20	19.18	19.04	19.53	19.79	18.69	18.61
1999	19.79	21.02	21.26	20.96	20.05	19.29	18.50	18.71	19.26	17.47	17.61	18.37
2000	18.82	18.94	19.74	20.22	19.77	19.29	18.15	18.56	19.15	18.64	18.59	18.69
2001	19.57	20.18	19.94	20.18	19.77	18.81	18.57	18.67	19.15	18.72	18.62	18.92
2002	18.10	18.74	18.67	18.14	18.03	17.29	14.38	14.56	15.23	15.19	15.05	14.97
2003	19.31	20.22	20.02	20.01	19.85	19.47	18.18	18.69	19.07	18.37	18.64	18.65
2004	19.84	20.15	19.97	20.21	19.79	19.37	18.17	18.66	19.02	18.29	18.51	18.63
2005	19.37	19.99	20.08	20.11	19.62	19.28	18.26	18.76	18.95	18.34	18.36	18.63
2006	18.79	20.32	20.75	20.47	20.51	18.57	14.04	18.60	19.24	15.45	15.38	14.68

Relative Humidity (%)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.54	0.52	0.48	0.55	0.60	0.72	0.75	0.83	0.87	0.78	0.64	0.60
Sunshine Hours (Hrs)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	7.42	7.10	6.70	6.18	6.36	5.33	3.74	4.07	5.38	6.97	7.69	7.77

Station Name: Gogeb Nr. Endeber

Station Number: 091007

Runoff (mm/day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.091	0.074	0.066	0.203	0.879	1.293	4.490	6.321	5.484	1.213	0.331	0.190
1986	0.050	0.103	0.121	0.368	0.273	1.937	5.697	5.849	9.239	1.536	0.233	0.138
1987	0.087	0.084	0.244	1.032	1.343	2.575	2.309	5.765	5.965	0.548	0.084	0.033
1988	0.024	0.068	0.054	0.069	0.051	0.447	5.098	7.930	6.703	4.006	0.666	0.207
1989	0.114	0.124	0.275	1.451	0.517	0.737	3.726	8.516	4.638	1.456	0.426	0.286
1990	0.152	0.583	1.204	1.688	0.525	1.664	6.641	8.776	4.552	1.717	0.298	0.133
1991	0.082	0.092	0.179	0.054	0.104	0.233	3.472	5.325	3.609	0.538	0.173	0.109
1992	0.083	0.229	0.160	0.184	0.172	0.913	2.543	15.918	5.635	1.574	0.517	0.297
1993	0.197	0.233	0.085	0.489	1.583	2.493	4.193	8.483	2.986	1.376	0.476	0.229
1994	0.152	0.086	0.132	0.150	0.154	0.736	3.278	3.999	7.469	0.654	0.222	0.136
1995	0.157	0.270	0.237	0.420	0.234	0.275	3.289	7.130	7.425	1.077	0.449	0.325

1996	0.282	0.082	0.310	0.499	1.988	5.785	3.917	10.602	2.607	0.979	0.286	0.178
1997	0.179	0.087	0.091	0.627	0.222	0.339	2.495	4.801	2.018	1.122	0.976	0.330
1998	0.519	0.260	0.382	0.305	0.814	1.003	9.420	12.046	7.147	5.340	0.603	0.239
1999	0.150	0.104	0.113	0.096	0.196	0.882	3.702	3.883	2.807	2.553	0.665	0.274
2000	0.191	0.138	0.125	0.122	0.169	0.329	0.853	3.287	4.557	3.988	1.049	0.391
2001	0.215	0.140	0.173	0.165	0.817	1.986	5.200	7.727	2.607	0.919	0.306	0.191
2002	0.202	0.141	0.202	0.140	0.150	1.101	2.859	4.188	3.334	0.626	0.214	0.196
2003	0.165	0.134	0.143	0.274	0.150	0.460	5.566	6.031	4.310	2.561	0.275	0.198
2004	0.170	0.146	0.140	0.312	0.145	0.627	2.087	7.687	3.406	2.173	0.362	0.189
2005	0.253	0.204	0.354	0.373	0.589	0.552	5.495	3.489	4.118	0.913	0.472	0.357
2006	0.281	0.127	0.168	0.224	0.279	0.908	4.047	9.659	4.689	1.022	0.293	0.187

Precipitation (mm /day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.533	0.000	0.789	4.546	5.697	5.898	9.589	7.234	4.250	0.589	0.178	0.053
1986	0.000	1.420	1.852	3.158	3.712	6.891	8.440	5.946	5.990	1.152	0.042	0.045
1987	0.000	1.714	2.543	3.688	2.355	5.882	3.549	6.688	2.510	1.990	0.000	0.000
1988	0.852	1.974	0.655	0.000	2.000	5.293	10.947	7.095	7.694	3.592	0.000	0.000
1989	0.000	0.372	3.635	2.813	3.776	4.115	10.076	9.164	6.339	2.000	2.293	1.757
1990	0.457	4.730	2.102	2.510	2.628	5.276	8.398	9.882	7.105	0.829	0.385	0.039
1991	0.000	3.592	3.214	0.447	6.128	10.191	9.046	7.303	4.016	0.230	0.000	1.207
1992	0.553	4.270	0.984	8.135	6.424	11.783	10.753	23.589	3.592	1.839	3.803	0.135
1993	1.049	4.484	2.796	8.181	6.691	8.320	10.188	8.747	5.115	0.135	0.000	0.000
1994	0.000	0.286	7.497	5.984	6.819	6.079	11.938	4.809	7.595	0.112	0.813	0.000
1995	0.000	0.891	1.326	10.523	2.497	4.214	8.289	12.977	0.924	0.602	0.000	1.829
1996	3.467	0.398	7.664	5.753	8.020	10.921	10.740	13.053	5.391	1.046	0.832	0.135
1997	2.451	0.000	3.178	6.776	3.842	1.605	8.243	5.026	4.490	4.414	1.750	0.000
1998	0.734	0.681	4.010	1.056	3.211	6.372	11.563	7.839	2.609	0.520	0.000	0.000
1999	0.138	0.000	0.000	0.711	2.385	7.391	8.789	4.105	6.625	6.536	0.000	0.000
2000	0.000	0.000	0.000	1.263	3.247	5.566	10.201	7.546	4.559	1.780	0.816	0.138
2001	0.204	0.365	2.207	1.230	3.467	5.086	13.184	8.987	3.842	3.217	0.112	0.181
2002	1.546	0.197	2.526	1.918	5.526	9.148	8.368	7.638	2.964	0.000	0.000	1.243
2003	0.579	2.089	2.513	4.043	0.459	6.477	12.151	7.171	6.668	0.832	0.332	0.306
2004	1.678	0.326	0.990	3.214	2.911	6.826	2.707	6.720	5.263	0.109	0.207	0.339
2005	0.930	0.072	2.742	3.745	3.742	6.750	7.914	9.545	5.321	2.092	0.619	0.043

2006	0.111	1.600	3.594	3.019	3.802	6.462	9.463	8.686	6.264	2.381	0.245	0.313

Temperature (˚C)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	16.27	15.65	16.51	15.43	14.58	16.45	15.68	15.70	16.10	16.64	16.91	16.92
1986	12.46	13.47	13.82	13.94	13.37	12.82	12.48	12.48	12.36	12.55	12.46	12.19
1987	19.51	20.83	17.79	17.93	17.29	16.39	16.03	15.95	16.31	16.79	17.16	17.36
1988	17.72	18.38	19.10	18.57	17.62	16.40	15.33	15.41	15.87	16.20	15.96	16.18
1989	16.13	17.24	17.61	17.12	17.34	15.95	15.36	15.20	15.67	16.06	16.72	16.77
1990	16.72	17.52	17.75	17.92	17.62	16.09	15.36	15.37	15.81	16.51	16.89	16.60
1991	17.79	18.10	18.20	18.68	17.58	16.92	15.40	15.34	15.98	16.57	16.65	16.53
1992	17.16	17.65	18.54	18.30	17.69	16.12	15.33	15.70	16.10	16.64	16.91	16.92
1993	17.30	18.14	18.25	18.06	17.58	16.45	15.68	15.70	16.10	16.64	16.91	16.92
1994	17.30	18.14	18.25	18.06	17.58	16.45	15.68	15.70	16.10	16.64	16.91	16.92
1995	17.30	18.14	18.25	18.06	17.83	16.74	15.47	15.51	15.77	17.13	16.89	17.60
1996	16.96	18.10	18.34	18.06	17.52	16.19	15.78	15.37	16.01	16.51	16.75	16.63
1997	17.37	18.55	19.13	17.78	17.83	16.64	15.78	15.79	16.60	17.13	17.13	17.04
1998	17.65	18.38	18.58	18.64	18.07	16.61	15.71	15.86	16.19	16.64	16.69	16.53
1999	17.30	18.97	18.03	18.78	17.65	16.23	15.30	15.51	16.01	16.26	16.44	16.60
2000	17.23	18.48	19.10	18.44	17.31	16.02	15.16	15.41	16.19	16.40	16.37	16.84
2001	17.13	18.24	17.79	18.29	17.48	16.19	15.67	15.93	16.32	16.68	16.58	17.08
2002	16.92	17.93	17.99	18.44	17.79	16.43	15.99	15.55	16.01	16.99	16.96	9.24
2003	17.13	18.65	18.89	18.44	18.48	16.64	15.64	15.72	16.12	17.23	17.31	16.56
2004	17.54	17.72	18.58	17.95	17.52	16.12	15.54	15.82	16.15	12.88	17.20	16.97
2005	17.20	18.83	18.72	18.68	17.65	16.71	15.88	16.24	16.46	16.78	16.75	16.53
2006	17.58	18.59	18.16	18.02	17.66	16.71	16.37	15.75	16.25	17.40	17.34	16.90

Relative Humidity (%)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RH	0.69	0.63	0.68	0.71	0.76	0.83	0.86	0.87	0.85	0.76	0.69	0.64
Sunshine Hours (Hrs)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SSH	12.31	8.02	8.01	7.03	7.48	5.63	3.96	4.06	5.87	8.32	9.00	9.51

Station Name: Gojeb Shebe

Station Number: 091011

Runoff (mm/day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.278	0.219	0.232	0.376	1.154	1.842	2.784	3.996	5.442	1.457	0.738	0.389
1986	0.245	0.264	0.341	0.441	0.597	2.122	2.109	2.703	3.000	1.099	0.448	0.370
1987	0.231	0.208	0.324	0.373	0.598	1.153	2.252	2.554	2.318	1.582	1.056	0.461
1988	0.383	0.321	0.251	0.191	0.496	1.229	2.172	5.471	5.410	5.358	0.771	0.392
1989	0.341	0.315	0.297	0.703	0.644	0.947	2.438	2.242	5.543	2.082	0.708	1.069
1990	0.515	0.463	0.678	0.648	0.806	2.405	2.382	4.558	4.116	2.504	0.825	0.533
1991	0.382	0.323	0.333	0.473	0.660	2.947	4.755	3.112	2.083	1.125	0.515	0.434
1992	0.297	0.337	0.287	0.450	1.202	1.729	3.259	3.332	3.366	4.365	1.185	0.602
1993	0.475	0.482	0.401	0.872	2.093	2.745	3.734	2.994	3.169	2.099	0.900	0.441
1994	0.324	0.235	0.254	0.288	0.686	1.733	4.113	4.980	3.912	0.931	0.670	0.488
1995	0.308	0.252	0.251	0.363	0.826	1.571	2.059	2.998	2.874	1.971	0.653	0.691
1996	1.519	1.519	0.703	0.994	1.713	3.548	3.253	3.427	3.874	2.572	0.718	0.549
1997	0.463	0.305	0.356	0.563	1.125	0.119	2.359	2.705	2.158	4.256	0.154	1.683
1998	0.211	0.602	0.410	0.589	1.757	1.312	3.314	6.570	3.627	2.748	1.150	0.160
1999	0.027	0.009	0.006	0.078	1.145	1.836	4.043	3.542	1.981	3.887	0.778	0.076
2000	0.007	0.005	0.004	0.637	2.184	2.369	4.213	4.083	3.621	4.298	0.106	0.362
2001	0.080	0.029	0.151	0.384	0.889	3.143	4.874	4.270	4.869	3.786	0.171	0.362
2002	0.478	0.507	0.346	0.440	0.383	1.143	1.927	2.780	2.178	1.337	0.402	0.330
2003	0.131	0.079	0.364	0.578	0.348	1.134	2.775	2.936	3.646	1.143	0.467	0.470
2004	0.374	0.350	0.262	0.277	0.726	1.447	2.453	3.357	3.929	2.908	0.308	0.282
2005	0.616	0.473	0.653	0.604	1.662	1.464	2.568	4.608	4.484	2.034	0.966	0.640
2006	0.567	0.618	0.637	0.018	0.024	0.032	4.330	5.922	3.925	2.039	1.292	1.091

Precipitation (mm /day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.520	1.286	3.816	6.180	8.075	6.426	8.089	9.456	5.082	2.610	2.542	1.368
1986	0.253	2.976	3.601	6.167	6.376	9.505	7.161	7.019	6.132	3.708	1.332	3.565
1987	1.237	2.913	3.851	4.595	8.457	6.044	3.985	7.849	5.513	5.403	1.124	2.236
1988	2.443	1.682	0.511	3.453	5.759	8.317	8.495	13.825	12.806	6.405	0.203	0.617
1989	1.595	1.487	4.815	6.977	4.478	7.803	8.640	8.059	8.065	4.503	1.922	4.865
1990	0.952	4.364	8.660	5.335	10.061	9.932	3.030	9.329	7.058	2.842	3.124	1.274

1991	2.656	3.021	3.640	6.717	7.276	7.939	5.760	8.505	5.966	2.619	1.761	0.803
1992	1.766	2.620	3.005	5.098	6.811	8.213	6.550	7.118	5.883	8.960	3.323	2.087
1993	1.259	2.827	3.213	5.490	7.748	7.698	5.474	4.191	6.335	5.422	0.608	0.355
1994	0.438	0.700	2.299	4.625	11.088	1.251	9.607	6.563	5.918	2.067	4.202	1.369
1995	0.101	1.737	2.217	6.088	6.062	5.906	3.859	6.925	7.255	1.950	1.541	5.548
1996	1.846	1.496	6.850	9.348	5.689	6.863	6.730	4.754	6.263	1.931	2.403	1.210
1997	2.227	0.169	3.687	8.039	7.379	8.798	6.313	7.133	5.372	10.148	5.947	5.135
1998	4.689	0.834	5.056	6.423	6.612	8.339	6.721	10.833	6.350	7.277	1.047	0.010
1999	0.550	0.371	3.127	6.973	7.029	4.898	6.503	6.206	5.251	4.192	0.687	0.794
2000	0.054	0.148	1.788	5.741	7.221	6.525	7.026	5.433	6.086	5.766	0.787	1.128
2001	0.491	1.308	3.599	4.439	7.955	8.451	7.430	5.663	5.703	4.867	1.939	0.914
2002	1.275	0.108	3.535	4.725	4.169	5.199	6.214	5.511	4.614	2.789	1.391	4.164
2003	1.776	0.527	3.845	6.092	2.469	8.213	6.174	6.954	6.786	1.648	1.820	2.032
2004	4.046	0.872	2.669	6.021	7.736	5.861	5.486	3.071	5.583	2.495	2.371	2.113
2005	0.426	0.703	6.180	6.837	8.114	4.479	6.003	6.849	8.566	3.866	3.061	0.025
2006	1.334	2.787	5.885	3.405	7.008	7.694	4.775	9.338	5.310	2.711	4.865	2.180

Temperature (˚C)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	16.49	17.11	17.42	19.81	19.61	18.86	17.73	17.79	18.07	18.34	18.44	18.44
1986	18.91	19.48	15.06	15.54	15.67	18.91	18.03	17.99	18.09	18.31	18.47	18.24
1987	18.57	19.34	19.46	20.11	19.91	19.09	18.40	18.14	18.24	18.62	18.42	18.50
1988	18.78	19.68	20.29	20.23	20.06	19.19	18.03	17.87	18.21	18.39	18.64	18.69
1989	18.84	19.14	19.58	19.74	19.91	18.87	17.90	18.04	18.11	18.76	18.95	11.77
1990	18.94	18.91	19.28	20.08	20.09	19.06	18.16	17.77	18.32	18.71	18.54	18.25
1991	18.69	19.33	19.81	20.04	19.97	19.44	17.82	17.89	18.29	18.41	18.54	18.54
1992	18.76	19.33	19.76	20.29	19.87	19.12	18.30	18.07	18.27	18.42	18.30	18.44
1993	18.67	19.23	19.51	13.21	19.50	18.91	17.82	17.89	18.18	17.97	17.97	18.07
1996	18.61	18.71	19.14	19.59	19.16	18.74	18.61	18.71	18.96	16.34	16.38	19.27
1997	19.38	20.58	20.71	20.38	20.31	19.47	18.68	18.59	18.91	18.79	18.55	18.67
1998	18.78	19.49	19.81	20.46	20.24	19.29	18.31	18.07	18.37	18.56	18.24	18.27
1999	18.79	19.86	19.86	20.08	19.74	18.87	18.05	18.04	18.26	17.39	17.68	17.95
2000	18.31	18.67	18.98	19.62	19.50	18.91	17.82	17.89	18.18	17.97	17.97	18.07
2001	18.61	19.16	19.16	19.62	19.50	18.59	18.03	17.89	18.18	17.97	17.97	18.07
2002	17.69	18.47	18.34	18.57	18.51	17.77	15.61	15.62	16.04	16.16	16.07	15.73

2003	18.61	18.87	19.16	19.62	19.50	18.92	17.82	17.89	18.18	17.97	17.97	18.07
2004	18.52	19.16	19.16	19.62	19.50	18.92	17.82	17.89	18.18	17.97	17.97	18.07
2005	18.52	19.16	19.16	19.62	19.50	18.92	17.82	17.89	18.18	17.97	17.97	18.07
2006	18.17	19.33	19.49	19.81	19.96	18.51	15.58	17.91	18.34	16.37	16.32	15.88

Relative Humidity (%)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.65	0.66	0.67	0.72	0.77	0.84	0.86	0.89	0.88	0.82	0.78	0.73
Sunshine Hours (Hrs)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	7.54	6.68	6.42	6.53	6.06	4.99	3.22	3.68	5.00	6.86	7.58	8.00

Station Name: Gumma Nr.Andaracha

Station Number: 092004

Runoff (mm/day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.06	0.06	0.11	0.54	0.61	0.95	4.14	5.03	5.72	1.26	0.46	0.37
1986	0.07	0.14	0.33	0.52	0.62	1.58	1.48	0.95	3.82	1.09	0.20	0.24
1987	0.08	0.06	0.11	0.18	2.01	1.15	4.66	3.52	2.25	1.11	0.21	0.22
1988	0.20	0.30	0.16	0.21	0.34	0.90	7.88	8.17	5.71	2.65	0.20	0.07
1989	0.17	0.08	0.18	1.09	0.51	1.14	4.99	3.24	2.34	1.01	0.25	0.64
1990	0.17	0.29	1.11	0.38	0.75	1.17	2.68	4.67	2.56	1.33	0.39	0.16
1991	0.20	0.13	0.36	0.51	0.84	1.74	3.34	4.42	2.39	0.92	0.20	0.29
1992	0.13	0.36	0.36	0.44	0.88	3.89	3.69	2.83	4.59	3.74	0.62	0.37
1993	0.19	0.30	0.22	1.03	3.43	3.55	4.51	3.19	2.95	3.99	0.34	0.14
1994	0.09	0.05	0.13	0.23	1.08	1.25	5.48	3.94	3.40	0.34	0.41	0.19
1995	0.08	0.14	0.18	0.64	0.77	0.71	4.51	4.46	2.60	0.60	0.20	0.22
1996	0.30	0.12	0.50	1.43	2.05	2.44	2.02	2.50	4.68	1.05	0.36	0.18
1997	0.21	0.11	0.18	1.79	1.39	2.24	7.09	1.07	5.10	2.40	0.28	0.64
1998	0.40	0.21	1.12	0.57	1.86	3.37	2.84	5.98	3.02	2.83	0.48	0.15
1999	0.09	0.06	0.14	0.15	1.74	1.90	4.30	2.62	1.75	1.66	0.45	0.16
2000	0.08	0.05	0.05	0.19	1.12	0.40	5.87	6.17	2.34	2.49	0.35	0.17
2001	0.08	0.05	0.05	0.19	1.12	0.40	5.87	6.17	2.34	2.49	0.45	0.17
2002	0.60	0.85	0.89	0.64	4.25	3.76	4.24	2.73	1.72	1.24	0.40	0.46
2003	0.56	0.28	0.80	0.71	0.67	1.48	2.46	5.45	2.42	0.71	0.46	0.58

2004	0.43	0.29	0.48	0.56	0.32	1.70	2.82	3.72	7.38	0.71	0.23	0.51
2005	0.25	0.23	0.47	0.67	1.41	1.84	3.88	3.81	3.22	2.36	1.08	0.30
2006	0.25	0.23	0.46	0.65	1.39	1.80	3.79	3.88	3.24	2.14	1.36	0.31

Precipitation (mm /day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	1.227	1.342	3.549	5.571	9.723	6.619	8.087	8.509	5.676	3.391	3.972	1.468
1986	0.315	3.327	3.446	4.922	6.465	7.129	7.906	6.469	5.848	2.956	2.129	3.130
1987	1.306	3.189	4.531	5.508	7.751	4.471	4.833	7.067	4.515	2.781	0.872	3.185
1988	2.669	2.416	0.939	3.481	4.790	7.666	3.774	10.919	9.538	7.190	0.560	1.161
1989	1.504	1.132	4.624	6.704	3.379	5.227	6.561	7.067	5.800	4.586	1.105	4.121
1990	1.516	4.107	6.567	5.357	9.761	7.676	4.377	8.592	7.551	2.397	2.966	1.756
1991	2.408	2.277	4.397	7.486	7.194	7.851	6.296	9.109	6.553	2.288	1.803	1.433
1992	2.586	3.143	3.405	3.997	6.107	8.583	6.758	6.978	5.756	9.434	3.475	2.120
1993	3.486	3.007	3.367	7.528	8.387	8.133	5.959	4.291	6.976	5.813	0.551	0.168
1994	0.356	0.545	2.343	5.530	9.419	6.616	8.329	5.230	5.032	1.908	3.708	0.950
1995	0.018	1.504	1.963	5.312	5.617	5.367	5.461	6.945	7.385	1.954	1.203	5.008
1996	1.529	1.253	5.460	7.263	6.049	6.211	5.926	5.427	6.672	2.809	2.929	0.832
1997	2.716	0.330	4.332	7.990	7.054	7.408	6.125	5.652	4.926	8.800	7.090	4.899
1998	3.875	1.311	2.768	6.219	7.347	7.705	6.577	9.498	6.359	6.206	0.586	0.005
1999	1.471	0.288	3.459	6.411	6.100	4.482	5.889	4.400	5.074	5.196	0.702	0.805
2000	0.163	0.175	2.888	6.009	7.304	5.344	7.827	4.835	4.634	7.745	1.044	0.966
2001	0.177	1.940	3.831	5.296	9.139	7.002	6.553	6.172	6.542	4.423	2.245	0.449
2002	1.253	0.530	5.497	4.463	4.024	7.533	5.527	5.402	5.341	4.661	1.059	3.991
2003	1.616	0.744	2.586	6.991	2.167	10.716	12.452	12.008	9.434	1.208	1.719	1.492
2004	3.597	0.563	3.022	6.936	5.150	4.126	5.376	7.695	7.848	2.921	2.543	3.131
2005	0.914	1.178	5.362	5.745	9.418	6.211	5.668	6.691	7.236	4.525	2.835	0.000
2006	1.144	2.564	5.646	3.179	8.093	6.456	8.304	7.591	5.863	4.341	4.142	3.065

Temperature (˚C)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	19.30	19.98	20.26	20.34	20.07	19.14	18.32	18.64	18.51	18.94	18.94	19.02
Relative Humidity (%)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.70	0.72	0.75	0.80	0.84	0.90	0.91	0.91	0.88	0.84	0.85	0.79

Sunshine Hours (Hrs)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	7.20	6.37	6.06	6.29	5.72	4.69	3.05	3.35	4.69	6.52	7.20	7.66

Station Name: Kulti Nr. Wolkite

Station Number: 091026

Runoff (mm/day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.069	0.055	0.040	0.067	0.150	0.292	1.997	2.477	2.285	0.575	0.230	0.131
1986	0.079	0.082	0.077	0.073	0.068	0.576	1.807	2.050	2.461	0.629	0.211	0.130
1987	0.085	0.069	0.146	0.116	0.220	0.770	1.457	2.708	1.402	0.520	0.211	0.149
1988	0.105	0.085	0.055	0.053	0.058	0.147	2.208	2.743	3.719	1.413	0.341	0.185
1989	0.129	0.095	0.094	0.121	0.084	0.267	2.163	6.826	2.869	0.736	0.249	0.180
1990	0.132	0.142	0.103	0.201	0.083	0.158	1.310	3.817	1.462	0.433	0.056	0.003
1991	0.045	0.043	0.050	0.019	0.008	0.071	0.690	2.566	1.890	0.445	0.103	0.060
1992	0.067	0.090	0.040	0.046	0.091	0.252	1.454	5.261	4.266	1.265	0.203	0.138
1993	0.120	0.088	0.047	0.231	0.376	1.200	4.650	6.248	5.256	0.679	0.208	0.521
1994	0.284	0.253	0.197	0.115	0.122	0.247	2.573	6.189	2.707	0.518	0.255	0.174
1995	0.132	0.117	0.100	0.214	0.246	0.211	0.824	3.238	1.834	0.415	0.213	0.164
1996	0.120	0.065	0.307	0.506	0.686	2.018	2.113	2.981	2.266	0.892	0.389	0.257
1997	0.216	0.142	0.128	0.191	0.170	0.411	1.625	2.865	1.045	0.433	0.317	0.214
1998	0.200	0.166	0.195	0.125	0.270	0.582	2.085	6.728	3.572	3.240	0.777	0.442
1999	0.354	0.269	0.257	0.224	0.304	0.548	1.654	3.890	2.266	2.764	0.733	0.478
2000	0.074	0.056	0.046	0.083	0.125	0.383	3.007	5.981	2.235	1.168	0.198	0.130
2001	0.078	0.066	0.122	0.094	0.334	0.841	2.035	5.385	1.206	0.289	0.133	0.087
2002	0.164	0.072	0.105	0.088	0.105	0.397	0.978	4.607	0.678	0.178	0.086	0.074
2003	0.066	0.056	0.072	0.169	0.102	0.216	4.761	2.052	0.858	0.290	0.158	0.082
2004	0.086	0.065	0.092	0.583	0.178	0.466	1.482	2.753	1.346	0.726	0.254	0.178
2005	0.155	0.129	0.207	0.217	0.320	0.303	2.470	2.398	2.536	0.699	0.265	0.209
2006	0.170	0.161	0.325	0.475	0.565	0.655	1.971	5.495	2.197	0.715	0.190	0.136

Precipitation (mm /day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC

1985	0.329	0.000	0.599	2.576	7.105	5.878	7.046	7.385	7.697	1.622	0.066	0.099
1986	0.000	0.266	2.125	2.536	1.132	10.819	7.977	5.365	4.954	1.901	0.253	0.250
1987	0.339	0.457	1.885	2.947	5.289	8.428	6.487	8.980	8.760	3.188	0.181	0.510
1988	0.595	1.391	0.697	1.250	3.184	6.405	6.569	5.286	4.753	3.980	0.214	0.072
1989	0.188	0.250	4.332	1.434	2.500	5.842	7.612	14.612	0.664	4.030	0.000	3.151
1990	0.112	1.007	3.135	2.786	4.095	8.184	0.000	8.204	3.365	0.668	0.799	0.000
1991	0.803	1.319	2.299	0.000	2.132	8.952	8.879	7.761	3.828	0.469	0.048	0.148
1992	1.082	2.350	1.497	3.132	2.612	6.010	8.155	11.105	4.289	2.322	0.842	0.000
1993	0.082	1.099	1.589	7.405	6.214	5.970	5.648	13.809	5.780	3.993	0.066	0.000
1994	0.457	0.000	1.878	2.207	4.803	2.632	11.204	9.799	3.707	0.164	0.039	0.000
1995	0.000	0.000	2.503	4.724	2.664	5.013	7.868	10.016	2.753	0.444	0.516	0.546
1996	1.477	0.000	3.201	3.280	5.829	5.668	9.109	5.855	6.888	0.000	0.789	0.497
1997	0.908	0.000	0.447	3.586	3.112	7.316	8.375	6.237	5.227	3.789	2.602	0.227
1998	0.211	0.000	0.618	0.980	5.461	9.280	11.276	8.224	6.559	6.641	0.000	0.000
1999	0.000	0.000	0.000	2.352	5.151	7.086	6.964	3.813	6.898	6.924	0.072	0.000
2000	0.000	0.000	0.000	5.247	3.556	7.112	7.207	10.477	3.359	3.951	0.743	0.115
2001	0.000	0.993	1.431	1.513	4.470	9.980	10.664	9.053	5.951	5.391	0.928	0.000
2002	0.865	0.095	2.526	2.553	0.941	7.359	5.865	5.836	2.421	0.181	0.000	0.954
2003	0.000	0.819	1.641	1.829	0.063	6.194	9.490	8.704	4.556	0.628	0.000	0.480
2004	0.237	0.309	0.602	1.352	1.026	7.507	9.497	6.026	5.385	1.543	0.164	0.474
2005	0.000	0.000	2.579	1.168	2.273	8.684	6.092	6.859	5.230	1.211	2.217	0.000
2006	0.000	0.148	1.691	2.316	4.115	8.438	7.595	13.546	6.770	3.023	0.730	1.342

Temperature (˚C)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	19.30	21.10	21.70	22.10	21.00	19.60	18.50	18.50	18.90	19.00	19.20	19.10
Relative Humidity (%)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.56	0.62	0.59	0.59	0.72	0.80	0.85	0.87	0.86	0.88	0.65	0.62
Sunshine Hours (Hrs)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	8.52	8.88	6.36	7.68	5.64	5.88	4.80	3.72	5.64	6.96	8.40	9.00

Station Name: Megech Nr. Gubere

Station Number: 091005

Runoff (mm/day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.076	0.074	0.071	0.141	0.524	0.455	1.362	4.635	2.479	0.456	0.124	0.081
1986	0.049	0.058	0.110	0.326	0.572	1.614	3.408	2.770	2.278	0.421	0.132	0.078
1987	0.050	0.050	0.448	1.803	0.355	1.798	1.263	2.389	1.981	0.364	0.129	0.078
1988	0.065	0.088	0.075	0.069	0.139	0.189	2.857	5.901	2.613	2.327	0.328	0.133
1989	0.080	0.082	0.069	0.695	0.255	0.392	2.857	2.658	1.978	0.715	0.163	0.131
1990	0.069	0.364	0.882	1.656	0.518	1.695	2.840	3.601	2.059	0.898	0.202	0.102
1991	0.067	0.074	0.091	0.046	0.108	0.248	3.595	3.907	2.158	0.301	0.111	0.078
1992	0.077	0.200	0.148	0.344	0.364	1.365	3.011	8.614	2.469	0.833	0.323	0.201
1993	0.097	0.152	0.052	0.323	1.157	0.907	5.604	3.408	2.250	0.947	0.213	0.092
1994	0.050	0.036	0.106	0.110	0.174	0.253	3.965	5.399	1.865	0.701	0.137	0.093
1995	0.056	0.066	0.063	0.363	0.198	0.164	1.818	3.621	2.765	0.282	0.115	0.084
1996	0.124	0.058	0.542	0.799	1.700	4.889	3.589	5.364	1.448	0.544	0.141	0.093
1997	0.090	0.047	0.076	0.796	0.153	0.113	1.081	2.467	0.732	0.583	0.333	0.097
1998	0.119	0.053	0.098	0.150	0.380	0.553	4.554	3.525	2.944	2.346	0.337	0.168
1999	0.141	0.112	0.093	0.072	0.166	0.559	2.057	3.722	0.993	1.682	0.275	0.115
2000	0.100	0.067	0.058	0.066	0.095	0.090	0.736	2.919	1.722	0.729	0.209	0.129
2001	0.108	0.085	0.132	0.127	1.048	2.275	4.212	5.239	2.288	0.541	0.201	0.132
2002	0.157	0.098	0.160	0.118	0.192	0.617	1.584	2.351	0.867	0.185	0.080	0.067
2003	0.059	0.048	0.065	0.175	0.124	0.218	1.986	3.546	1.812	0.534	0.141	0.088
2004	0.081	0.057	0.050	0.497	0.218	0.269	1.467	3.777	1.666	1.231	0.279	0.184
2005	0.158	0.128	0.220	0.232	0.364	0.341	2.417	2.577	1.898	0.408	0.129	0.066
2006	0.043	0.035	0.206	1.131	0.802	0.522	1.863	3.907	2.112	0.577	0.199	0.136

Precipitation (mm /day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.533	0.000	0.789	4.546	5.697	5.898	9.589	7.234	4.250	0.589	0.178	0.053
1986	0.000	1.420	1.852	3.158	3.712	6.891	8.440	5.946	5.990	1.152	0.042	0.045
1987	0.000	1.714	2.543	3.688	2.355	5.882	3.549	6.688	2.510	1.990	0.000	0.000
1988	0.852	1.974	0.655	0.000	2.000	5.293	10.947	7.095	7.694	3.592	0.000	0.000
1989	0.000	0.372	3.635	2.813	3.776	4.115	10.076	9.164	6.339	2.000	2.293	1.757
1990	0.457	4.730	2.102	2.510	2.628	5.276	8.398	9.882	7.105	0.829	0.385	0.039

1991	0.000	3.592	3.214	0.447	6.128	10.191	9.046	7.303	4.016	0.230	0.000	1.207
1992	0.553	4.270	0.984	8.135	6.424	11.783	10.753	23.589	3.592	1.839	3.803	0.135
1993	1.049	4.484	2.796	8.181	6.691	8.320	10.188	8.747	5.115	0.135	0.000	0.000
1994	0.000	0.286	7.497	5.984	6.819	6.079	11.938	4.809	7.595	0.112	0.813	0.000
1995	0.000	0.891	1.326	10.523	2.497	4.214	8.289	12.977	0.924	0.602	0.000	1.829
1996	3.467	0.398	7.664	5.753	8.020	10.921	10.740	13.053	5.391	1.046	0.832	0.135
1997	2.451	0.000	3.178	6.776	3.842	1.605	8.243	5.026	4.490	4.414	1.750	0.000
1998	0.734	0.681	4.010	1.056	3.211	6.372	11.563	7.839	2.609	0.520	0.000	0.000
1999	0.138	0.000	0.000	0.711	2.385	7.391	8.789	4.105	6.625	6.536	0.000	0.000
2000	0.000	0.000	0.000	1.263	3.247	5.566	10.201	7.546	4.559	1.780	0.816	0.138
2001	0.204	0.365	2.207	1.230	3.467	5.086	13.184	8.987	3.842	3.217	0.112	0.181
2002	1.546	0.197	2.526	1.918	5.526	9.148	8.368	7.638	2.964	0.000	0.000	1.243
2003	0.579	2.089	2.513	4.043	0.459	6.477	12.151	7.171	6.668	0.832	0.332	0.306
2004	1.678	0.326	0.990	3.214	2.911	6.826	2.707	6.720	5.263	0.109	0.207	0.339
2005	0.930	0.072	2.742	3.745	3.742	6.750	7.914	9.545	5.321	2.092	0.619	0.043
2006	0.111	1.600	3.594	3.019	3.802	6.462	9.463	8.686	6.264	2.381	0.245	0.313

Temperature (˚C)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	18.09	18.61	18.94	18.78	18.32	15.19	14.34	14.10	14.52	15.19	15.03	15.57
1986	15.93	16.63	16.79	16.86	16.55	15.19	14.34	14.10	14.52	15.19	15.03	15.57
1987	18.74	19.67	18.40	18.48	18.11	16.67	15.82	15.56	16.06	16.78	16.71	17.30
1988	18.38	19.17	19.46	19.42	18.93	17.43	16.43	16.22	16.70	17.39	17.20	17.74
1989	18.06	18.94	19.16	19.12	18.88	17.34	16.43	16.17	16.66	17.36	17.35	17.86
1990	18.18	18.99	19.19	19.28	18.93	17.36	16.43	16.21	16.69	17.45	17.39	17.82
1991	18.39	19.11	19.28	19.44	16.55	17.53	16.44	16.20	16.72	17.46	17.34	17.81
1992	18.27	19.02	19.35	19.36	18.95	17.37	16.43	14.10	14.52	15.19	15.03	15.57
1993	15.93	16.63	16.79	16.86	16.55	15.19	14.34	14.10	14.52	15.19	15.03	15.57
1994	15.93	16.63	16.79	16.86	16.55	15.19	14.34	14.10	14.52	15.19	15.03	15.57
1995	15.93	16.63	16.79	16.86	18.98	17.50	16.45	16.24	16.68	17.58	17.39	18.03
1996	18.23	19.11	19.31	19.31	18.91	17.39	16.52	16.21	16.73	17.45	17.36	17.83
1997	18.31	19.20	19.47	19.26	18.98	17.48	16.52	16.29	16.85	17.58	17.44	17.92
1998	18.37	19.17	19.36	19.43	19.02	17.47	16.50	16.31	16.76	17.48	17.35	17.81
1999	18.30	19.29	19.25	19.46	18.94	17.39	16.42	16.24	16.73	17.40	17.30	17.82
2000	18.28	19.19	19.46	19.39	18.87	17.35	16.39	16.22	16.76	17.43	17.28	17.19

2001	17.57	18.37	18.40	19.41	18.91	17.39	16.50	16.32	16.79	17.49	17.32	17.92
2002	18.22	19.08	19.24	19.39	18.97	17.43	16.56	16.24	16.73	17.55	17.40	16.33
2003	16.58	19.22	19.42	19.39	19.11	17.48	16.49	16.28	16.75	17.60	17.47	17.82
2004	18.34	19.04	19.36	19.29	18.91	17.37	16.47	16.30	16.76	16.71	17.45	17.90
2005	18.27	19.26	19.39	19.44	18.94	17.49	16.54	16.38	16.82	17.51	17.36	17.81
2006	18.35	19.21	19.27	19.30	17.33	17.49	16.64	16.29	16.78	17.63	17.48	16.27

Relative Humidity (%)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RH	0.64	0.64	0.70	0.69	0.78	0.82	0.85	0.89	0.87	0.73	0.69	0.61
Sunshine Hours (Hrs)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SSH	9.56	7.87	8.12	6.90	7.72	5.51	4.13	4.03	5.52	8.74	9.49	9.32

Station Name: Wabi Nr. Wolkite

Station Number: 091004

Runoff (mm/day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.058	0.055	0.051	0.123	0.488	0.937	4.207	13.461	3.338	0.493	0.193	0.541
1986	0.517	0.648	0.957	1.372	1.528	2.702	4.157	3.906	4.201	0.691	0.230	0.167
1987	0.133	0.126	0.619	2.407	1.145	1.744	2.166	4.414	1.370	0.368	0.118	0.077
1988	0.082	0.103	0.079	0.069	0.089	0.812	6.734	11.498	6.366	3.875	0.390	0.208
1989	0.086	0.094	0.079	0.479	0.092	0.539	5.751	6.038	4.483	1.653	0.440	0.186
1990	0.096	0.544	1.370	2.641	0.786	2.705	5.695	7.464	3.946	1.531	0.280	0.128
1991	0.080	0.089	0.113	0.052	0.137	0.353	7.450	7.301	4.163	0.441	0.141	0.095
1992	0.093	0.276	0.197	0.513	0.546	2.470	6.086	20.178	4.855	1.407	0.478	0.279
1993	0.136	0.219	0.071	0.480	1.816	1.409	5.943	5.606	3.635	1.474	0.311	0.129
1994	0.069	0.049	0.150	0.156	0.251	0.373	6.430	8.084	4.119	0.607	0.192	0.114
1995	0.077	0.088	0.070	0.342	0.134	0.534	3.489	5.077	2.904	0.353	0.132	0.089
1996	0.151	0.067	0.519	1.001	1.494	6.192	6.580	10.357	2.380	0.885	0.315	0.140
1997	0.133	0.075	0.110	0.624	0.149	0.258	1.935	3.432	0.800	0.950	0.356	0.122
1998	0.175	0.109	0.282	0.220	0.427	0.841	7.586	11.037	4.812	3.798	0.502	0.243
1999	0.115	0.067	0.116	0.086	0.224	0.892	3.943	7.752	1.718	3.134	0.397	0.146
2000	0.080	0.055	0.043	0.093	0.159	0.279	4.203	6.046	2.844	1.209	0.291	0.168
2001	0.085	0.068	0.153	0.108	0.580	1.955	6.262	7.719	3.143	0.479	0.172	0.098

2002	0.226	0.077	0.126	0.100	0.126	0.727	2.384	4.590	1.472	0.252	0.098	0.080
2003	0.069	0.055	0.077	0.237	0.121	0.325	5.178	6.331	2.007	0.481	0.216	0.091
2004	0.097	0.068	0.106	1.208	0.253	0.899	4.125	9.326	3.633	1.610	0.404	0.252
2005	0.211	0.166	0.308	0.328	0.547	0.509	4.738	4.557	4.907	0.898	0.427	0.312
2006	0.238	0.221	0.559	0.922	1.157	0.825	3.520	8.193	4.061	0.925	0.275	0.178

Precipitation (mm /day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.723	0.000	0.702	3.082	4.383	4.420	9.676	7.164	4.287	0.933	0.073	0.022
1986	0.165	1.341	2.292	2.594	3.723	5.810	7.353	5.692	4.051	1.136	0.017	0.042
1987	0.000	1.274	3.501	3.606	3.326	5.283	5.255	8.088	2.191	0.965	0.000	0.000
1988	0.685	1.336	0.458	0.500	1.004	7.432	10.675	8.462	6.833	2.112	0.000	0.000
1989	0.331	0.722	3.549	3.942	2.351	4.420	7.653	8.385	4.865	1.189	0.937	1.302
1990	0.265	3.678	1.962	2.765	2.284	5.160	7.478	9.841	4.787	0.339	0.157	0.016
1991	0.105	1.595	3.459	0.251	3.147	6.160	8.118	8.312	3.439	0.131	0.000	0.836
1992	1.929	2.889	1.946	3.326	3.435	8.152	8.182	15.600	4.131	1.660	1.638	0.055
1993	0.561	4.202	1.234	7.401	6.022	6.262	8.920	10.188	8.229	0.757	0.000	0.000
1994	0.000	0.150	4.578	3.461	4.309	6.878	8.824	6.923	5.299	0.046	0.394	0.000
1995	0.000	1.798	1.205	8.275	3.739	2.734	8.239	12.067	1.803	0.316	0.000	0.946
1996	2.030	0.163	6.097	5.366	5.416	10.124	9.033	11.139	4.588	0.546	0.560	0.055
1997	2.336	0.000	2.100	4.079	2.683	3.991	8.000	5.487	3.502	3.810	1.106	0.000
1998	1.930	1.784	1.639	2.656	3.907	7.610	9.917	8.801	4.016	1.274	0.000	0.000
1999	0.241	0.000	1.523	0.590	2.929	6.547	8.453	6.486	5.203	4.646	0.000	0.000
2000	0.000	0.000	0.099	1.827	2.842	4.794	8.804	7.278	5.537	1.303	0.948	0.399
2001	0.126	0.357	2.493	1.524	4.163	4.765	9.690	6.437	3.148	1.842	0.046	0.074
2002	1.523	1.660	2.834	1.869	3.284	7.740	9.146	7.747	2.353	0.000	0.000	1.844
2003	1.032	1.091	2.431	3.572	0.351	5.335	10.261	7.609	5.779	0.494	0.208	0.477
2004	1.930	0.149	1.346	4.316	2.022	8.129	6.248	6.020	5.837	0.497	0.217	0.144
2005	1.244	0.030	3.138	4.740	4.089	6.262	6.201	9.308	4.562	1.145	0.284	0.103
2006	0.055	1.553	3.340	2.547	2.752	5.963	8.480	7.785	5.613	1.150	0.220	0.128

Temperature (˚C)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	19.37	20.25	20.40	20.42	19.90	18.38	17.43	17.19	17.65	18.62	18.49	19.17
Relative Humidity (%)												

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.63	0.65	0.70	0.69	0.79	0.82	0.85	0.90	0.88	0.72	0.69	0.60
Sunshine Hours (Hrs)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	8.78	7.83	8.15	6.86	7.78	5.48	4.17	4.02	5.42	8.86	9.63	9.26

Station Name: Walga Nr. Wolkite

Station Number: 091010

Runoff (mm/day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.013	0.011	0.008	0.027	0.098	0.224	1.844	3.546	0.626	0.236	0.031	0.017
1986	0.015	0.017	0.022	0.070	0.062	0.492	1.647	1.553	1.153	0.176	0.033	0.017
1987	0.017	0.018	0.086	0.119	0.118	0.403	0.747	2.093	1.249	0.044	0.011	0.012
1988	0.009	0.014	0.010	0.020	0.024	0.104	1.981	3.344	2.511	0.764	0.086	0.022
1989	0.011	0.013	0.018	0.102	0.072	0.135	1.245	2.081	1.205	0.214	0.029	0.019
1990	0.006	0.009	0.024	0.009	0.019	0.077	0.724	1.768	0.808	0.253	0.031	0.012
1991	0.006	0.009	0.024	0.009	0.019	0.077	0.724	0.878	0.006	0.001	0.019	0.034
1992	0.027	0.053	0.020	0.066	0.071	0.175	1.023	4.222	2.150	0.483	0.050	0.010
1993	0.019	0.023	0.007	0.057	0.177	1.015	2.778	3.769	2.732	0.754	0.124	0.023
1994	0.011	0.004	0.013	0.031	0.014	0.113	1.472	1.950	0.852	0.081	2.675	1.405
1995	0.003	0.002	0.003	0.070	0.013	0.069	0.491	2.001	0.972	0.117	0.008	0.002
1996	0.013	0.001	0.058	0.100	0.190	1.451	2.796	3.411	1.130	0.235	0.029	0.010
1997	0.007	0.003	0.006	0.057	0.042	0.187	0.817	0.681	0.314	0.109	0.038	0.004
1998	0.007	0.003	0.031	0.031	0.090	0.383	2.290	3.506	1.842	1.081	0.216	0.035
1999	0.001	0.005	0.001	0.007	0.024	0.130	0.807	2.519	0.802	0.819	0.073	0.035
2000	0.007	0.004	0.003	0.002	0.034	0.062	0.535	1.110	0.865	0.520	0.033	0.002
2001	0.007	0.006	0.015	0.010	0.077	0.341	1.425	1.842	0.611	0.061	0.017	0.009
2002	0.000	0.000	0.003	0.001	0.003	0.114	0.706	3.069	0.501	0.035	0.009	0.007
2003	0.006	0.004	0.004	0.022	0.005	0.084	2.719	3.638	1.303	0.127	0.001	0.008
2004	0.005	0.008	0.009	0.007	0.007	0.118	0.668	1.309	0.664	0.224	0.002	0.028
2005	0.022	0.016	0.035	0.038	0.071	0.065	1.196	2.279	1.573	0.297	0.055	0.002
2006	0.026	0.023	0.030	0.018	0.040	0.118	0.703	1.982	0.837	0.136	0.031	0.018

Precipitation (mm /day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC

1985	0.739	0.010	0.708	3.126	4.432	4.429	9.630	7.424	4.324	0.996	0.074	0.035
1986	0.159	1.379	2.273	2.688	3.676	6.030	7.344	5.918	4.235	1.105	0.016	0.039
1987	0.030	1.237	3.662	3.466	3.534	5.280	5.537	8.266	2.421	0.942	0.008	0.024
1988	0.697	1.353	0.485	0.564	0.996	7.376	10.572	8.694	6.692	2.135	0.000	0.000
1989	0.360	0.795	3.577	4.025	2.309	4.889	7.794	8.477	4.968	1.202	0.911	1.341
1990	0.281	3.653	1.987	2.773	2.344	5.538	7.770	10.235	4.942	0.333	0.182	0.033
1991	0.154	1.547	3.347	0.319	3.007	6.083	8.196	8.534	3.575	0.144	0.000	0.789
1992	1.950	2.897	1.913	3.159	3.269	7.972	8.317	15.056	4.201	1.730	1.512	0.111
1993	0.539	4.004	1.180	7.328	6.062	6.645	9.076	10.430	8.371	1.315	0.031	0.000
1994	0.000	0.156	4.311	3.310	4.228	6.965	8.940	6.913	5.284	0.042	0.382	0.000
1995	0.000	1.725	1.323	7.851	3.794	2.865	8.713	12.117	2.096	0.324	0.011	0.916
1996	1.958	0.229	6.161	5.251	5.462	9.920	9.185	11.357	4.858	0.593	0.631	0.114
1997	2.337	0.003	2.001	4.144	2.770	4.380	8.082	5.734	3.594	3.724	1.191	0.050
1998	1.949	1.825	1.659	2.597	3.977	7.614	9.903	9.101	4.324	1.751	0.040	0.000
1999	0.247	0.017	1.491	0.607	3.027	6.682	8.529	6.730	5.492	4.595	0.005	0.006
2000	0.016	0.001	0.139	1.993	2.916	4.972	8.653	7.431	5.681	1.425	0.967	0.432
2001	0.134	0.399	2.637	1.604	4.242	4.947	9.799	6.574	3.672	1.848	0.057	0.122
2002	1.507	1.656	2.795	2.084	3.241	7.760	9.545	7.911	2.624	0.015	0.002	1.776
2003	1.086	1.040	2.436	3.803	0.361	5.598	10.296	7.641	5.729	0.542	0.200	0.514
2004	1.892	0.191	1.433	4.401	1.946	8.307	6.626	6.084	6.162	0.711	0.220	0.200
2005	1.249	0.046	3.095	4.745	4.037	6.321	6.461	9.493	4.728	1.213	0.303	0.098
2006	0.055	1.481	3.533	2.651	2.837	6.144	8.625	8.104	5.707	1.185	0.225	0.128

Temperature (˚C)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	18.57	19.39	19.62	19.69	19.28	17.77	16.81	16.57	16.99	17.79	17.62	18.23
1986	18.53	19.45	19.63	19.70	19.29	17.77	16.81	16.54	16.99	17.78	17.62	18.22
1987	18.56	19.43	19.66	19.69	19.29	17.78	16.81	16.56	16.99	17.83	17.61	18.13
1988	18.60	19.47	19.63	19.68	19.28	17.76	16.84	16.55	17.01	17.81	17.60	18.22
1989	18.50	19.39	19.60	19.68	19.23	17.72	16.81	16.52	16.99	17.78	17.60	18.13
1990	18.58	19.44	19.62	19.65	19.26	17.73	16.77	16.53	16.98	17.77	17.61	18.21
1991	18.57	19.41	19.62	19.68	19.25	17.73	16.79	16.52	16.97	17.75	17.58	18.19
1992	18.56	19.43	19.59	19.65	19.24	17.72	16.77	16.50	16.93	17.76	17.57	18.19
1993	18.53	19.38	19.53	19.63	19.22	17.68	16.74	16.46	16.92	17.77	17.54	18.16
1994	18.48	19.32	19.57	19.62	19.20	17.69	16.74	16.47	16.91	17.70	17.53	18.15

1995	18.47	19.33	19.51	19.64	19.21	17.57	16.71	16.46	16.89	17.67	17.51	18.17
1996	18.52	19.32	19.56	19.59	19.17	17.67	16.70	16.45	16.90	17.69	17.52	18.14
1997	18.52	19.23	19.52	19.59	19.17	17.66	16.80	16.56	17.02	17.83	17.67	18.27
1998	18.62	19.45	19.66	19.70	19.31	17.78	16.82	16.56	17.01	17.84	17.59	18.19
1999	18.55	19.37	19.58	19.68	19.29	17.75	16.80	16.53	16.97	17.82	17.58	18.21
2000	18.46	19.37	19.59	19.70	19.29	17.77	16.82	16.55	17.00	17.83	17.64	18.23
2001	18.58	19.42	19.65	19.70	19.28	17.75	16.80	16.55	16.96	17.82	17.50	18.25
2002	18.58	19.42	19.65	19.70	19.30	17.78	16.83	16.55	17.02	17.79	17.64	18.29
2003	18.60	19.43	19.65	19.72	19.28	17.76	16.83	16.57	17.01	17.77	17.60	18.22
2004	18.55	19.44	19.64	19.73	19.28	17.78	16.82	16.58	17.01	17.82	17.63	18.27
2005	18.59	19.44	19.66	19.73	19.31	17.79	16.84	16.58	17.04	17.82	17.63	18.22
2006	18.57	19.44	19.67	19.72	19.32	17.77	16.84	16.58	17.01	17.82	17.65	18.29

Relative Humidity (%)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	0.63	0.65	0.70	0.69	0.79	0.82	0.84	0.90	0.88	0.73	0.69	0.60
Sunshine Hours (Hrs)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	8.78	7.83	8.15	6.86	7.78	5.47	4.17	4.01	5.42	8.85	9.62	9.26

Station Name: Werabessa Nr. Tolie

Station Number: 091022

Runoff (mm/day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.111	0.138	0.157	0.179	0.208	0.334	0.522	1.809	1.932	1.118	0.177	0.129
1986	0.085	0.090	0.098	0.082	0.098	0.964	1.641	1.518	0.500	0.312	0.193	0.151
1987	0.092	0.066	0.099	0.098	0.115	0.342	1.272	1.549	1.583	0.356	0.148	0.090
1988	0.061	0.062	0.020	0.001	0.003	0.097	1.329	2.052	2.200	0.635	0.459	0.201
1989	0.101	0.106	0.097	0.228	0.106	0.476	2.006	3.160	3.194	2.735	0.301	0.190
1990	0.085	0.104	0.049	0.048	0.149	0.766	1.324	3.677	3.616	1.326	0.241	0.134
1991	0.106	0.078	0.107	0.067	0.078	0.302	1.429	2.027	0.771	0.497	0.172	0.136
1992	0.121	0.131	0.068	0.066	0.202	0.550	2.086	4.325	2.296	2.206	0.374	0.203
1993	0.104	0.106	0.080	0.303	0.630	2.328	2.417	5.498	3.236	2.014	0.513	0.231
1994	0.164	0.114	0.050	0.017	0.032	0.200	1.500	2.926	3.969	0.579	0.296	0.131
1995	0.119	0.152	0.043	0.046	0.053	0.123	0.804	3.774	2.467	0.651	0.172	0.090

1996	0.082	0.035	0.123	0.116	0.708	3.801	3.572	4.129	3.994	1.228	0.344	0.198
1997	0.155	0.088	0.093	0.149	0.150	1.031	1.940	1.744	1.215	0.920	0.842	0.476
1998	0.306	0.229	0.245	0.153	0.213	0.408	2.325	4.950	2.753	2.382	0.859	0.627
1999	0.461	0.364	0.331	0.305	0.358	0.667	1.747	2.444	2.625	3.008	0.786	0.813
2000	0.365	0.319	0.273	0.349	0.493	0.916	2.029	3.300	3.563	2.126	0.863	0.766
2001	0.403	0.346	0.401	0.391	0.873	1.254	2.816	3.418	1.644	0.850	0.787	0.560
2002	0.763	0.763	0.767	0.765	0.767	0.927	1.779	2.304	1.485	0.813	0.775	0.772
2003	0.771	0.769	0.768	1.730	1.473	0.272	0.551	1.002	0.666	0.381	0.267	0.774
2004	1.651	0.773	0.776	0.772	0.772	0.933	1.725	2.649	1.719	1.086	0.766	1.789
2005	0.794	0.786	0.813	0.817	0.865	0.857	2.487	4.048	3.030	1.190	0.842	0.766
2006	0.800	0.796	0.805	0.789	0.820	0.933	1.775	3.620	1.969	0.959	0.807	0.788

Precipitation (mm /day)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	0.885	0.159	0.845	4.453	5.748	5.231	8.928	11.273	4.889	1.768	0.144	0.249
1986	0.000	1.982	1.814	4.318	3.001	9.743	7.735	9.389	7.767	0.655	0.001	0.005
1987	0.459	0.895	5.603	1.472	6.120	5.533	8.916	10.312	5.940	1.067	0.123	0.377
1988	0.957	1.886	0.968	1.278	1.314	5.654	9.162	11.523	5.036	3.125	0.000	0.000
1989	0.639	1.718	4.037	4.746	2.344	11.630	10.942	10.190	7.178	1.741	1.140	2.130
1990	0.604	3.766	2.428	2.808	3.401	11.153	12.474	16.056	8.291	0.473	0.649	0.290
1991	0.824	1.718	1.629	1.405	2.285	6.793	9.767	11.329	5.855	0.373	0.000	0.280
1992	1.642	3.642	1.002	2.879	2.182	6.976	11.485	10.701	5.013	2.814	0.630	0.969
1993	0.430	1.268	1.071	6.619	6.983	13.185	11.999	13.403	9.141	9.196	0.489	0.000
1994	0.000	0.308	1.722	2.240	4.197	7.925	12.020	5.824	6.115	0.012	0.390	0.000
1995	0.000	0.272	3.115	2.712	4.065	5.414	15.742	13.361	6.001	0.570	0.165	0.872
1996	1.543	1.304	7.853	3.770	7.289	7.324	12.204	15.457	9.224	1.502	1.791	1.021
1997	2.411	0.044	1.048	6.299	4.554	8.996	9.438	9.161	5.389	2.722	2.728	0.788
1998	1.715	1.960	2.954	1.032	4.687	7.138	10.416	13.100	8.198	8.383	0.634	0.000
1999	0.285	0.257	0.343	0.893	4.211	9.019	9.808	9.290	10.370	4.742	0.071	0.091
2000	0.236	0.008	0.661	4.190	4.197	7.924	7.104	9.878	7.400	3.446	1.192	0.796
2001	0.273	1.016	4.623	2.652	5.106	7.763	12.990	9.719	11.662	2.550	0.257	0.876
2002	1.308	0.944	2.114	5.255	3.596	8.736	15.070	10.331	6.837	0.219	0.026	0.528
2003	1.687	0.734	2.567	7.404	0.553	9.958	11.703	7.955	5.431	1.399	0.141	0.969
2004	1.243	0.892	2.566	5.171	1.235	10.382	10.582	7.354	10.690	3.663	0.264	1.091
2005	1.201	0.302	2.302	4.416	3.131	7.425	11.012	12.348	7.517	2.627	0.732	0.000

2006	0.083	0.447	6.503	4.401	4.538	9.051	11.200	13.245	7.386	2.238	0.320	0.209

Temperature (˚C)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1985	15.10	15.30	16.65	16.45	15.35	14.80	13.55	14.00	13.95	14.15	14.55	14.25
1986	13.95	15.60	15.80	15.75	16.25	14.95	14.25	13.95	14.05	14.05	14.25	14.10
1987	14.35	16.15	16.55	16.30	15.70	15.30	14.75	14.50	14.65	15.30	14.45	14.12
1988	15.45	16.30	16.90	17.00	17.05	15.00	13.90	13.85	14.55	14.35	13.65	13.75
1989	12.75	14.10	15.00	14.90	14.60	13.80	14.15	13.70	14.10	13.85	13.45	14.12
1990	14.40	14.95	15.75	15.55	15.95	14.45	13.75	14.40	13.80	13.95	14.35	13.85
1991	15.15	15.35	15.90	16.70	16.30	14.85	13.55	13.80	14.15	13.50	13.50	13.05
1992	13.65	15.05	15.50	15.50	15.50	14.10	13.15	12.70	12.60	13.40	13.10	13.35
1993	13.45	14.20	14.55	14.50	14.45	13.35	13.05	12.50	12.25	13.85	12.75	12.75
1994	13.05	13.50	15.15	15.30	14.35	13.40	12.80	12.40	12.70	12.85	12.90	12.95
1995	12.95	14.20	14.45	15.30	14.70	14.69	12.10	12.80	12.60	12.85	12.60	12.55
1996	12.85	13.60	14.65	14.15	13.60	12.30	11.45	11.65	12.10	12.50	12.35	12.15
1997	13.10	11.27	13.86	14.23	13.76	12.59	13.90	15.10	15.85	15.65	15.75	15.45
1998	15.95	16.40	17.20	18.00	17.55	16.45	14.70	14.45	15.10	15.85	14.15	13.90
1999	14.55	15.45	15.40	17.15	16.55	15.20	14.65	14.25	14.10	14.95	14.10	14.20
2000	14.48	15.60	17.15	17.20	16.70	15.25	15.05	14.55	14.80	15.50	14.55	14.45
2001	14.55	16.10	16.30	17.25	15.95	14.45	14.10	14.45	14.25	15.90	14.21	15.30
2002	14.95	15.95	17.00	17.00	17.40	16.30	15.55	14.95	15.45	15.80	15.70	15.85
2003	16.00	16.85	17.70	17.70	17.60	15.40	14.90	15.30	15.25	14.90	15.00	14.65
2004	14.95	16.85	17.25	17.50	17.35	15.55	15.10	15.90	15.60	15.90	15.65	15.90
2005	15.65	17.75	18.35	18.40	17.45	16.15	15.70	16.25	15.90	15.90	15.50	15.10
2006	16.15	17.65	17.85	17.60	17.85	15.85	15.85	15.45	15.05	16.00	16.05	16.15

Relative Humidity (%)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RH	0.60	0.62	0.66	0.68	0.73	0.79	0.77	0.83	0.89	0.82	0.69	0.66
Sunshine Hours (Hrs)												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SSH	8.69	7.83	7.91	6.90	7.42	5.36	4.01	3.88	5.34	8.52	9.37	9.10

Appendix E: Statistical characteristics of Regression equation

Statistical characteristics of S –max Regression equation

S-max	Coefficients (β)	F_{cal}	R^2
Intercept	-9.528	3.93	0.72
A	0.018		
P	-0.404		
PET	-0.413		
S	0.112		
Lon	-0.302		
El	4.896		

Statistical characteristics of Alpha(α) Regression equation

Alpha	Coefficients (β)	F_{cal}	R^2
Intercept	-13.863	4.66	0.76
A	-0.237		
P	3.618		
PET	1.653		
S	0.505		
Lon	4.718		
El	-6.449		

Statistical characteristics of Epsilon (ε) Regression equation

Epsilon	Coefficients (β)	F_{cal}	R^2
Intercept	1.851	4.84	0.76
A	-0.063		
P	1.391		
PET	-1.638		
S	0.226		
Lon	-1.725		
El	1.998		