Addis Ababa University

Addis Ababa Institute of Technology

School of Graduate Studies

Development of Water Allocation and Utilization System for Koka Reservoir under Climate Change and Irrigation Development Scenarios

(Case Study Downstream of Koka Dam to Metahara)

A thesis Submitted to the School of Graduate Studies in Partial fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Major Hydraulic Engineering)

By:

Tadesse Fufa

Advisor:

Dr. Belete Berhanu

Addis Ababa University Ethiopia

November, 2016

ADDIS ABABA INSTITUTE OF TECHNOLOGY

School of Civil and Environmental Engineering

Development of Water Allocation and Utilization System for Koka Reservoir under Climate Change and Irrigation Development Scenarios

Submitted in partial fulfillment for the degree of Masters of Science in Civil Engineering

(Major in Hydraulic Engineering)

By: Tadesse Fufa Merga

Approval by Board of Examiners

--	----------------	--------
Chairman (department of graduate committee)	Signature	Date
--	-----------------	--------
Advisor		
--	------------------	-------
Internal Examiner		
--	------------------	-------
External Examiner		

Acknowledgement

My deep appreciation goes to my advisor Dr. Belete Berhanu of Addis Ababa University for his encouragement, advice, support and, his valuable guidance throughout the course of this study and, all his contribution through materials support and also his trust and confidence makes me to work on my interest topic.

I would like to acknowledge the Ministry of Water, Irrigation and Electricity (MoWIE) particularly hydrology, GIS department and Library; Oromia Water works & Design enterprise (OWWDE); Ethiopian Electric Power Utility (EEPU) particularly Ato Andarge for their appreciable supporting by providing me hydrological data and other reference materials; and the Ethiopia Meteorological Service Agency for providing me the relevant data and information required free of payment.

My deepest thank is to my beloved parents. Their unconditional love, inspiration and always encouraging me, support me, and give me strength to go through my study.

A special group of friends also supported me through their friendship and professional help; among them I would like to mention: Legesse S. who stands with me through contribution his appreciable ideas.

Above all, sincere thanks go to the Almighty God for making this thesis success. This day what God have done for me is really beyond what I can imagine and I have dreamt. Indeed, thanks for everything you have been doing for me.

ABSTRACT

The subject of climate changing is one of the central issues facing the atmospheric sciences community today. The most profound effect of such changes may be by altering in hydrologic cycles and changes in regional water availability, within a context of increasing water scarcity; climate change threatens to worsen the current supply-demand imbalance. This Study was conducted in Upper Awash Catchment in the Central Rift Valley of Ethiopia, to assess the consequences of climate change and irrigation expansion on current and future water use practices of koka reservoir release for its downstream irrigations water use schemes using a WEAP model. Records of hydrology, meteorology, and irrigation water supply for the study area have been statistically tested and arranged as an input data source to fit the model. Meteorological and grid climatic data were corrected with multi-regression and distribution mapping (DM) method respectively and the two data were also correlated with each other. The demand and the supply for the baseline and the future development activities of the area were compared in climate change and irrigation expansion scenarios. This thesis analyses first the model calibration, validation and its statistical measure were seen and the result shows that it is very good and the model can simulate the current and the future scenarios. The results of this analysis revealed that the reservoir capacity fluctuating between the minimum operating level and the maximum outflow level; as the result unless the minimum flow requirements are maintained, the future irrigation demands are unmet in more or less. For the climate change scenario, the volume of reservoir evaporation in the baseline period was 404.5Mm^3 and for the coming first and second 35 years the volume of evaporations are 421.4 and 426.8Mm^3 respectively. While compared with the baseline period, in the first 35 year the reservoir evaporation increased by 16.9Mm^3 and 22.3Mm^3 for the coming two 35 years. The irrigation expansions scenario indicated that from the total 947.7Mm^3 demand of irrigation for the current existing command areas, the supply delivered was 946.7Mm^3. The planned irrigation expansions demand for the future time period is 1659.1Mm^3 and the supply delivered 1649.3Mm^3. Relating the future with the baseline period the demand and the unmet were increased by 711.4 Mm^3 and 8.9Mm^3 respectively. It is necessary that more detailed water resource assessment should be done, including sustainable abstractions.

Keywords: Koka reservoir, climate change, irrigation development, water allocation and WEAP model.

Table Contents

List of Figures

List of Tables

List of Abbreviations

ARBWA	Awash River Basin Water Audit
COSMO	Consortium for Small Scale Modeling
CDF	Cumulative Distribution Function
DEM	Digital Elevation Model
DM	Distribution Mapping
EEPU	Ethiopian Electric Power Utility
GDP	Gross Domestic Product
GTP	Growth and Transformation Plan
FAO	Food and Agriculture Organization
GIS	Geographical Information System
Ha	Hectare
ICTZ	Inter-Tropical Convergence Zone
IPCC	Intergovernmental Panel on Climate Change
Kc	Crop coefficient
kms	Kilometers
LOCI	Local Intensity Correction
m	Meter
masl	Mean Above Sea Level
Mm3	Million meter cube
M3/s	Meter Cube per Second
OWWDSE	Oromia Water Works Design and Supervision Enterprise
MoWIE	Ministry of Water, Irrigation and Electricity
NMSA	National Meteorological Services Agency
NSE	Nash-Sutcliffe Efficiency
R2	Coefficient of Determination
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
PIK	Post Dam Institute for Climate Impact Study
RMSE	Root Mean Square Error
SEI	Stockholm Environment Institute
SN	Scenarios
SRES	Special Report on Emission Scenario
WWDSE	Water Works Design and Supervision Enterprise
WEAP	Water Evaluation and Planning System

1.0 INTRODUCTION

1.1Background

Water is not only influenced by human activities, but also by natural factors, such as climate change. Hence, the impact of climate change on water resources is the most crucial research agenda in worldwide level today (IPCC, 2007). This change affecting certain components of the hydrological cycle, especially precipitation and temperature, this alters the spatial and temporal availability of water resources. It can change flow magnitude; variability and timing of the main flow event are among the most frequently mentioned hydrological issues (Habtom, 2009). Climate variations can also affect the use of agricultural land associated with irrigation water demand systems (kinfe, 1999).

According to Intergovernmental Panel on Climate Change (IPCC), 2007d, "Observational evidence from all continents and most oceans shows that many natural systems were being affected by regional climate changes, particularly temperature increases and decreasing of precipitation. The developing countries, such as Ethiopia is more vulnerable to climate change because of its economy is extensively dependent on agriculture and natural resources that are sensitive to climate change, so the impact of climate change has far reached in Ethiopia(Marius, 2009).

Water demand is increasing as a result of the rapid population growth, agricultural expansion, industrial development, and higher standards of living in addition to climate change (Ahmed et al, 2015). Awash Basin is one of the largest basins in the country with high population pressure, degradation of land and highly dependent on agricultural economy. This increase in demand for the limited water resources puts pressure to improve the allocation of scarce water. Because irrigation is the major water consumer sector in the world as well as in Ethiopia, so it is important to ensure efficient water allocation (Ahmed et al, 2015).

The Awash Basin has been generally divided in different major Sub-basins according to their physiographic point of view, among them upper Sub-basin is the major basin which includes the main source of water for the whole Awash with some other tributaries. The Koka reservoir is one of the proposed projects included in the upper Sub-basin. The koka dam is the second next to

Aba semuel dam commissioned in Ethiopia, in 1960 primarily for hydropower generation; now it is used as a multi-purpose dam for electric power generation and downstream irrigation development uses. The implementation of this reservoir was to minimize the food scarcity for the surrounding area. Generally, the introduction of irrigation made farmers feel more secure about their basic food supply and enabled them to diversify their crops based on local market demand and export opportunities.

Studies shows there are uncertainty related to climate change in Ethiopia, and then quantifying, the existing and upcoming reservoirs capacity in related to climate variability needs urgent scientific intervention. Therefore, quantitative estimates of hydrologic effects of climate change and irrigation expansions are essential for understanding and solving the potential water resource management problems associated with water allocation for irrigation as well as for future water resource planning, reservoir design and management, and protection of the natural environment.

To address this need, the study assessed the impact of climate change and irrigation expansion on available water resources of koka reservoir in the upper sub-basin of the Awash using a decision support system known as the Water Evaluation and Planning (WEAP) Model. WEAP is a systematic framework developed for the evaluation of climate change and other drivers that water managers commonly challenging (Azman et al., 2007). Indeed, WEAP 21 model is one of the useful tools for the integrated water resources management and it can be used as a database, forecasting and also as a policy analysis tool, depending on the focus of the study. In this regard, the applicability of WEAP was assessing the impact of climate change as well as the irrigation development on water allocation of koka reservoir was tested in this study.

1.2 Statement of the Problem

It has been widely accepted that global warming, due to the enhancing greenhouse gas effect forces an increasing warning on water resources. Although climate change is expected to affecting many sectors of the natural and man-made environment, water related development is considered the most critical affected sector related with climate change. According to studies were conducted in Abay and Awash River basins show that the basins are sensitive to climate change (Endalkachew, 2012).

The Awash basin is known by population density and intensively utilized river basin in Ethiopia due to its strategic location, access roads, and available land and water resources (Zemede, 2011). Irrigation potential of the Awash basin is estimated to be 206,000ha (FAO and MoWIE, 2013). The current irrigated area of the basin were 165,031ha in 2012 is expected to increase to about 338,300ha by the end of 2030. These will be occurs under small scale irrigation schemes about 198,631ha and 139,627ha were under medium and large (FAO and MoWIE, 2013).

Extensive irrigation schemes have been functional for many years following the construction of the main structure of Koka dam in 1960, which depend largely on stored waters released from koka reservoir for their irrigation, rearing of livestock and other domestic activities. Storage of the Koka Reservoir is estimated to be decreasing due to irrigation expansion in addition to sedimentation (Berhanu, 2008). There is some small and large scale irrigation projects are currently planned, designed and on the implementations like (Fentale irrigation project and Welinchiti irrigation project) expansion of Wonji and Metehara sugar plantation are being accomplished. This ongoing, reduction in reservoir capacity and increasing demand need, the water management of the reservoir was becoming very difficult (Zemede, 2011). Hence, reservoirs water level currently operating irrigation is going down and causing scarcity of demand to serve throughout the season in the coming period. Therefore climate change impact and downstream irrigation development were additionally the major one that should be seen and considered in the evaluation of koka reservoir water allocation which is the main sources of, irrigation and some other supply of the surrounding area.

1.3 Research questions

- What are the effects of climate change on the available reservoir water?
- How much irrigation water required downstream of the reservoir?
- What techniques could be used to improve downstream water requirement allocation?

1.4 Objectives of the Study

1.4.1 General objective

The main aim of this thesis is to develop effective water allocation system for Koka reservoir under climate change and downstream irrigation expansion scenarios using WEAP model.

1.4.2 Specific objectives

- To evaluate impact of climate change on reservoir water evaporation
- To evaluate capacity of reservoir to support downstream irrigation development
- To develop effective water allocation techniques under climate change

1.5 Limitation of the Study

The study focuses on the upper awash catchment respond to major stresses of climate change and irrigation expansion in terms of the water availability at the catchment scale. Aiming at the objective, this study did not take into account the other development; rather than irrigation water allocation at downstream of the reservoir under the two scenarios. Moreover, it was beyond the scope of this study to identify the problem of flooding, sediment and hydropower if it may be happened under future scenarios troubles. The study also did not take into account the effect of climate change on the water quality.

1.6 Study Approach

The framework of the study is presented in Figure 1.1

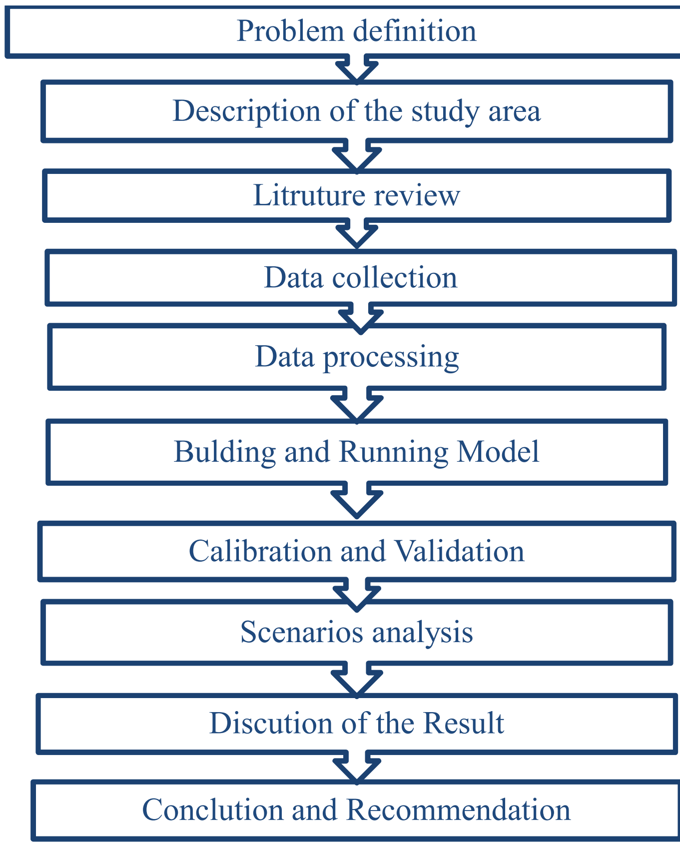


Figure 1. 1 Framework of the study

1.7 Thesis Outline

This thesis contains six chapters and organized as follows: Chapter one is an introduction to the study. Chapter two reports on a literature review about the subject matter. Chapter three describes the study area and methodology applied. Chapter four is about data processing in this research and WEAP model setup. In chapter five the results were shown and discussed. At the end in Chapter six conclusions and recommendations were seen.

2.0 LITERATURE REVIEW

Climate is "average" weather (current atmospheric condition) for a given place or a region. It describes typical weather conditions for a given area based on long-term averages, usually decades or longer. For example, it could show up a change in climate normal (expected average values for temperature and precipitation) (IPCC, 2007).

2.1 Climate Change

Climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods, whether due to natural variability or as a result of human activity (IPCC, 2007).

Climate change is facing the entire world nowadays. It is now widely received that climate change is by now happening and further change is unavoidable; the global average combined land and ocean surface temperature data calculated shows a warming of 0.85oc over the period 1880 to 2012 (IPCC, 2014). This is more strongly after 1970; many studies discovery specifies that most of the increase in average global surface temperature over the last 50 years is attributable by human activities (Endalkachew, 2012).

It was estimated that, change and sea level is expected to rise at rate of about 1.7 mm/yr as the ocean expands as heat is gradually diffused downwards in the ocean (Endalkachew, 2012). The IPCC also notes that observations over the past century shows, changes were occurring in the amount, intensity, frequency and types of precipitation globally (IPCC, 2007a).

The IPCC was established in 1988 by the World Meteorological Organization and the United Nations Environment Program, and its role is to “assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation”. Among the different assessment that were carried out by the IPCC, the most recent which published in 2007, states the projected global surface warming lies within the range 0.6 to 4.0oc, whereas the projected see level rise lies within the range 18 to 59 cm at the end of next century (IPCC, 2007a).

The major effect of climate change is increasing temperatures which will in turn increase evapotranspiration and thus crop water demand (FAO and MoWIE, 2013). The attempt to estimate the effect of temperature increase on irrigation water demand showed that water demand per hectare increased by about 2.15% in two decades (2030) and 4.38% in four decades (2050). Therefore, the effect of climate change on irrigation water demand is ignored in the scenario analysis although an attempt could be made in simulating.

2.2 Climate Change in Ethiopia

For the past four decades, the average annual temperature in Ethiopia has been increasing by 0.37oC every ten years, which is slightly lower than the average global temperature rising (Emerta, 2013). According to Emerta, the greater part of the temperature rise was observed during the second half of the 1990's and temperature rise is more pronounced in the dry and hot spots of the country, which are located in the northern, northeastern, and eastern parts of the country. The lowland areas are the most affected, as these areas are largely dry and exposed to flooding during extreme precipitation in the highlands.

Future temperature projections of the IPCC mid-range scenario show that the mean annual temperature will increase in the range of 0.9 to 1.1ºC by 2030, in the range of 1.7 to 2.1ºC by 2050, and in the range of 2.7 to 3.4ºC by 2080 in Ethiopia compared to the 1961 to 1990 (Emerta, 2013).

However the country has both dry and wet periods over the past four decades, precipitation has a general decreasing trend since the 1990s (Abayneh, 2011). The decrease in precipitation has multiple effects on water availability for irrigation and other farming uses, especially in the north, northeastern, and eastern lowlands of the country. The average change in rainfall is projected to be in the range of 1.4 to 4.5 percent, 3.1 to 8.4 percent, and 5.1 to 13.8 percent over 20, 30, and 50 years, respectively, compared to the 1961 to 1990 usual. According to Abayneh, the overall trend in the entire country is more or less constant.

Related with rainfall and temperature change and variability, there was a recurrent draught and flood events in the country. There was also observation of water level rise and dry up of lakes in some parts of the country depending on the general trend of the temperature and rainfall pattern of the regions.

2.3 Climate Change in the Study Area

Some studies conducted in Abay and Awash basins shows that the basins are climate sensitive. The catchments under consideration are found in the Awash basin; therefore climate change should be considered to evaluate the present and future condition of the main water supply source of Koka reservoir for downstream irrigation development demand.

2.4 Climate Change Impacts on Water Resource and Reservoir

Water is interacted in all components of the climate system. Findings of the IPCC 2001, strongly suggests that water resource respond to global warning in ways that negatively impacted the water availability and water supplies. The reduction in the runoff volume will lead to the decrease in the inflow to the reservoirs accordingly; longer period might be required to fill the reservoir. As the result of the increase in temperature the rate of evaporation from the reservoir open water surface may increase and this may create the reservoir to fail to supply at least the required amount of demand water because of its depletion or decrease in the active storage water level (Habtom, 2009).

The most dominant climate drivers for water availability are precipitation, temperature and evaporative (determined by net radiation at the ground, atmospheric humidity and wind speed, and temperature). Water evaporated from the surface and transpired from plants rises with air temperature. These make large reductions in runoff and increase water shortages as a result of a combination of increased evaporation and decreased precipitation. The frequency and severity of droughts could increase in some areas as a result of a decrease in rainfall, more frequent dry spells, and higher ET (Kenneth et al. 1997).

2.5 Climate Scenarios

Demographic development, Socio-economic development, technological change, energy and land use, and emission of greenhouse gases and air pollutants are the driving force for the future climate change may occur with respect to a range of variables (IPCC, 2000). These future scenarios of forcing agents (e.g., greenhouse gases and aerosols) are served in to the climate models as input, and the output of these climate models is further used in climate change analysis and hence, the assessment of impacts, adaptation and mitigation. Several sets of scenarios including the scenarios from the Special Report on Emission Scenarios (SRES) and, more recently, the Representative Concentration Pathways (Agizew et al.; 2015) are used in climate research. In the following section, brief descriptions of the various scenarios were presented.

SRES – Emission scenarios

The Intergovernmental Panel on Climate Change (IPCC) a Special Report on Emission Scenarios in 2000 and it has been used to make projections of possible future change and thus, given the name SRES scenarios (IPCC, 2000). IPCC Third Assessment Report (TAR) and Fourth Assessment Report (AR4), published in 2001 and 2007 respectively, were based on these SRES scenarios.

SRES scenarios cover a wide range of the main driving forces of future emissions, from demographic to technological and economic developments. The scenarios include different future developments that might influence greenhouse gas (GHG) sources. Among all the SRES scenarios, four pointer scenarios (A1, A2, B1 and B2) are often used(Agizew et al.; 2015). The following paragraph briefly describes each of the scenarios family:

The A1 and B1 scenario family has similar emphasize describes a future world very rapid economic growth, global population that peaks in mid-century and declines then after, and the rapid introduction of new and more efficient technologies, but B1deffirent with rapid changes in economic structures toward a service and information economy, with reduction in material intensity, and the introduction of clean and resource-efficient technologies (Haileyesus, 2011). In general the similarity of the two scenarios are ongoing globalization and project a homogeneous world, while the A2 and B2 scenarios put emphasis on social, economic, and environmental development on regional and local basis and project a heterogeneous world. A2 scenario describes Fertility patterns across regions converge very slowly, which results in continuously increasing global population, economic developments are primarily regionally oriented and per capital economic growth and technological change are more fragmented and slower than in other storylines. B2 scenario family is characterized by a continuously increasing population, but at a slower rate than in A2. According to (Haileyesus, 2011) there are three subsets of A1family which are distinguished by their technological emphasis: fossil intensive (A1F1), non-fossil energy sources (A1T), or a balance across all sources (A1B). In the case of A1B scenario, balanced is defend as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end-use technologies.

RCP – Emission scenarios

Recently there has been an increasing interest in scenarios that clearly determine the impact of different climate-policies in addition to the no-climate-policy scenarios such as SRES (Agizew et al.; 2015). The need for new scenarios encouraged the IPCC to request scientific communities to develop a new set of scenarios for the assessment of future climate change. Therefore a set of new scenarios is constructed containing emission, concentration and land-use trajectories referred to as "Representative Concentration Pathways" (RCP). In its name, the word "representative" signifies that this set of RCPs should be well-matched with the full range of emission scenarios (with and without climate policy) available in the current scientific literature. The word "concentration" emphasizes that instead of emissions, concentrations are used as the primary product of the RCPs, designed as input to climate models. There are four RCPs scenarios existing. Among, the four RCP dynamically down scaled regional climate multi-model outputs of CORDEX-Africa which were (RCP 2.6, RCP 4.5, RCP 6 and RCP 8.5) the RCP 8.5 is used and selected because the concentrations emission of CO2 is higher than when compared to the other RCPs. Comparison of CO2 concentrations obtained by RCP emission scenarios are indicated in Figure 2.1.

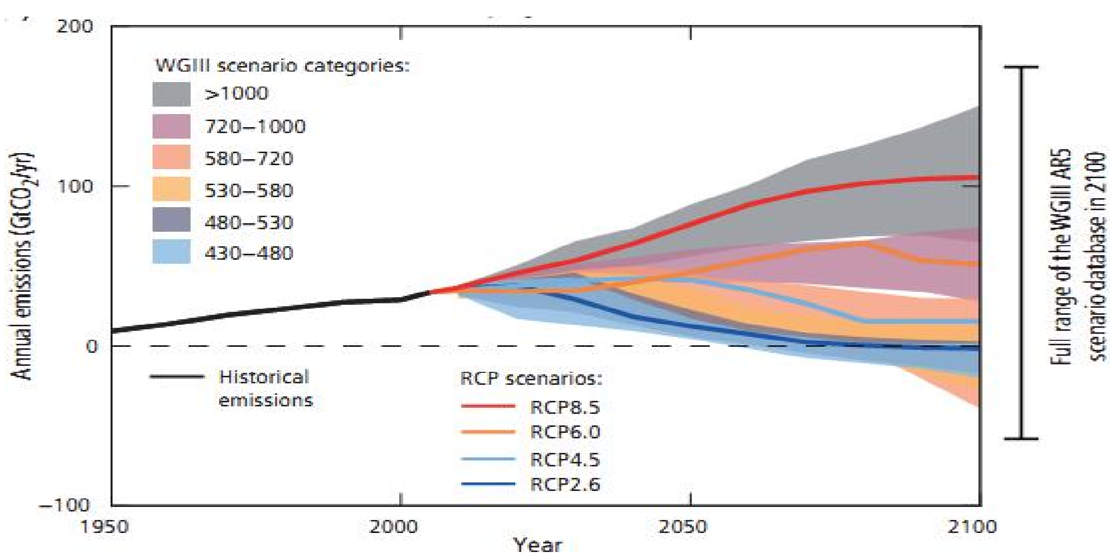


Figure 2. 1 Annual anthropogenic CO2 emission scenarios (IPCC, 2014)

2.6 Irrigation Schemes in the Awash River Basin

The Awash River Basin is the most important river basin in Ethiopia, and serves for 15.71 million populations and distributed accordingly into Addis Ababa (22.73%), Afar (9.85%), Amhara (18.74%), Dire Dawa (2.71%), Oromia (37.5%), SNNPR (0.9%) and Somali (7.55%) (FAO and MoWE, 2013). The main population centers lie in the upper part of the basin mainly above an elevation of 1,500m because of its strategically location (zemede, 2011).

The Awash Basin accounts for about half of the national irrigation schemes. Schemes currently operative under public enterprises are transferred to either the communities in the surrounding areas or to private developers (Abebe et al, 2011). In most cases however, the communities themselves did not use the irrigated land. Therefore, some investors made arrangements with the communities and are currently operating the farms, growing mainly cotton and millet. Large areas of irrigated land have been left fallow; the reasons behind this are lack of capacity at the communities level and a lack of capacity at regional governments to implement and control land and water management policies; this resulted in conflict between different clans because irrigation water demand need at different time. As a result, also private investors backed away from investing in the development and operation of these farms area (Awulachew et al, 2007).

By now the Awash River is as good as over committed with no possibility for further development but, the construction of additional dams at Kesem and Tandaho help to minimize the water stress and intensive use of the river water that may come for the future.

According to the growth and transformation plan (GTP) of the federal and regional state, 89,000 ha currently under irrigation and further 200,000 ha areas of suitable land available for irrigation in the awash river basin (Hague, 2013). The basin homes the largest irrigations schemes of the GTP and any future abstraction of water upstream should ensure the availability of water to the GTP projects. The total area of the upper Awash catchment is 1,937,323ha Out of the total surface area of the sub-basin 66.6% (1,290,313.95ha) used for agriculture production. This displays that the sub basin is highly exploited for the production of different crops (according OWWDSE, 2014) and more than 24,000ha land is irrigated still now from the only water source of Awash River (Berhanu, 2008). Although the basin is known as the most irrigated basin of the country, there are still a multiple of irrigation expansion projects planned and being implemented on the basin. Currently, the irrigation schemes directly getting water from koka reservoir are:

Table 2. 1 Existing and planned irrigation schemes under koka Dam

No	Project Name	Actual irrigated (ha)	Planned irrigation (ha)	Total (ha)
1	Wonji sugar state	7022	4560	11582
2	Tibila Irrigation Project	923	5714	7000
3	Merti-Nura Era	3672	……	3672
4	BosetFentale	5880	12120	18000
5	Metehara Sugar Estate	10244	……	10244
6	A_Awash	8525	……	8525
	Total	36,266	22,394	58,660

Source: FAO and ARBWA document (2013)

2.7 Previous Studies of the Area

Proceeding to the beginning of any activity, review of earlier work is very important to get general understanding of the area and to minimize the time and cost that would have been spent for collecting related information. Accordingly, previous studies and data aimed for different purposes, the current study has been collected from different organizations. Most of the previous studies and more general information considered were:

2.7.1 Awash basin master plan by Halcrow (1989)

Most studies on the Awash River basin were based on modeling results of Halcrow (1989) considering the following broad levels of irrigation development scenarios.

i. Sustaining the irrigated areas of 68800ha, of which (Upper valley 23300 ha, Middle valley 19900 ha and lower valley 25600ha).
ii. Expanding irrigation up to 40 years by setting the following Scenarios:
    - Scenario I: Koka raised by three meters and Kesem constructed.
    - Scenario II: Koka raised by three meters and Tendaho and Kesem constructed.
iii. Long term expansion beyond the level determined by the economic viability, to determine the potential limit of expansion in irrigation.

According to Halcrow 1989 the major source of irrigation water for various demands in basin was the release from Koka reservoir. The live storage required at Koka to sustain 68800ha is 850MMC power generations being priority (or 660 MMC irrigation is being priority) will be reached in 2008 assuming annual sedimentation rate of 25Mm3/year. Mean that giving priority either for hydropower or irrigation by considering annual sedimentation inflow rate until 2008 the 68800ha of demand land are sustained.

2.7.2 Booker Tate and MCE Studies

Booker Tate & MCE (2003) Study was on Wonji/Shao sugar factory expansion, have reviewed and updated the Feasibility study on Irrigation and Agricultural land Extension covered the following topics.

1. **River inflow in to Koka Reservoir**

They estimated monthly inflow of Koka dam (Mm3) using the Halcrow (1989) regression equation which was based on the measured flow of Awash river at Hombole (Mm3) and river at Mojo (Mm3). The equation is:

$Q_{Koka} = 1.065Q_{Hombole}+1.180Q_{Mojo}$…………………….............................………………....2.1

2. **Evaporation estimated from Koka reservoir**

The basis for the estimation of evaporation from reservoir was the climatic data collected from nearby stations like Wonji, Nazareth (Adama) and Koka stations. For reliable wind speed data the Ziway station data was used rather than Nazareth (Adama) station. The estimation of evaporation from reservoir was undertaken by Penman method.

Table 2. 2 Booker Tate & MCE (2003) Estimated of Koka Reservoir Evaporation (mm)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Koka Reservoir	168.6	163.7	192.4	185.9	200.4	190.6	166.2	167.2	164.8	178.2	168.7	165.5	2112

Source: Welenchiti Feasibility Report (WWDSE, 2015)

3. Expansion impact assessment on reservoir

To assess the impact of the irrigation expansion on the power generation of reservoir, Booker Tate & MCE established a water balance model that simulates the existing release at Koka. They used Hydro 10 model with two reservoir operation procedures:

- Rule A - when storage is < 25% of the capacity (1590.7m amsl), power demand is reduced to 50% of normal.
- Rule B - the critical level is different in each month, varying from 6.7% to 48% of capacity, and power demand is reduced to 75% of normal when storage is below the curve. This rule is based on typical water level patterns in the reservoir during the period of record.

The scenarios used the reduced reservoir capacity estimated for 2010, 2020 and 2030, and they tested with both the current irrigation demand plus potential expansion land. They concluded that the main impact on water availability is the declining capacity of Koka reservoir. With the existing 2003 level of irrigation demand the reliable energy production potential at the three stations is expected to decline by 30% by the year 2030, with expanded irrigation it would decline by 42% by the year 2030.

2.7.3 Ministry of water resources (2005)

According to the 2005 investigation of MoWIE the annual irrigation area is increased to 50,000ha which is 23% lower than the 1989 development. Major reduction in irrigation area has been observed in the last 16 years (1990-2005) in the lower and middle. From this preliminary analysis one can suppose that expansion of the existing land by about 16000ha for cotton or about 8000ha for sugar cane will bring back to the 1989 development level. Based on Halcrow prediction the development of 68800ha could be sustained up to the year 1998 without additional storage. In both cases the raising of Koka dam by 3m which adds about 615MMC of live storage is considered. The construction of Kesem and Tendaho dams are included in this scenario. They indicated that a maximum development expansion in the lower valley with Tendaho dam constructed is 36900ha, adding with the 1989 existing irrigation reach 62500ha.

Table 2. 3 Existing and potential net irrigation areas (ha) as proposed by Halcrow with respect to MoWIE

Sub-basin	Exiting1989 (Halcrow)	Existing 2005 MoWIE	Expansion proposed Halcrow1989	Expansion proposed MoWIE2005	Total Halcrow1989	Total MoWIE2005
Upper valley	23284	23504	10625	17903	33910	41407
Middle valley	21896	14591	36320	20000	58216	34591
Lower valley	25600	11600	36900	48000	62500	59600
Total	70,780	49,695	83,846	85,903	154,626	135,598

Source: Feasibility study of Wonji/Showa expansion WWDSE 2005.

The above table illustrations that the 2005 MoWIE expansion proposed was more extensive in the upper and lower valleys as compared to the Halcrow proposal. The total expansion of the 2005 proposal was 85,903 ha approaching the potential Halcrow expansion of 83,846 ha.

The Halcrow expansion pre-supposes the raising of the Koka dam along with construction of Tendaho and Kessem dams, whereas the MoWIE expansion was based on the construction of the Tendaho and Kessem dams both in 2008.

2.8 Water Allocation Model

WEAP Model: Water Resources System Simulation modeling helps to understand the relationship between available water for demand under existing conditions and future development scenarios. In particular, the water resource modeling is used to identify areas of conflict caused by water scarcity.

WEAP is one of the Water Evaluation and Planning System model and is originally developed by the Stockholm Environment Institute at Boston, USA (SEI, 2015). It represents the system in terms of its various supply sources (e.g. rivers, streams, groundwater, and reservoirs); withdrawal, transmission and wastewater treatment facilities; ecosystem requirements, water demands and pollution generation. The data structure and level of detail may be easily modified to meet the requirements of a particular analysis, and to reflect the limits imposed by restricted data.

The WEAP model applications generally include several steps. The study description sets up time frame, spatial boundary, system components and arrangement of the problem. The Current Accounts, which can be viewed as a calibration steps in the development of an application, provide the actual water demand, resources and supplies for the system. Scenarios built on the Current Accounts and allow one to investigate the impact of alternative assumptions or policies on future water availability and use. Finally, the scenarios are evaluated with regard to water sufficiency, benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables (SEI, 2015). So for this study WEAP model is selected because of its inclusive, straightforward, easy-to-use, flexible data input, interfacing with Excel (import-and export) and Possibility to model the impact of climate change scenarios on reservoir. As a database, WEAP provides a system for maintaining water demand and supply information. As a forecasting tool, WEAP simulates water demand, supply, flows, storage and discharge.

3.0 MATERIALS AND METHODOLOGY

3.1 Description of the Study Area

Awash River basin is one of the major twelve basins in Ethiopia. The basin has a total catchment area of 115,560km^2 and total length of 1200km (FAO and MoWIE, 2013). The Awash River originates from Becho, West of Addis Ababa in the central Ethiopian Highland with an elevation up to 3000masl. It flows down in the Rift Valley after passing through Koka Reservoir and where it terminates in Lake Abe at 250masl near the border of Ethiopia (H.Y. Gebretsadik et al, 2016). It is surrounded to the north by the Danakil River Basin, to the west by the Abbay River Basin, to the south-west by the Omo-Gibe and Rift Valley Lakes River Basins, to the south-east by the WabiShebele River Basin and to the east by the Republic of Djibouti, the Somali Democratic Republic and the Aysha Dray Basin. The basin lies between longitude 7°52'12" N and 12°08'24" N, and latitude 37°56'24" E and 43°17'24" E. It crosses three administrative regions, Oromiya, Afar and Amhara, and two administrative cities, Addis Ababa and Dire Dawa (zemede, 2011).

The Koka reservoir is located in the upper awash sub basin at the central parts of the oromia region government in East Shoa zone. It located at 80 km south east of Addis Ababa between (8^{o}26'N and 39^{o}02'E) at 1590masl. The koka dam is the second hydro-electric power plant next to Aba samuel dam in Ethiopia, went into operation in 1960. It was primarily for hydropower generation, but now works as a multi-purpose dam in addition to electricity it is used for downstream irrigation demand supply and operated by Ethiopian Electric Power Utility (EEPU).

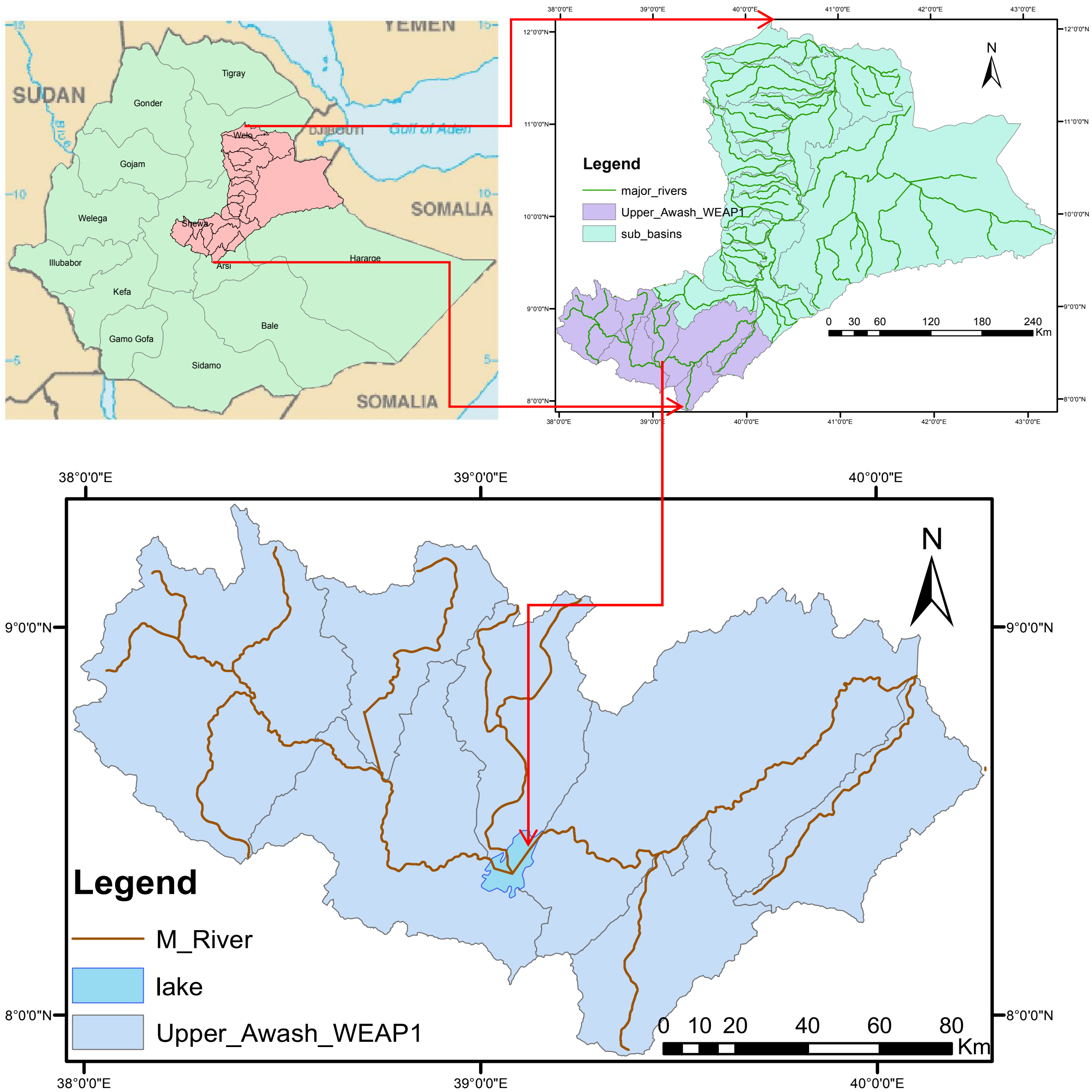


Figure 3. 1 Location of koka reservoir within upstream basin

3.1.1 Physical Characteristics of the Basin

The Awash River Basin divided into two main physiographic sections the Ethiopian plateau and the Rift Valley (FAO and MoWIE, 2013). The Ethiopian plateau topography is generally flat with elevations between 2,500masl to 2,000masl. The lowest elevation of the plateau is commonly considered to be at 1,500m.

On bases of physical and socio-economic factors, the basin is divided into four zones referencing mean above sea level (masl). Thus, Upper Valley (above 1,500m), Middle Valley (between 1,500m to 1,000m), and Lower Valley (below 1,000m) as well as the Eastern Catchment between 2,500m to 1,000m) that joins Awash River just before it ends at lake Abe. The valleys are part of the Great Rift Valley System which the Rift Valley part of the Awash Basin being seismically active. The Lower Awash Valley comprises the deltaic alluvial plains in the Tendaho, Asaita, and Dit Behri area. This basin contains important economic activities for the country such as power generation, mining, agriculture and tourism.

Although the alluvial plains in the Rift Valley are relatively wide, there are deeply carved river valleys and volcanic masses rising to 3,850m. The physical geography of the Awash Basin is dominated by the underlying geology and lithology. The plateau is separated from Rift Valley by a series of major fault scarps producing a steep escarpment at the western edge of the valley.

3.1.2 Climate

The climate of the Awash Basin is influenced by the Inter-Tropical Convergence Zone (ICTZ), a zone of low pressure that characters the convergence of dry tropical easterly and moist south easterly winds is responsible for seasonal rainfall distribution within the basin as a result of annual migration of the ITC between May and November produces the major rainfall in Ethiopia. Upper Awash region gets its main rainy season in July and August when ITCZ is positioned in Northern Ethiopia. The weak high pressure system over Ethiopia has a south-east and North West axis, which depresses the movement of ITCZ southward from Upper Awash region and run parallel to it. Therefore, the region from July to August is under the influence of the dry north east or the wet south-west winds; this makes rainfall in the Middle Awash region smaller than the rest of Ethiopia and irregular.

3.1.2.1 Rainfall

The annual rainfall distribution resulting from this cycle is shown most clearly in the two distinct rainy periods which are characteristic of the northern plains of the basin. The western part of the basin has mono-modal rainfall with the peak rainfall in July to August while the eastern part is dominated by bi-modal rainfall in Belg (short) and Kiremt (long) rainfall peaks. The major peak located in the Awash is in July to August and the minor peak is in October to December months.

On the high plateau to the west of Addis Ababa, the rainfall distribution shows a continuous increase from the small rains to the summer peak rainfall. The distribution of rainfall over the highland areas is modified by orographic effects and is significantly related with altitude. According to the following description, the annual and monthly rainfalls are characterized by high variability (Figure 3.2). Spatially, annual rainfall varies from 508.9mm at Metehara towards the east of the basin to 1206.6mm in the highlands west of Addis Ababa, referring to upper part of the basin.

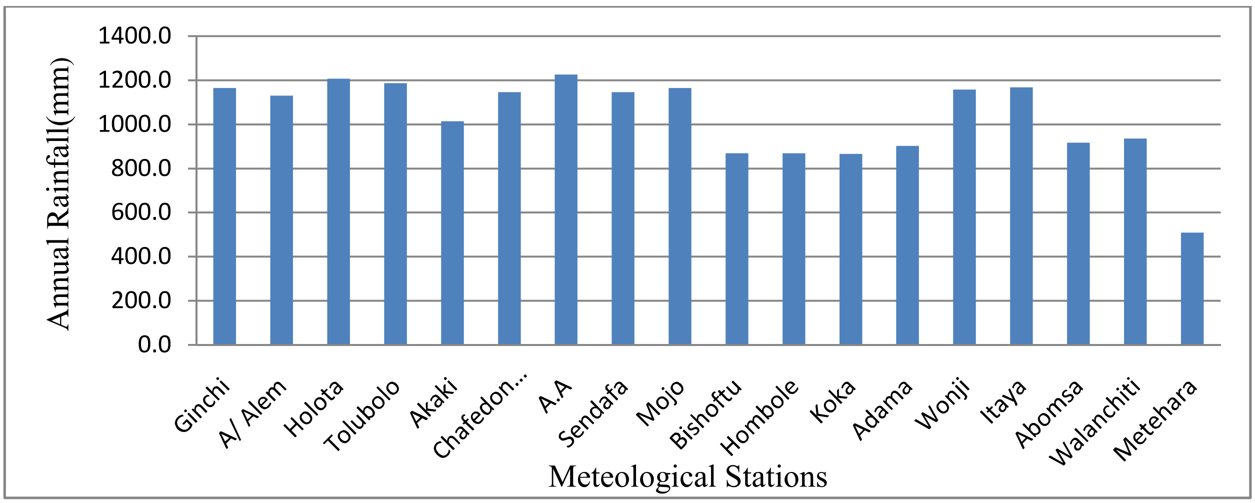


Figure 3. 2 Annual rainfall in the basin

3.1.2.2 Temperature

The temperature varies considerably in the basin within altitude. The mean annual maximum temperature of the study area varies from 22.84^{O}C to 33.68^{O}C; while the mean minimum temperature varies from 6.54^{O}C to 17^{O}C. The mean annual temperature of the area estimated according to the data of the fourteen stations varies from 14.69^{O}C to 25.34^{O}C.

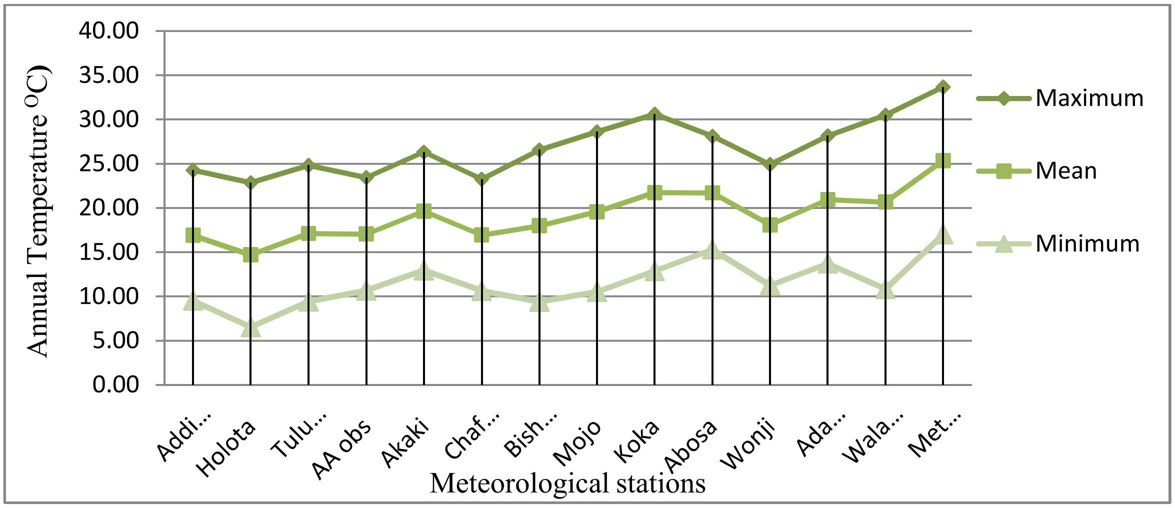


Figure 3. 3 Annual mean temperature in the basin

This shows that a strong relationship between temperature and altitude as summarized in table blow which shows means temperatures in the growing season related to altitude.

Table 3. 1 Temperature and Altitude in the Awash River Basin

Mean Temperature (°C)	Altitude (m)	Mean Temperature (°C)	Altitude (m)
> 27.5	< 450	15 - 17	2 250 – 2 550
25 - 27.5	450–900	12 - 15	2 550 - 3 100
22.5 - 25	900–1 400	10 - 12	3 100 – 3 400
20 - 22.5	1400–1 750	7.5 - 10	3 400 – 3 850
17-20	1750-2250	< 7.5	> 3850

Source: Zemede (2011)

3.1.2.3 Relative humidity

Relative humidity has been measured at different stations in or adjacent to the basin. There is relatively little variation over the basin with the mean annual relative humidity varying from 64.61% in Addis Ababa to 77.07% at Metehara. Seasonal variation, expected would be higher in the lower rainfall areas.

3.1.3 Land Use and Soil Type

The land use condition in the upper awash catchments includes mainly of cultivated agricultural land, grassland, Water body and forest land, rural and urban settlements. It is estimated that 62% is rain fed cultivated, 4.13% is irrigation cultivated, 15.86% is grassland, and 9.98% is Urban or Exposed Rock. In the upper most part where there is high rainfall, land use is complete in May with barley and teff. Steeper slopes are heavily wooded with natural acacia and eucalyptus. On the lower most part, however, rainfall is too unreliable and the sparse dry acacia scrub gives way to wide stretches of bare ground with clumps of coarse grass and occasional thickets of acacia. The soil type in the upper awash sub-basin is diverse. The most common soil types are Clay, Clay-Loam, Loam, Sandy-Clay-Loam, Silt-Loam (OWWDSE, 2015). Land use and soil type have a direct impact on supply and potential to create.

Table 3. 2 Land Use Groups Used in the WEAP Model

Major Land Use Type	Area Sq_km	% ge
Vegetation	123.01	0.67
Forest Land	324.18	1.77
Urban or Exposed Rock	1824.84	9.98
Irrigation Cultivated	754.94	4.13
Rain fed Cultivated	11337.73	62.02
Grass Land	2899.42	15.86
shrub Land	159.84	0.87
Rural Settlement	614.36	3.36
Water Body	243.06	1.33

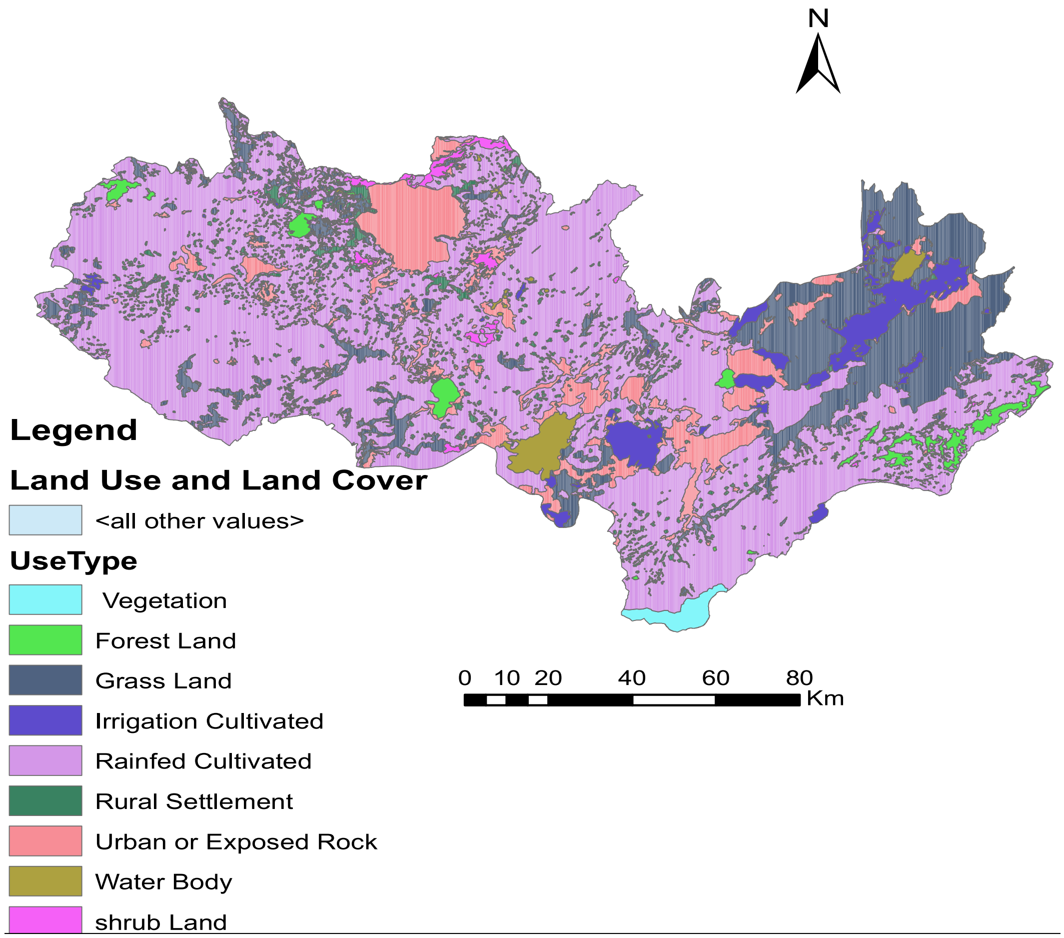


Figure 3. 4 Land use and Land cover of upper awash basin

Source: Oromia Water Works Design and Supervision Enterprise (OWWDSE, 2014)

3.2 Methodology

3.2.1 Watershed delineation

Prior to data collection the boundary of the study area was delineated. The Digital Elevation Model (DEM) following drainage boundaries with Rift valley reservoir basin coverage was shown blow.

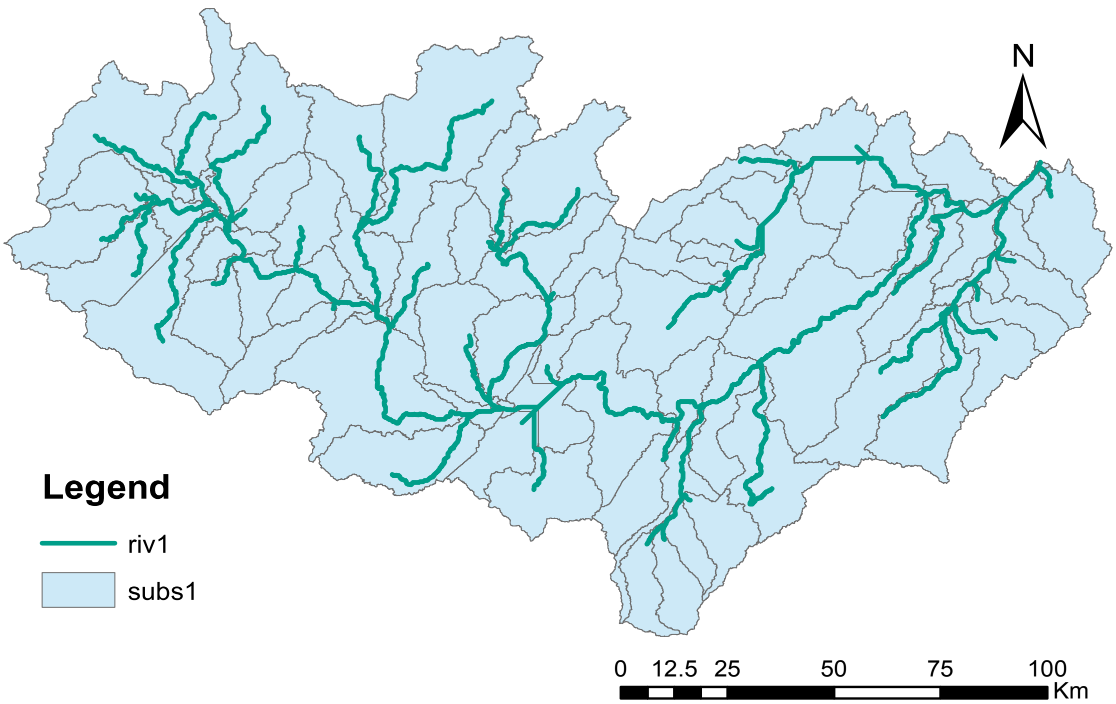


Figure 3. 5 Upper Awash sub basin

3.2.2 Data collection

Before using and processing of any research, the primary task of the study was getting/collecting relevant information or data of the study area. This section identifies and discusses the types and source of data required for the study.

Materials Used

The materials used for this research depending on the objective were Arc view GIS tool to obtain hydrological and physical parameters and spatial information of the study area, DEM data used as an input data for ARC-GIS software for catchment delineation and estimation of catchment characteristic, Hydrological and meteorological data, WEAP model for basin simulation and Microsoft EXCEL to analyze WEAP outputs.

3.2. 2.1 Hydrological data

Hydrological gauging stations in Upper Awash basin are mainly maintained by the Hydrology Department of the Ministry of water and energy (MoWIE) which processes and files data. For this study, the hydrological data were collected from the following source:

- Ministry of Water, Irrigation and electricity (MoWIE), daily flow data of four stations of different years have been collected.
- From Ethiopian Electric Power Utility (EEPU) and Oromia water works and design supervision enterprise (OWWDSE).

In the Koka sub basin there are about 21 hydrological gauging stations that records the flow, out of these awash at Hombole and Mojo River gauging stations are the major one which flows to koka reservoir, because of the other streams are the tributes to the main Awash River. Fig 3.6 below shows the basic spatial distribution of stream flow gauging stations in the koka watershed.

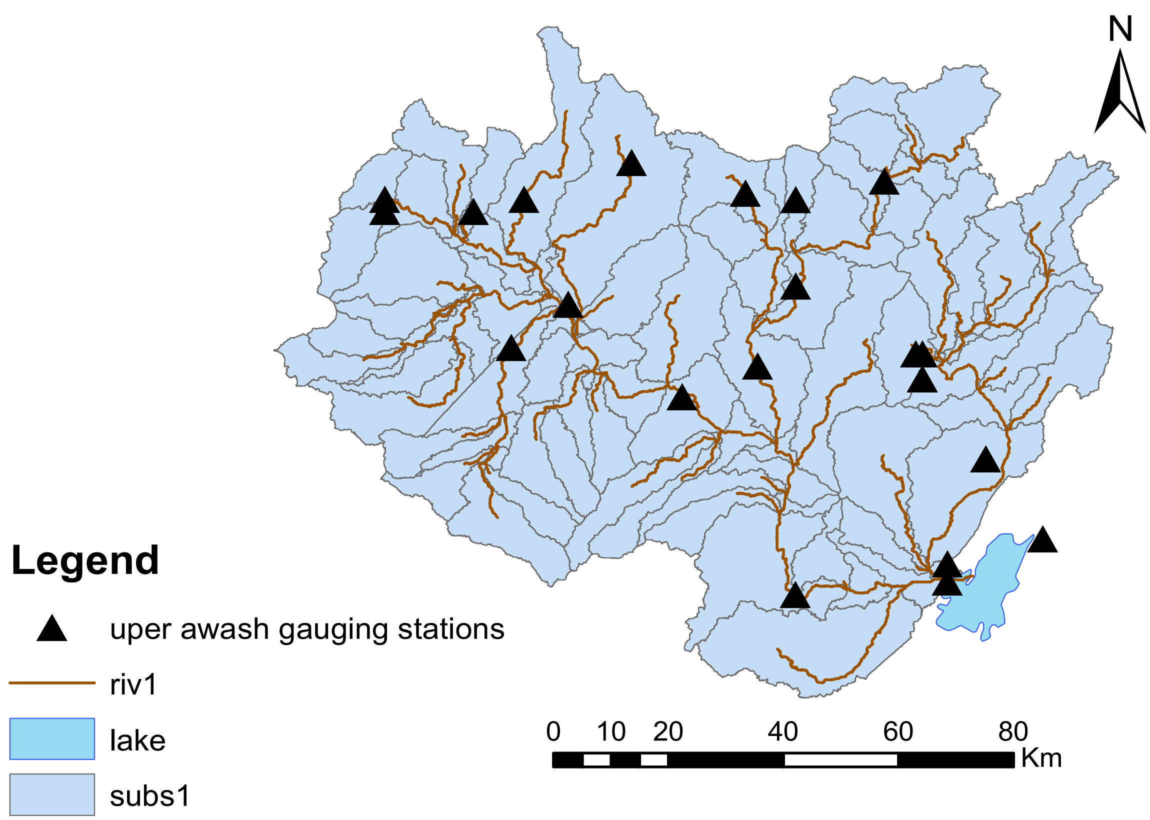


Figure 3. 6 Stream flow gauging stations

Table 3. 3 Major hydrological stations in the koka watershed

Station No	River	Station	Latitude	Longitude	Drainage Area	Period	River Basin
031012	Awash	At M_Kunture	$8^{o}42'$	$38^{o}36'$	4456	1980-2012	Awash
031004	Akaki	At Akaki	$8^{o}53'$	$38^{o}47'$	884.4	1980-2012	Awash
031013	Awash	At Hombole	$8^{o}23'$	$38^{o}47'$	7656	1980-2013	Awash
031014	Mojo	At Mojo	$8^{o}36'$	$39^{o}05'$	1264.4	1980-2013	Awash

3.2.2.2 Meteorology data

At present there are several meteorological stations, which were installed by National Meteorological Agency (NMA) of Ethiopia. In spite of the fact that sufficient numbers of meteorological stations have been established throughout the project area, information regarding the detail climatic conditions of the area is very limited because of malfunctioning of gauging stations, recorder not timely measuring the data etc.

The quality of the studies is dependent on the quality of required elements and quantity or long term records of data. The most commonly observed problems were related to insufficient and incomplete basic data. In this study, there was a problem of insufficiency of complete data for meteorological at high and low land areas. Meteorological data of this study was mainly based on rainfall data obtained from the National Meteorological Service Agency of Ethiopia (NMAE) and the summary of the selected stations presented with table 3.4 blow.

Table 3. 4 Summary of selected rainfall stations within the study area

S/No	Stations	Latitude	Longitude	Altitude (m.a.s.l)	Years of data used	(%) Missed data	Sub- Basin
1	Ginchi	9.0170	38.1330	2132	1980-2014	0.308	Awash
2	AddisAlem	9.0420	38.3830	2372	1980-2014	14.712	Awash
3	Holota	9.00	38.50	2400	1980-2014	67.177	Awash
4	Tullubolo	8.6540	38.2070	2190	1980-2014	6.224	Awash
5	Addis Ababa	9.0190	38.7480	2386	1980-2014	1.068	Awash
6	Akaki	8.8690	38.7860	2057	1980-2014	0.387	Awash
7	Bishoftu	8.7330	38.950	1900	1980-2014	14.818	Awash
8	Sendafa	9.1520	39.0220	2569	1980-2014	10.297	Awash
9	ChafeDorsa	8.7330	39.1230	2392	1980-2014	12.935	Awash
10	Mojo	8.6050	39.1080	1763	1980-2014	13.055	Awash
11	Hombole	8.3680	38.7740	1743	1980-2014	23.025	Awash
12	KokaDam	8.4690	39.1550	1618	1980-2014	26.411	Awash
13	Adama	8.550	39.2830	1622	1980-2014	4.394	Awash
14	Wonji	8.50	39.20	1540	1980-2014	56.107	Awash
15	Etaya	8.1330	39.3330	2129	1980-2014	37.556	Awash
16	Abomsa	8.46670	39.8330	1630	1980-2014	34.811	Awash
17	Walinchiti	8.670	39.430	2165	1980-2014	11.833	Awash
18	Metahara	8.8590	39.9190	944	1980-2014	26.965	Awash

Filling missing rainfall data

Missed measured precipitation data may face to many problems in hydrologic analysis and design. Because of the cost associated with data collection and some natural and man-made conditions sometimes make it very difficult to have complete records of data at every stations clearly. Conditions above mentioned sometimes prevent to obtain quantitative and qualitative data of the study area. For gauges that require periodic observation, the failure or absence of the observer to make the necessary visit to the gauge, destruction of recording gauges, and instrument failure because of mechanical or electrical malfunctioning can result in missing data. Any such causes of instrument failure reduce the length and information content of the precipitation record. Hence, the multi-regression filling method was used to compute the missed data for analyzing rainfall data of upper awash basin.

After selecting which station best matches with the records of the station in query using less percentage of missing data method, performing multi-regression between them gives the equation into which the given value should be calculated to get the estimated records of the missing data for the corresponding time period. In most cases missing data should be filled using multiple station as the missing may not be found as a whole only in one station, in such case either the rest unfilled will be in filled using monthly mean of already available (if they are short period) or another regression will be done with another station which has a record on those months and years.

Homogeneity test

Homogeneity analysis was used to separate a change in the statistical properties of the time series data. The causes can be either natural or man-made. These include alterations to land use and relocation of the observation gauging station. Therefore in order to select the representative meteorological station for the analysis of areal rainfall estimation, checking homogeneity of group stations is essential, the homogeneity of the selected gauging stations daily rainfall records were carried out by non-dimensional equation:

$$P_i = \frac{\overline{P_i}}{\overline{P}} \quad \text{………………………………………………………………………………………..3.1}$$

Where: - Pi = Non dimensional Value of precipitation for the month i

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

$\overline{P}$ = Over year’s average yearly precipitation of the station

Consistency test

Consistency of time series data analyzed based on theory that a plot of two cumulative quantities that are measured for the same time period should be straight line and their proportionality unchanged, which is represented by slop. Therefore, inconsistency of the record was done by the double-mass curve technique. This technique is based on the principle that when each recorded data comes from the parent population, they are consistent. The double mass curve technique was used to adjust precipitation records to take account of non-representative factors such as change in location or exposure of rain gauge. The accumulated totals of the gauge in question are compared with the corresponding totals for a representative group of nearby gauge. If significant change in the system of the curve is observed, it should be corrected by:

$$P_X' = P_X * \frac{M'}{M} \quad \text{……………………………………………………………………..........3.2}$$

Where:- Px’ = Corrected precipitation at station x

Px = Original recorded precipitation at station x

M' = Corrected slope of the double mass curve

M = Original slope of the double mass curve

Areal rainfall determination

In a given drainage basin rain gauge stations are evenly distributed into sub-basin. The rain of one station in a basin may be different from that of the second station in the same catchment. From this idea the average precipitation value on the entire basin is worked out, so as to get average rain catchments to have the limits of the catchment carefully defined. Therefore, rainfall over an area of interest has to be estimated from these point measurements.

There are usually three ways of determining the areal precipitation over a catchment from rain gauge measurement. These methods are the Arithmetic means, the Thiessen polygon and the Isohyetal method. However, the Thiessen polygon was used for this study for its sound theoretical basis and availability of computational tools. But the method is dependent on a good network of representative rain gauges and does not allow the hydrologist to consider factors, such as topography (Daniel, 2008).

To determine the mean areal rainfall, the rainfall amount of each station was multiplied by the area of its polygon and the sum of these products was divided by the total area of the catchment. If P1, P2, P3……Pn are the rainfall magnitudes recorded by the gauging stations 1, 2…….n, respectively and if the areas of Thiessen Polygon A1, A2, and A3...…An, are formed as representative of the respective stations then the average rainfall over the catchment is given by:

$$P_{avg} = \frac{P_1 A_1 + P_2 A_2 + P_3 A_3 + ...P_n A_n}{A} \quad \text{…………………………………………………………3.3}$$

Where: - Pavg = areal precipitation over the sub-basin (mm); P1, 2…n = precipitation depth in each station (mm);

A1, 2 …n = area of each polygon (km2);

A = total watershed area of sub-basin (km2).

3.2.2.3 Regional climate model (RCM) data

In this study, outputs from Regional climate model (RCM) data were used. RCM abbreviation stands for "COSMO climate limited area modeling" and COSMO stands for group for "small scale modeling". RCM as non-hydrostatics regional climate model that developed by German Weather Service (Mulunshawanigatu, 2013). According to this person RCM covers the whole of Europe and the Africa regions bordering the Mediterranean Sea with horizontal model resolution between 1 and 50km and temporary resolution one day and 1hour. The first bias correction is done by global reanalysis data by the Post dam Institute for climate Impact studies (PIK). These first data corrected is obtained from Addis Ababa University school of civil and environmental Engineering department. Further bias correction for precipitation and temperature for the stations over the study area was needed.

Despite of high resolution climate data provision of regional climate model, the techniques of first data correction has its own limitations. The main limitations of RCM technique are systematic errors (Mulushewanigatu, 2013). The theoretical and practical limitations may cause bias and should be corrected by bias correction methods. Thus the RCM grid data in the upper awash basin were indicated blow.

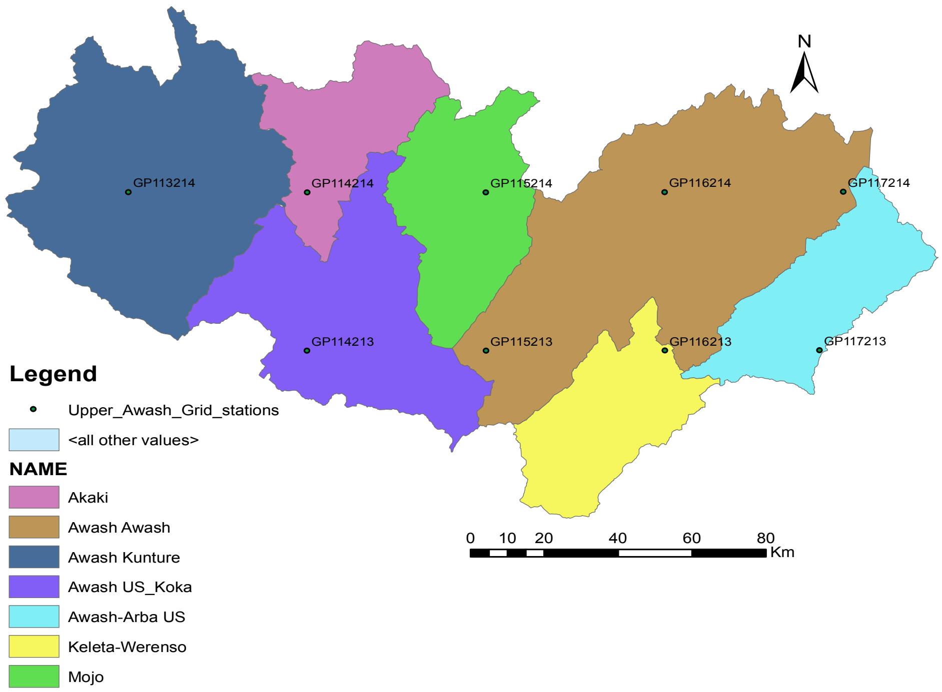


Figure 3. 7 RCM grid data stations in the upper awash basin

3.2.3 RCM data correction procedure

In this section, the approach to remove the biases (errors) from the RCM data in this study is described. The bias corrected was based on the Distribution mapping; a method that has been extensively discussed and applied in similar studies based on climate model predictions (G. H. Fang et al., 2014).

The time period from 01/01/1980 to 31/12/2014 was adopted as the baseline (or present-day) scenario in this study. Observed daily meteorological variables (precipitation, air temperature, solar radiation, wind speed and relative humidity) for this period were first compared against the meteorological variables derived from the RCM climate models for the same period. Even though all models reproduced the seasonal cycle of the five meteorological variables quite well, almost all of the models showed significant discrepancies at some time for some particular months and for some variables, in comparison to the observed data. For example, in general, all models underestimated solar radiation and air temperature in all months. Also, the models significantly overestimated precipitation, particularly between March and August. They also overestimated wind speed in spring. As for vapor pressure, there was a generalized underestimation in summer. These biases were removed using the statistical approach described below.

The Distribution mapping bias removal approach is to match the distribution function of raw RCM data to that of observation data. It was used to adjust mean, SD and quintiles. The distribution mapping (DM) method considers computing parameters, the Gamma distribution with shape parameter (α) and scale parameter (β) often used for precipitation distribution the two parameters were obtained from easy fit software by inputting monthly local intensity scaling corrected and monthly observed data.

$$f_r(x/\alpha,\beta) = x^{\alpha-1} * \frac{1}{\beta^{\alpha} * \Gamma(\alpha)} * e^{\frac{-x}{\beta}}; x >= 0, \alpha, \beta > 0 \qquad 3.4$$

Where: Γ is the Gamma function. Since the raw RCM-simulated precipitation contains a large number of drizzle days, which may substantially distort the raw precipitation distribution, the correction is done on LOCI corrected precipitation PLOCI, m, d.

$$P_{cor,m,d} = F_r^{-1}\left(F_r\left(P_{LOCI,m,d} / \alpha_{LOCI,m}, \beta_{LOCI,m}\right) / \alpha_{obs,m}, \beta_{obs,m}\right) \qquad 3.5$$

For temperature, the Gaussian distribution (or normal distribution) with mean μ and SD σ are usually assumed to fit temperature best.

$$f_N(x/\mu,\sigma) = \frac{1}{\sigma * \sqrt{2\pi}} * e^{\frac{-(x-\mu)^2}{2\sigma^2}; x \in IR} \qquad 3.6$$

And then similarly the corrected temperature can be expressed as:

$$T_{cor,m,d} = F_N^{-1}(F_N(T_{raw,m,d} / \mu_{raw,m}, \sigma_{raw,m}) / \mu_{obs,m}, \sigma_{obs,m}) \qquad 3.7$$

Where FN (.) and F-1N (.) are Gaussian CDF and its inverse, μ raw, m and μ obs, m are observed means for the raw and observed precipitation series at a given month m, and σ raw, m and σ obs, m are the corresponding SDs, respectively.

In order to produce a future time-series of the meteorological variables, these calculated biases were applied to the observed historical climate data. The DM method thus assumes that future model biases will be the same as those in present-day simulations. The approach used was mentioned in figure 3.8 blows.

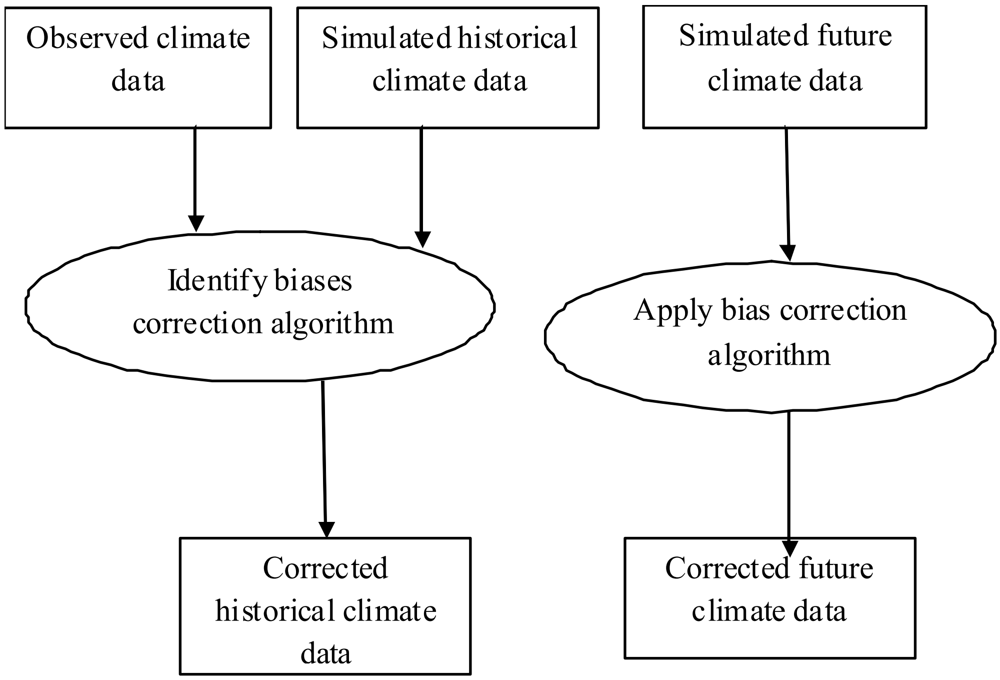


Figure 3. 8 Bias correction framework

3.2.3.1 RCM data evaluation

The performance evaluation of these RCM data corrected precipitation and temperature datasets were tested with time series performances against observed precipitation data. The time series-based metrics include the Nash–Sutcliffe measure of efficiency (NSE), the correlation coefficient (R2), and the percent of bias (PBIAS). NSE indicates how well the simulation matches the observation, and it ranges between – ∞ and 1.0, with NSE = 1 indicating a perfect fit. The higher this value, the more reliable is the model. PBIAS measures the average tendency of the simulated data to their observed counterparts. Negative values indicate an overestimation (i.e., the simulated dataset is higher than the observed dataset), while positive values indicate an underestimation (the simulated dataset lower than the observed dataset). The optimal value of PBIAS is 0.0, with low-magnitude values in both directions, possibly indicating accurate model simulations. The above indication defined as follow:

$$R^2 = \frac{\sum_{i=1}^{n}(P^i_{obs} - \overline{P}^i_{obs})^2 - \sum_{i=1}^{n}(P^i_{sim} - \overline{P}^i_{sim})^2}{\sum_{i=1}^{n}(P^i_{obs} - \overline{P}^i_{obs})^2} \qquad 3.8$$

$$NSE = 1 - \frac{\sum_{i=1}^{n} \left(P_{Obs}^{i} - P_{Cor}^{i}\right)^2}{\sum_{i=1}^{n} \left(P_{Obs}^{i} - P_{Obs}^{mean}\right)^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.9$$

$$PBIAS = \frac{\sum_{i=n}^{n} \left(P_{Obs}^{i} - P_{Cor}^{i}\right) * 100}{\sum_{i=n}^{n} \left(P_{Obs}^{i}\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.10$$

Where: PiObs and PiCor are the i th observed and simulated variables, Pmean is the mean of observed variables, and n is the total number of observations.

3.3 Model Calibration

Calibration is an iterative exercise used to establish the most suitable parameter in modeling studies. It is very important because reliable values for some parameters can only be found by calibration (Reuben, 2007). It involves the identification of the most important model parameters and changing the parameter set. Model parameters changed during calibration were classified into physical and process parameters. Physical parameters represent physically measurable properties of the watershed; while the process parameters are those not directly measurable. Model calibration can be manual, automatic and a combination of the two methods (Tigist, 2009). Manual calibration use trial and error techniques in parameter adjustment through a number of simulation runs. It is subjective to the modeler's assessment and can be time consuming. Computer based automatic calibration involves the use of a numerical algorithm which finds the extreme of a given numerical objective function. Model performance is assessed statistically by comparing the model output and observed flow values. The statistical measures commonly used are the coefficient of determination (R2), Nash-Sutcliffe Efficiency (NSE) and the Root Mean Square Error (RMSE) (Tigist, 2009).

3.4 Model Validation

Model Validation is the process of representing that a given site specific model is capable of making accurate predictions. This was done by applying the calibrated model using a different data set out of the range of calibration without changing the parameter values. The model is said to be validated if its accuracy and predictive capability in the validation period have been proven to lie within acceptable limits (Reuben, 2007). Observed and simulated hydrograph values were again compared as in the previous calibration procedure. If the resultant fit is acceptable then the model's prediction as valid.

3.5 Catchment Simulation Methods

There was a choice among five methods to simulate catchment processes such as evapotranspiration, runoff, infiltration and irrigation demands. These methods include (1) the Rainfall Runoff (simplified coefficient method), (2) Irrigation Demands Only (Simplified Coefficient Approach), (3) the Soil Moisture Method, (4) the MABIA Method, and (5) the Plant Growth Method (PGM). The choice of method should depend on the level of complexity desired for representing the catchment processes and data availability.

The Soil Moisture Method was used for this work because of its more complexes representing the catchment with two soil layers, as well as the potential for snow accumulation and in addition the method allows for the characterization of land use and soil type impacts to these processes. In the upper soil layer, it simulates evapotranspiration, considering rainfall and irrigation on agricultural and non-agricultural land, runoff and shallow interflow (SEI, 2015). Base flow routing to the river and soil moisture changes are simulated in the lower soil layer (Figure 3.9). Each watershed unit was representing different land use, and a water balance was computed for each fractional area, j of N. Climate is assumed uniform over each sub-catchment, and the water balance of the sub-catchment was given as,

$$Rd_j \frac{dz_{1,j}}{dt} = p_e(t) - PET(t)K_{c,j}(t)\left(\frac{5z_{1,j} - 2z_{1,j}^{\ 2}}{3}\right) - p_e(t)z_{1,j}^{\ RRF_{j_1}} - (1-f_j)k_{s,j}z_{1,j}^{\ 2} - f_j k_{s,j} z_{1,j}^{\ 2} \quad ..3.11$$

Here z1,j = [1,0] is the relative storage given as a fraction of the total effective storage of the root zone, Rdj (mm) for land cover fraction, j. Pe is the effective precipitation. PET is the Penman-Montieth reference crop potential evapotranspiration where kc,j is the crop/plant coefficient for each fractional land cover. The third term (Pe (t) z1,jRRFj) represents surface runoff, where RRFj is the Runoff Resistance Factor of the land cover. The higher values of RRFj lead to less surface runoff. The third and fourth terms are the interflow and deep percolation terms, respectively, where the parameter ks,j is an estimate of the root zone saturated conductivity (mm/time) and fj is a partitioning coefficient related to soil, land cover type, and topography that fractionally partitions water both horizontally and vertically. The total runoff (RT) from each sub-catchment at time t is,

$$RT(t) = \sum_{j=1}^{N} A_j \left(p_e(t) z_{1,j}^{RRF_j} + f_j k_{s,j} z_{1,j}^{2} \right) \ldots\ldots\ldots \quad 3.12$$

Base flow emanating from the second bucket is computed as:

$$S_{\max} \frac{dz_2}{dt} = \left(\sum_{j=1}^{N} (1 - f_j) k_{s,j} z_{1,j}^{2} \right) - k_2 z_2^{2} \ldots\ldots\ldots 3.13$$

Where the inflow to this storage, Smax is the deep percolation from the upper storage and Ks2 is the saturated conductivity of the lower storage (mm/time), which was given as a single value for the catchment.

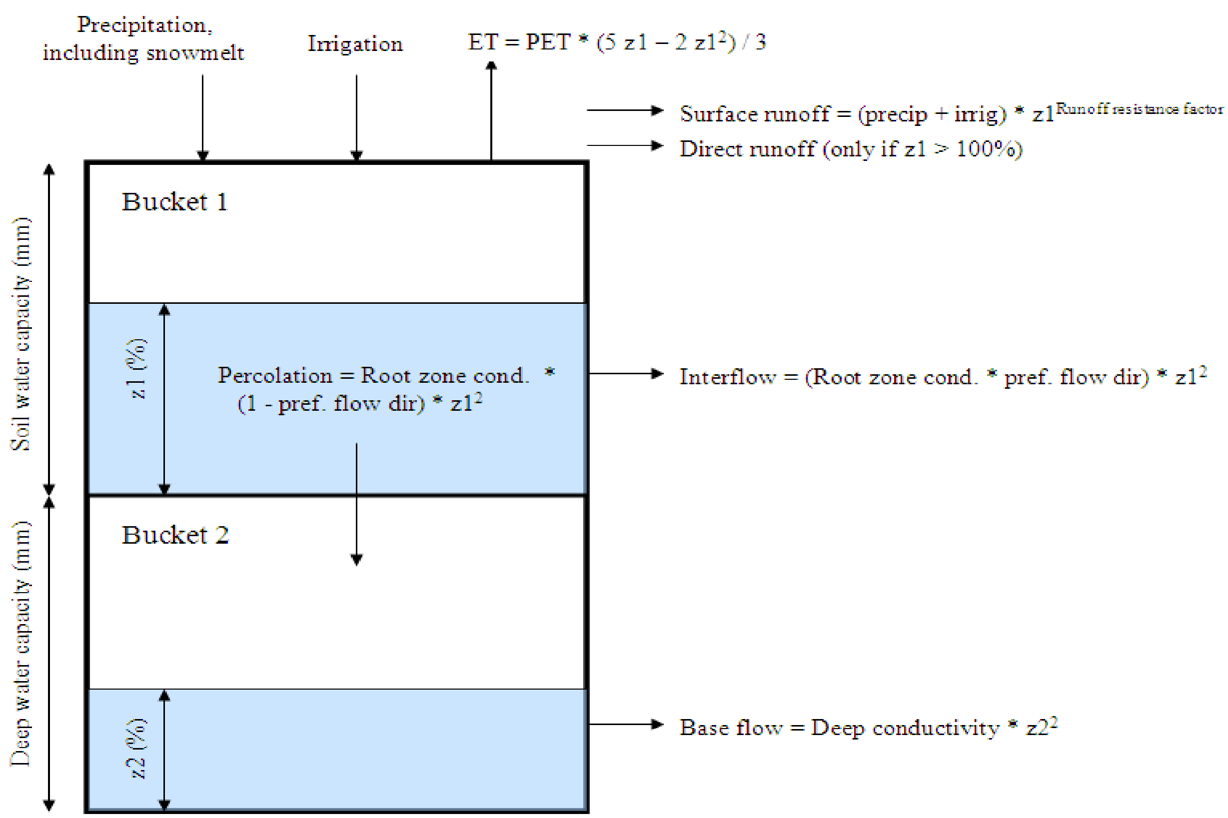


Figure 3. 9 Concept of soil moisture and equations (source: WEAP User Manual)

3.5.1 Reservoir storage zone calculation

In general, the main purpose of the reservoir is to provide a source of water for demand sites during dry periods. WEAP model can simulate a reservoir; by taking in account the reservoir's operating rules, downstream requirement priorities, net evaporation on the reservoir, and hydropower generation.

The operation of a reservoir is decided according to pre-defined operating rules. Such operation rules are approximation of reality and divide the reservoirs into water level-related Zones. Generally Reservoir storage is divided into four zones or pools. These include, from top to bottom, the flood-control zone, conservation zone, buffer zone and inactive zone. The conservation and buffer pools together constitute the reservoir's active storage. WEAP ensure that the flood-control zone is always kept vacant, i.e., the volume of water in the reservoir cannot exceed the top of the conservation pool. Fig 3.10 shows zoning of reservoir storage:

Flood-control zone (Sf) that can hold water temporarily thereafter release storage to reduce potential downstream flood damage,

Conservation zone (Sc) which is available storage zone for downstream demands including water supplies, irrigation and navigation, etc.,

Buffer zone (Sb) that can be used to control and regulate water demands during dry periods and

Inactive zone (Si) which is dead storage mainly required for sediment collection. WEAP allows the reservoir to freely release water from the conservation pool to fully meet the downstream demand requirements. Once the storage level drops into the buffer pool, the release will be restricted according to the buffer coefficient, to conserve the reservoir's decreasing supplies. Water in the inactive pool is not available for allocation although under extreme conditions evaporation may draw the reservoir into the inactive pool.

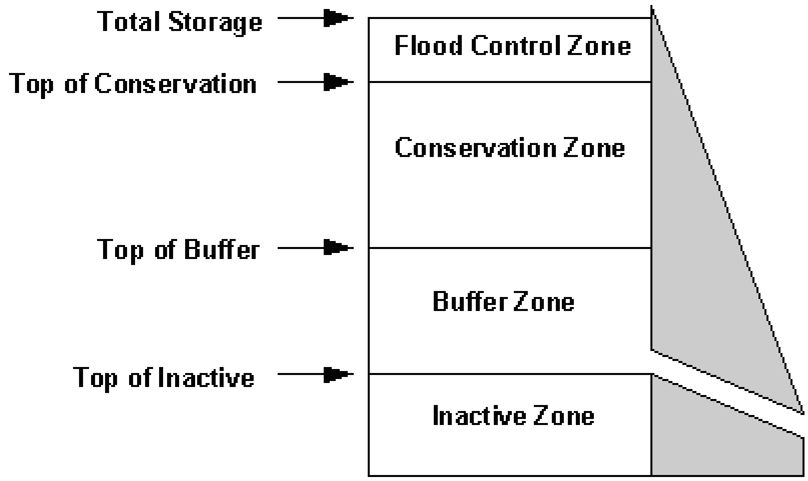


Figure 3. 10 Reservoir storage zones (source: WEAP User Manual)

The amount available to be released from the reservoir is the full amount in the conservation and flood control zones and a fraction of the amount in the buffer zone (the buffer coefficient fraction). Each of these zones is given in terms of volume. The water in the inactive zone is not available for release.

St = Sf + Sc + (bc * Sb) ……………………………………………………………………….3.14

Where St is total available water that can be released from the reservoir, Sf is storage of flood control, Sc is storage of conservation, bc is the buffer coefficient and Sb storage of buffer.

All of the water in the flood control and conservation zones is available for release, and equals the amount above Top of Buffer (ToB),

$$\textit{Flood Control and Conservation Zone Storage}_{Res} = \textit{Storage for Operation}_{Res} - \textit{Top of Buffer}_{Res}$$

Or zero if the level is below Top of Buffer.

$$\textit{Flood Control and Conservation Zone Storage Res} = 0$$

Buffer zone storage equals the total volume of the buffer zone if the level is above Top of Buffer,

$$\textit{Buffer Zone Storage}_{Res} = \textit{Top of Buffer Zone}_{Res} - \textit{Top of Inactive Zone}_{Res}$$

Or the amount above Top of Inactive if the level is below Top of Buffer,

$$\textit{Buffer Zone Storage}_{Res} = \textit{Storage for Operation}_{Res} - \textit{Top of Inactive Zone}_{Res}$$

Or zero if the level is below Top of Inactive.

Buffer Zone Storage $_{Res}$ *= 0*

WEAP uses the Buffer Coefficient to slow releases when the storage level falls into the buffer zone. When this occurs, the monthly release cannot exceed the volume of water in the buffer zone multiplied by this coefficient. In other words, the buffer coefficient is the fraction of the water in the buffer zone available each month for release. Thus, a coefficient close to 1.0 will cause demands to be met more fully while rapidly emptying the buffer zone, while a coefficient close to 0 will leave demands unmet while preserving the storage in the buffer zone. Essentially, the top of buffer should represent the volume at which releases are to be cut back, and the buffer coefficient determines the amount of the cut back.

Note: The buffer coefficient determines how much of the water that is in the buffer zone at the beginning of a time step is available for release. However, this doesn't restrict WEAP from releasing some or all of water that flows into the reservoir during the time step. Even if the buffer coefficient is 0, WEAP can still release any water that flows into the reservoir in that time step if needed to meet downstream demands in this case, the storage level will not decrease, but it may not increase either.

3.5.2 Water demand calculation

The calculation process, as described in the WEAP User Guide, is based on mass balance of water for every node and link is subject to demand priorities, supply preferences. Calculation starts from the first month of the Current Account year to the last month of the last scenario. For non-storage nodes, such as points on a river, the currently month’s calculation is independent from the previous month’s calculation. For storage nodes, such as reservoirs, soil moisture, or aquifer storage, the storage for the current month depends upon the previous month’s value. Whatever water enters the system during a month, it will either be stored in a reservoir, aquifer, or catchment soils, or leave the system by demand site consumption or evapotranspiration.

The identified sites were included in the model as individual demands rather than group demand in configuration on the schematics, however it might lower the flexibility in modeling how each irrigation site may make demands on the surface water network according to its particular cropping pattern.

Using the demand priorities and supply preferences, WEAP determines the allocation order to follow when allocating water demand. Demand sites with higher priorities are processed first by the WEAP Allocation Algorithm. These priorities are useful in representing a system of water rights and also important during a water shortage (SEI, 2005). Supply Preferences indicate the preferred supply source where there is more than one source to a demand site. The allocation order represents the actual calculation order used by WEAP for allocating water. Table 3.5 shows how the priority was assigned to each compartments of demand category.

Table 3. 5 Assigned priority levels for the upper awash catchment

Demand type	Priority level
Irrigation	1
Flow requirement	2
Reservoir	3

Demand for water was calculated as the sum of the demands for all the demand site bottom level branches (Br). A bottom-level branch is one that has no branches below it. Annual water demand was then calculated as follows:

$$AnnualDemand = \sum_{Br} Totalactivitylevel * WaterUseRate \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.15$$

The total activity level for a bottom-level branch is the product of the activity levels in all branches from the bottom branch back up to the demand site branch (where Br is the bottom level branch, Br’ is the parent of Br, Br’’ is the grandparent of Br). The Total Activity Level was given as:

$$TotalActivityLevel = ActivtyLevel_{Br} * ActivityLevel_{Br'} * ActivityLevel_{Br''} * \ldots\ldots\ldots\ldots 3.16$$

The activity levels for each branch and the water use rates for all the bottom level branches were inputs into the model. Monthly demands were calculated based on each month’s fraction specified as data under Demand\Monthly Variation of the adjusted annual demand as follows:

$$MonthlyDemand_{DS,m} = MonthlyVariationFraction_{DS,m} * AdjustedAnnualDemand_{DS} \ldots\ldots\ldots\ldots 3.17$$

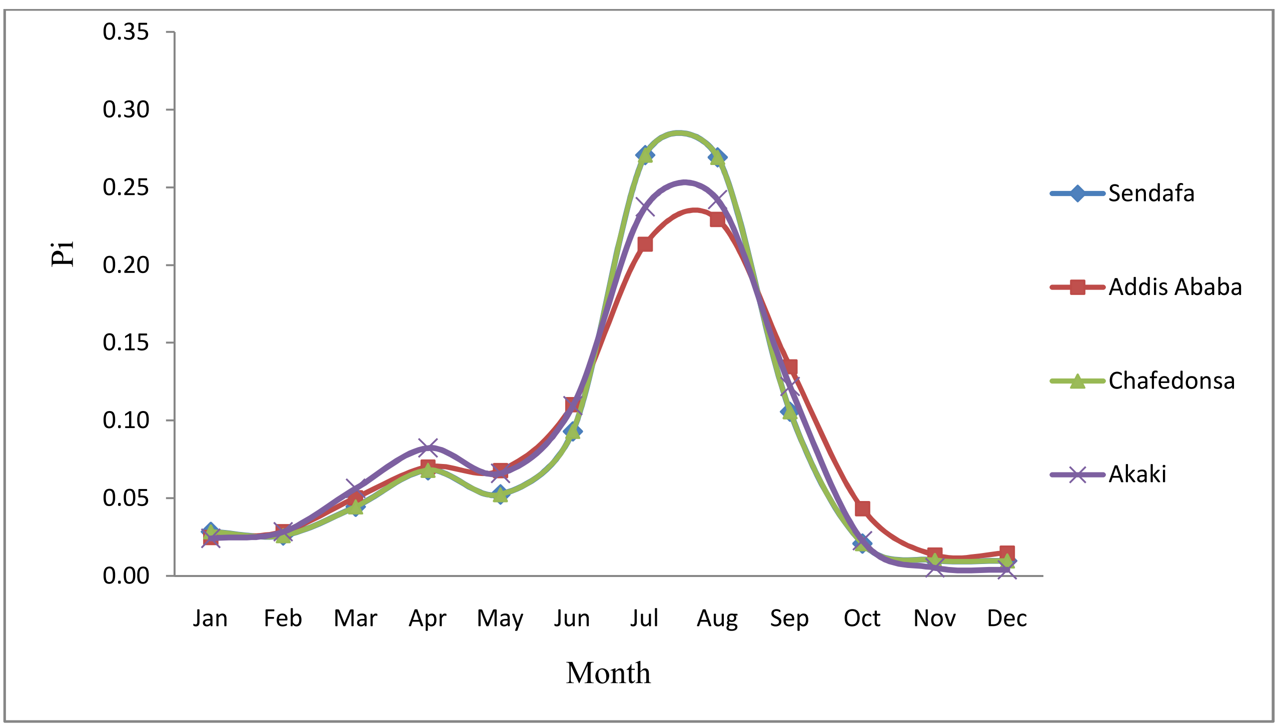
4.0 DATA PROCESSING AND WEAP MODEL SETUP

4.1 Data Analysis

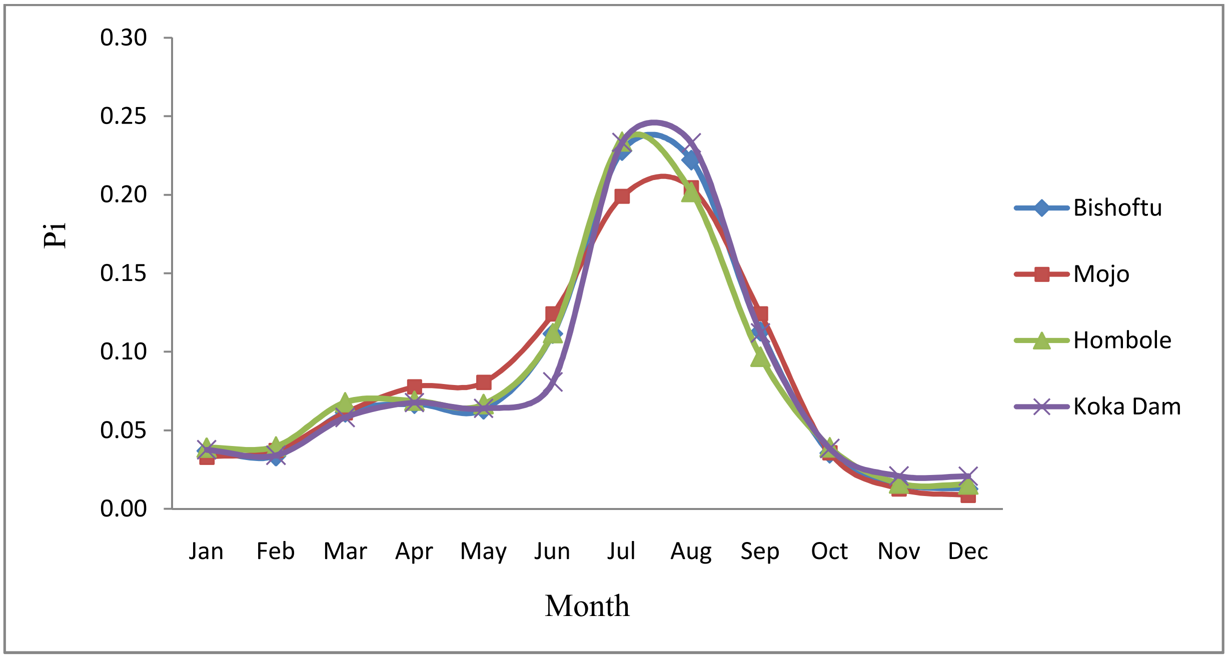
The continuity of a recorded data may be broken with missing data due to many reasons such as damage or fault in gauging station during a measuring period. So, before starting any model simulation, it is important to check whether the data were homogenous, consistence, sufficient and complete with no missing data. The existing missing data estimated using the data filling methods. Because incorrect data leads to inconsistency and ambiguous results that may contradict to the actual value.

4.1.1 Homogeneity test

The selected stations were plotted for comparison with each other; for illustration, figures 4.1 below show the result of homogeneity analysis result and Appendix 2.1 also has figures plotted to check similarity of the other selected group stations. Same-mode and pattern of the stations are observed and hence group stations selected are homogenous since all the value of Pi are less than 0.3.



A) Homogeneity test for Sendafa, Addis Ababa, Chafe-donsa and Akaki stations

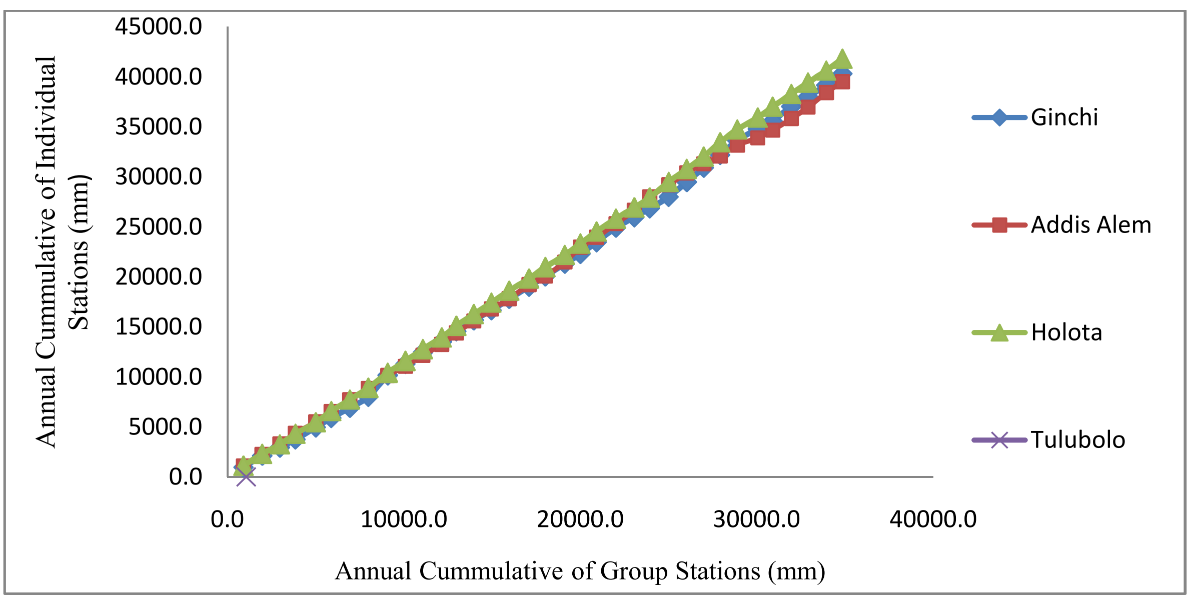


B) Homogeneity test for Bishoftu, Mojo, Hombole and Koka Dam stations

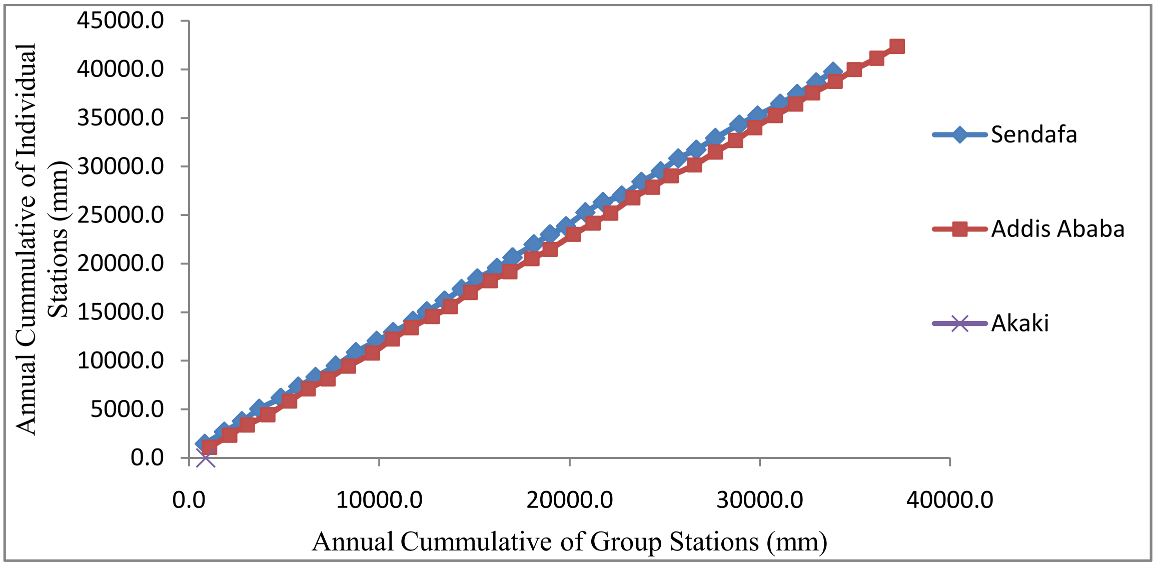
Figure 4. 1 Homogeneity test for selected stations

4.1.2 Consistency test

According to the double mass curves analysis, all the stations were consistent. For illustration the double mass curves for some selected stations are presented below and for the others it was attached in Appendix 2.2



A) Consistency test for Ginchi, AddisAlem, Holota and Tulubolo stations



B) Consistency Test for Sendafa, Addis Ababa, and Akaki stations

Figure 4. 2 Consistency Test for selected stations

4.1.3 Areal rainfall determination

In a given drainage basin rain gauge stations are evenly distributed into sub-basin. The rain of one station in a basin may be different from that of the second station in the same catchment. From this idea the average precipitation value on the entire basin is worked out, so as to get average rain catchments to have the limits of the catchment carefully defined. Therefore, rainfall over an area of interest has to be estimated from these point measurements.

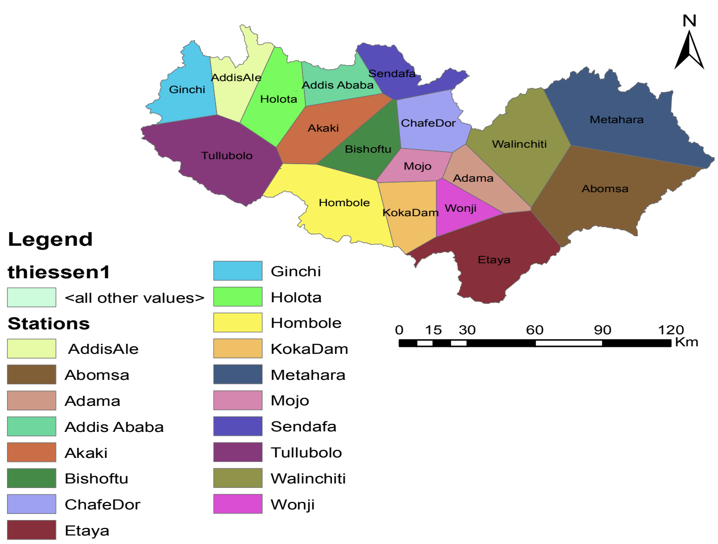


Figure 4. 3 Thiessen polygons for the selected rainfall stations.

Table 4. 1 Areal rainfall interpolated using Thiessen polygon method for Major upper awash sub basin

S/N	Sub-basin	Area (Km2)	Area Ratio	Annual rain fall (mm)	Weighted rainfall
1	M/Kunture	4557.32	0.22	1164.73	256.2406
2	Akaki	1634.02	0.08	1133.03	90.6424
3	U/S Koka	3194.04	0.15	870.90	130.635
4	Mojo	2075.64	0.10	870.88	87.088
5	A_Awash	5744.284	0.28	824.20	230.776
6	Keleta	1742.25	0.08	1158.44	92.6752
7	Arba	1793.95	0.09	908.91	81.8019
	Total	20741.5	1.00	990.1557	970.616

Sub-basin and seasonal rain fall variation profile

Mean monthly rainfall profile illustrates local seasonal rainfall variation as well as spatial differences within the basin. Relevant Statistics of the selected key stations base series rainfall values within this region are given in table 4.2. The corresponding profiles are graphically illustrated in figure 4.4 and 4.5.

The monthly profile indicates the occurrence and relative strength of the dry, wet and intermediate season of monthly rainfall in the different location of the catchments area. The rainfall patterns of the study area reflect the Bi-Modal regime with wetland dry seasons.

Table 4. 2 Mean Monthly Rainfall of the sub basin (mm)

Sub-basin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
M/Kunture	28.71	37.28	65.40	77.06	91.43	165.23	246.04	243.07	123.26	37.22	23.42	26.60	1164.73
Akaki	15.30	28.98	57.48	82.30	69.91	115.00	284.26	292.67	132.24	30.81	11.50	12.58	1133.03
U/S Koka	20.30	33.81	61.92	58.80	60.22	94.08	207.86	187.42	86.97	30.45	13.68	15.41	870.90
Mojo	15.37	26.48	49.23	57.41	55.37	79.59	212.07	221.63	98.25	27.82	12.60	15.07	870.88
A_Awash	16.89	36.50	62.58	62.98	50.91	48.33	196.66	197.04	88.83	39.25	13.14	11.09	824.20
Keleta	38.20	46.91	80.52	84.19	106.52	109.30	226.87	199.55	146.26	59.89	33.55	26.67	1158.44
Arba	35.59	41.89	74.44	83.83	69.13	58.74	154.25	160.83	101.87	70.28	34.32	23.74	908.91
Mean	24.34	35.98	64.51	72.37	71.93	95.75	218.28	214.60	111.10	42.24	20.32	18.74	990.16

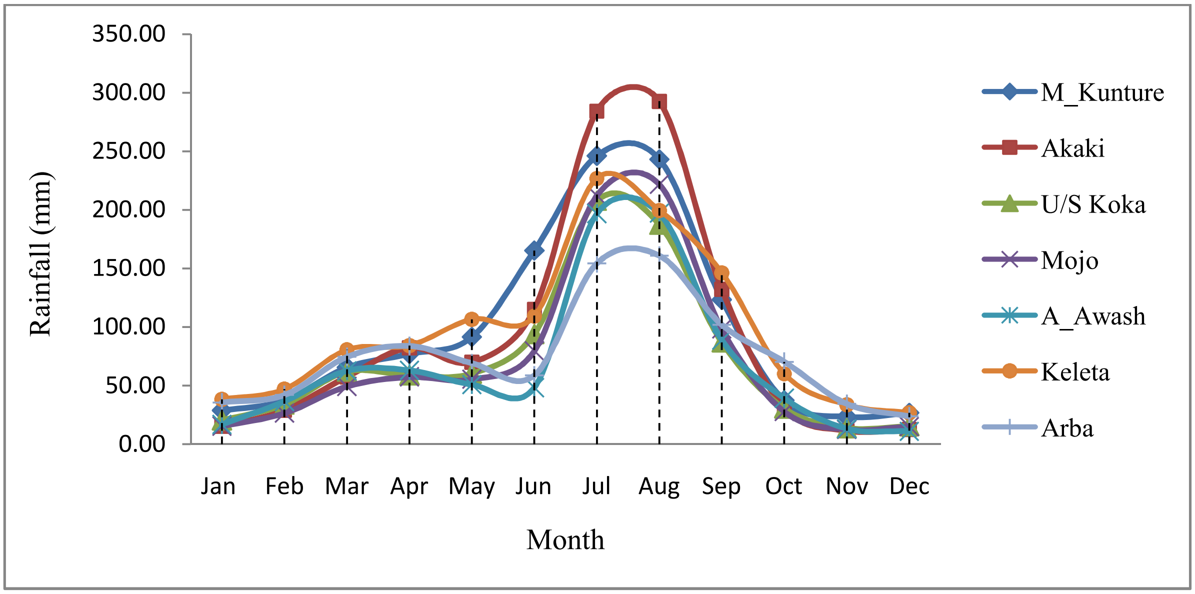


Figure 4. 4 Comparison of Seasonal Rainfall Variation in the major sub-basin Area

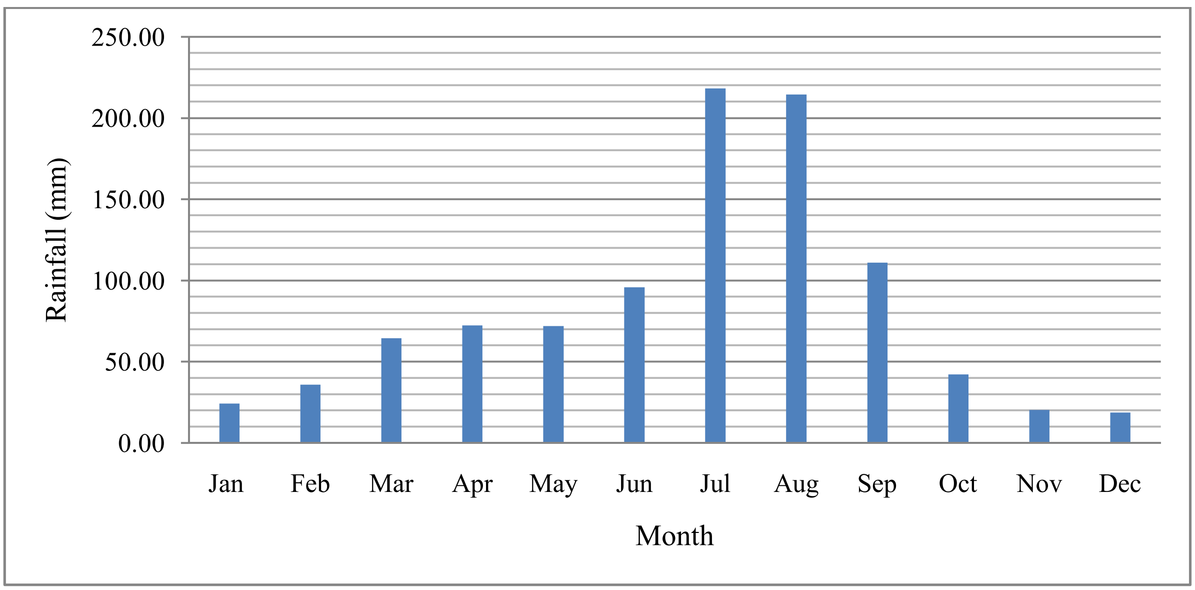
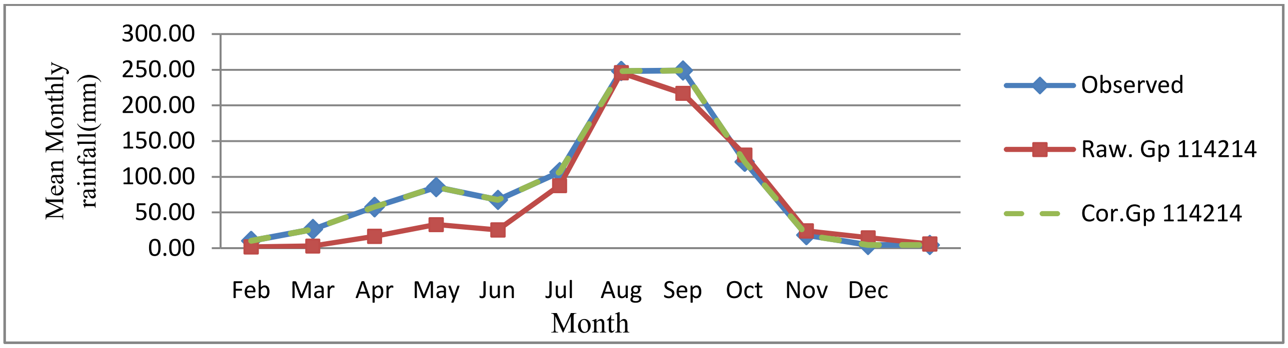


Figure 4. 5 Seasonal Rainfall Variations for the Study Area

4.1.4 RCM performance evaluation

The performancy evaluation of RCM data assesment was done as per the statistical measure with the corrected RCM precipitation data time series against observed precipitation data. Figure 4.6 and Table 4.3 blow shows the summary of evaluation. (See others at an annex 2.3).



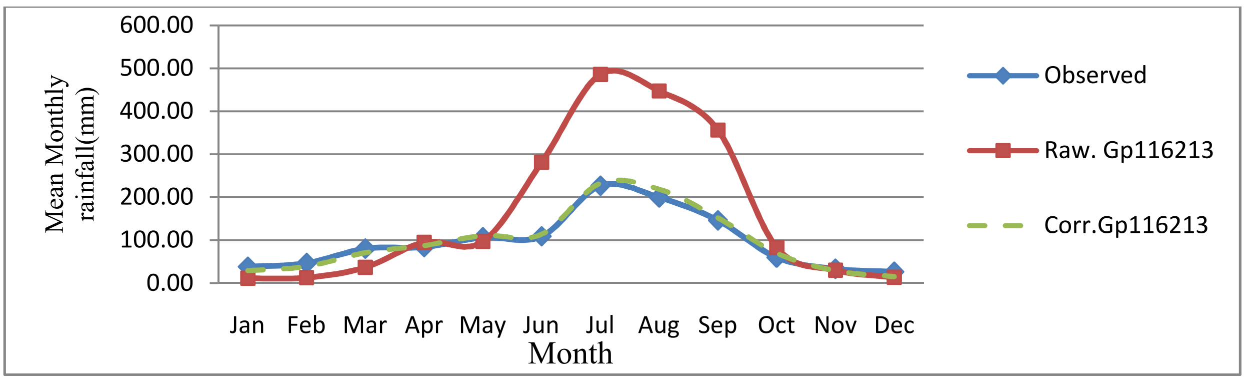


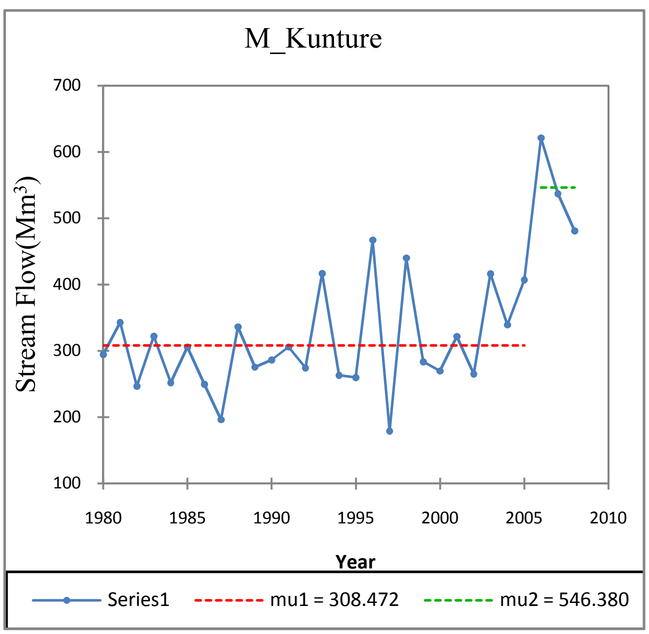
Figure 4. 6 Stations and grid-based comparison of mean monthly rainfall datasets

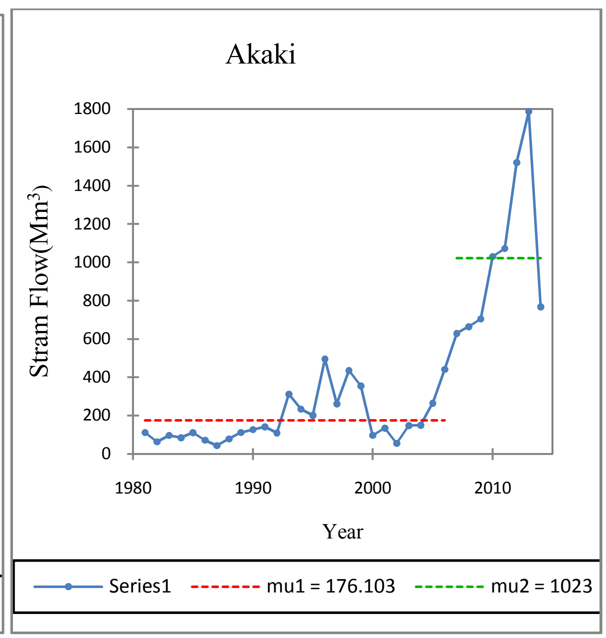
Table 4. 3 Statistical measures of mean monthly corrected RCM PPt data sets.

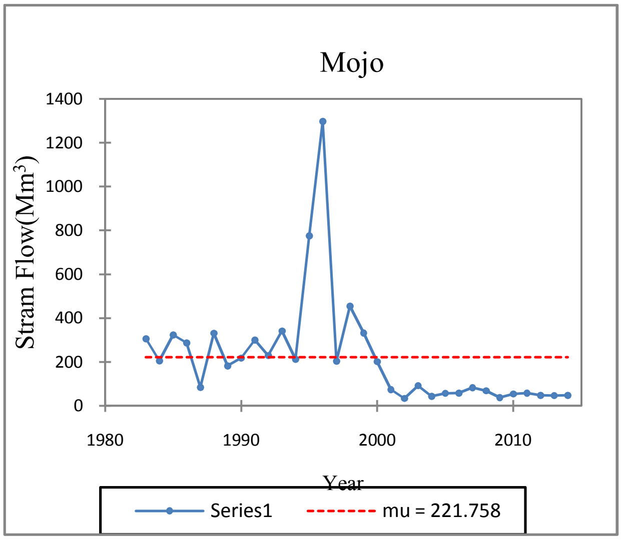
RCM Grid Data	NSE	PBAIS	R^2
GP113214	0.72	9.19	0.93
GP114213	0.69	-1.15	0.86
GP114214	0.80	5.15	0.97
GP115213	0.81	2.97	0.95
GP115214	0.05	-2.16	0.90
GP116213	0.52	-8.50	0.85
GP116214	0.46	16.28	0.76
GP117213	0.44	1.78	0.75
GP117214	0.50	9.81	0.76

4.1.5 Steam flow data trend analysis

The figures blow indicates two major things of the stream flow data due to land use and land cover change on the upper awash basin. The main features seen on the major streams gauging stations were an overestimated and under estimated stream flow data. The major causes of this change on stream flow were as the result of land cover change through the time on catchment area. The overestimated gauging measures occurs due to the disaster, like the 1996 flooding for each gauging stations of upper awash sub-basin, but more the problem indicated on the Mojo stream flow gauging station trend, the other overestimation was due to rainy season in July and August months and in addition to these urbanization causes high runoff generation like the Akaki gauging station due to the land pavement. The second was the under estimation problem of the steam flow gauging stations; this was also due to land use and land cover change which result in high percolation of runoff, conservational structures development and the data measuring problems at the gauging stations or during rating curve developing at office. The summery of these all problems courses the stream flow data fluctuation in the time.







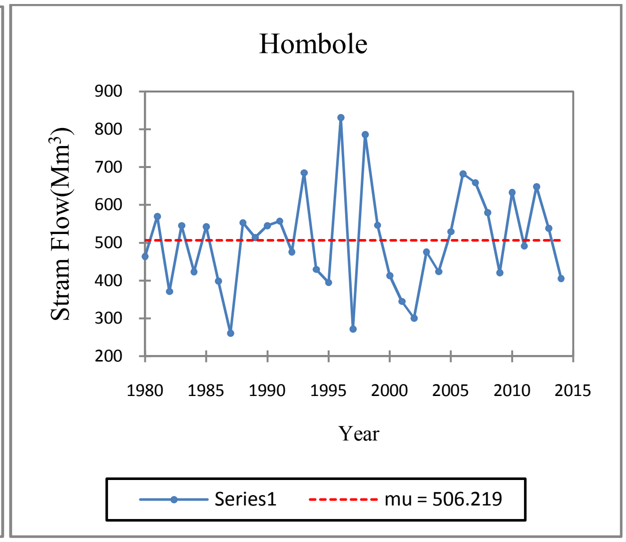


Figure 4. 7 Stream Flow data trend indicator

4.2 WEAP model set up

WEAP consists of five main views: Schematic, Data, Results, Overviews and Notes. The schematic view is GIS-based tools for easy arrangement of the system including objects like demand nodes, rivers and reservoirs. The data view allows creating variables and relationships, entering assumptions and projections mathematical expressions, and dynamically link to Excel. The result view allows detailed and flexible display of all model outputs, in charts and tables, and on the Schematic. On the other hand the overview highlights key indicators of the system for quick viewing. Finally the note view provides a place to document your data and assumptions.

A typical stepwise approach followed to develop WEAP for an area:

i. Create a geographic representation of the area,
ii. Enter the data for the different supply and demand sites,
iii. Compare results with observations and simulated model data,
iv. Define scenarios and
v. Compare and present the results of different scenarios.

The Priority assignment recommendation for each demands are between1 to 99. Level 1 is the highest demand priority for water in the system. This means that WEAP tried to satisfy all the demands at this level before any other level of priority demand. The model uses these priority levels when allocating water for the demand sites. The model delivers water to all the level one priority sites at the same time and, if there is any water remaining in the system, it will then deliver water to the remaining priority levels.

4.2.1 Configuration of WEAP model

In the schematic part of WEAP the boundary of watershed delineated, rivers, demand sites and reservoirs are specified. GIS maps of rivers and reservoir are used to determine the exact location of the streams in WEAP. Importantly, these features act as storage within the model and also as local sites of evaporation losses. The Koka reservoir is schematized in this approach. The total inflows to Koka reservoir which are Awash and Mojo rivers enter as head water. In addition to these the inflows from ungauged catchments to the reservoir is also configured as a river system with head water flow. Out flow of Koka reservoir which is Awash River configured as minimum flow requirement with highest priority in order to ensure its flow to river awash.

Demand areas from the surface water in the study area were integrated into eight groups for setting up of the WEAP model. The irrigation areas were taken together based on the water abstraction sources, the demand sites which included in the schematics are:

- A_ Awash irrigation which abstract water from Awash River as the water source.
- Wonji irrigation which abstract water from awash River as the water source.
- Tibla irrigation which abstract water from Awash River as the water source.
- Nurahera irrigation which abstract water from Awash River as the water source.
- Fentale irrigation which abstract water from Awash River as the water source.
- Metehara irrigation which abstract water from Awash River as the water source.
- Keleta irrigation water supply which abstracts water from Keleta River.
- Arba irrigation water supply which abstracts water from Arba River.

The model consider the return flows from each irrigation sites. However return flow from domestic water supply was not included since the quantity is insignificant it is preferred to overlook. Fig 4.8 shows the schematic configuration of the WEAP model of the study area for the existing condition.

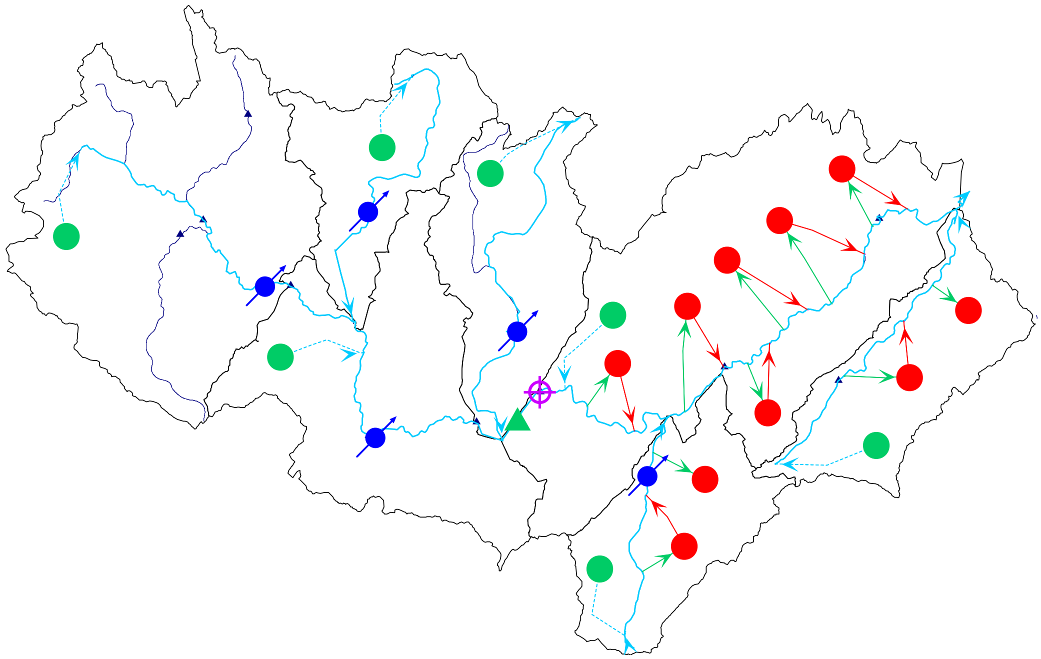


Figure 4. 8 Schematic part of the WEAP model for Upper Awash

4.2.2 Input data to WEAP

The WEAP input data refers to the data that was included and used for the "WEAP" model. The model was based on long term average conditions using monthly mean values of river flow, climate data like (rainfall, temperature, humidity and wind speed), Koka reservoir water evaporation of the Booker Tate and MCE estimation in 2003 and water demands for existing users (Irrigation schemes etc.) in addition these land use and average Kc value were used wich was obtained from FAO paper 56 (see Annex 1 & 2).

5.0 RESULT AND DISCUSSIONS

5.1 Evaluation of the WEAP Model

5.1.1 Ranges of general parameters

Before starting with the actual calibration and validation procedure it should be necessary an understanding of the influence potential of calibration and validation parameters on model performance. Therefore the parameters were adjusted in variable possible ranges to overlap the mean monthly observed stream flow with the model simulated data and the model response was evaluated. Table 5.1 is a possible parameter range of the basin.

Table 5. 1 Calibration parameters in possible ranges

Instance	Variable/Parameter	Range	Unit
Catchment	Soil Water capacity	> = 0	mm
	Deep Water Capacity	> = 0	mm
	Runoff Resistance factor	> = 1000	---
	Root zone conductivity	20	mm/month
	Deep conductivity	> = 0.1	mm/month
	Preferred flow direction	> = 1	----
	Initial z_1	0 - 100	%
	Initial z_2	0 - 100	%

5.1.2 Calibration and validation results

In this section, simulated model results were compared with the observed flows for each control stations. These comparisons are carried out taking account the statistical parameters mentioned in previous sections. For this research, observed stream flows from four stations located along the river basin were compared with the simulated outputs of the model and the two data's result should be over lapped monthly, this shows that the model simulate the output from the catchment land use and land cover should be matched with the recorded stream flow data. In general, the results indicated that the model able to relate the hydrological dynamic of the basin with the measured data as it was shown in the calibration and validation processes result. Figure 5.1 and

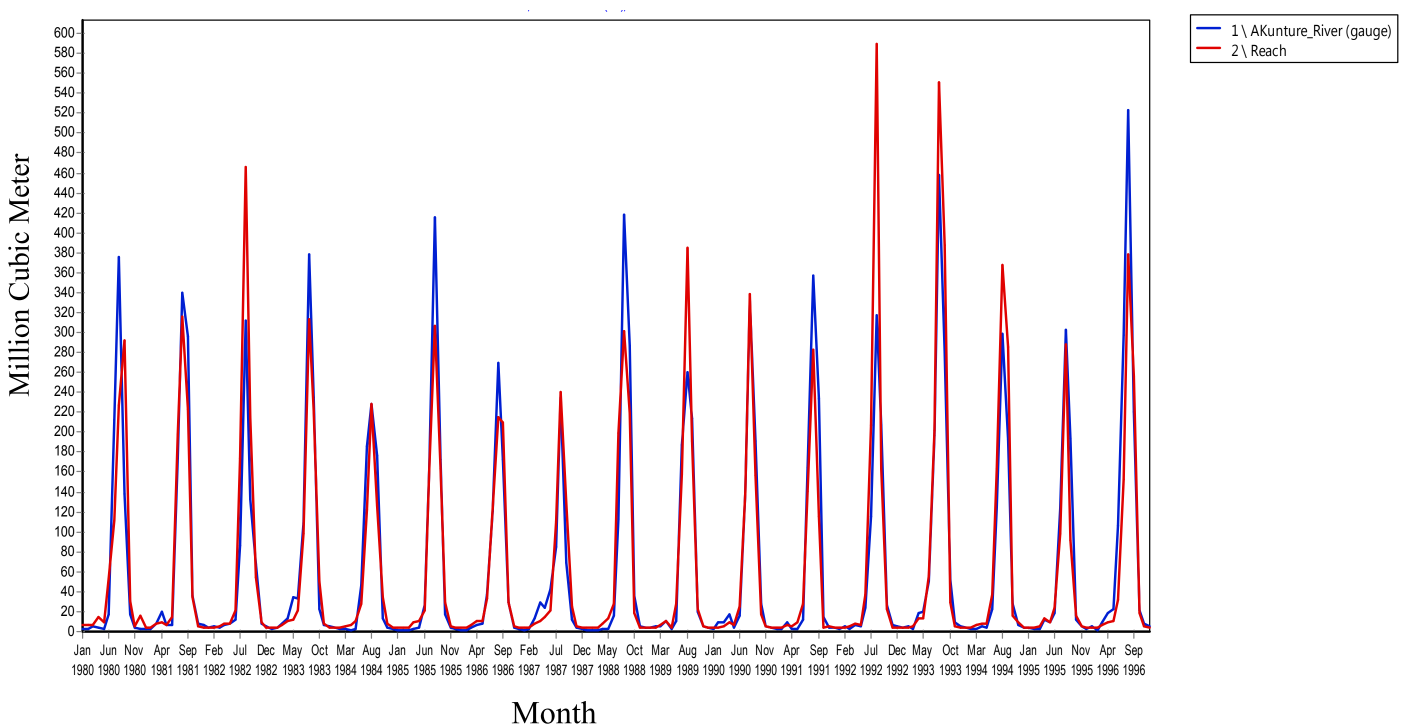
5.2 shows the calibrated results of different stations in different data ranges and with the calibration parameters the stream flow results were also validated between different time periods of the data range.

5.1.2.1 Calibration

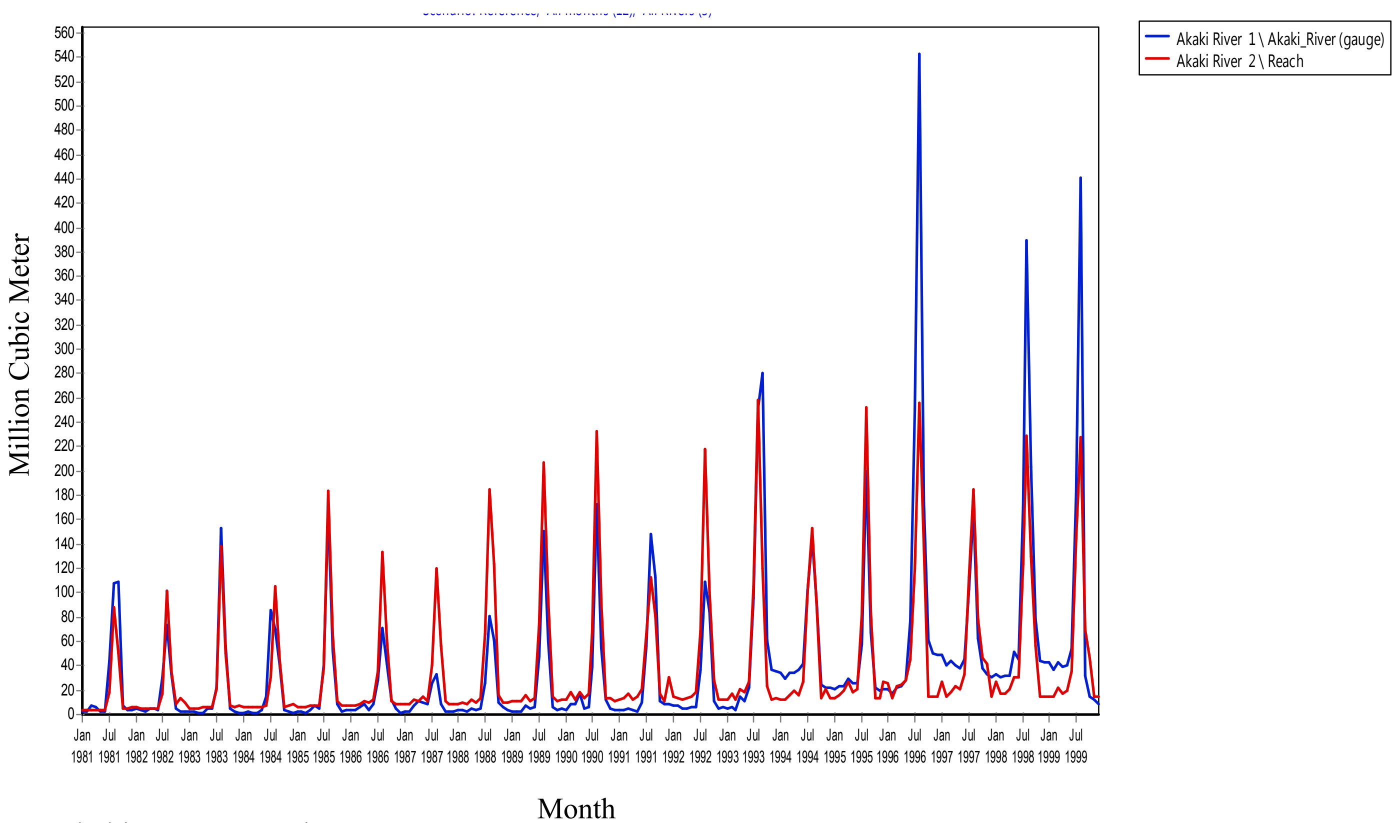
Calibration and validation are necessary to make sure the WEAP model is correctly representing the situation of the study area. Calibration is the subsequent steps of adjusting the most parameters of the watershed in order to the model consider the basin reality while simulating the result. The WEAP Model performances of downstream gauges are depending on the performance of upstream gauges. Thus the head flow gauge should be calibrated first, in order to have a stable upper boundary condition for the downstream gauges. Therefore WEAP model was calibrated and validated before analyzing the scenarios.

Monthly model simulated and observed stream flows for the calibration of the different period can be seen in figures 5.1a-d for the major control stream flow gauging stations: M_Kunture, Akaki, Hombole and Mojo. They were done for the period (1980-1996) for M_Kunture; (1981-1999) for Akaki; (1980-1999) for Hombole and (2001–2008) for Mojo depending on data availability without missed. Calibration was performed by comparing observed stream flows and simulated result of the model in the watershed.

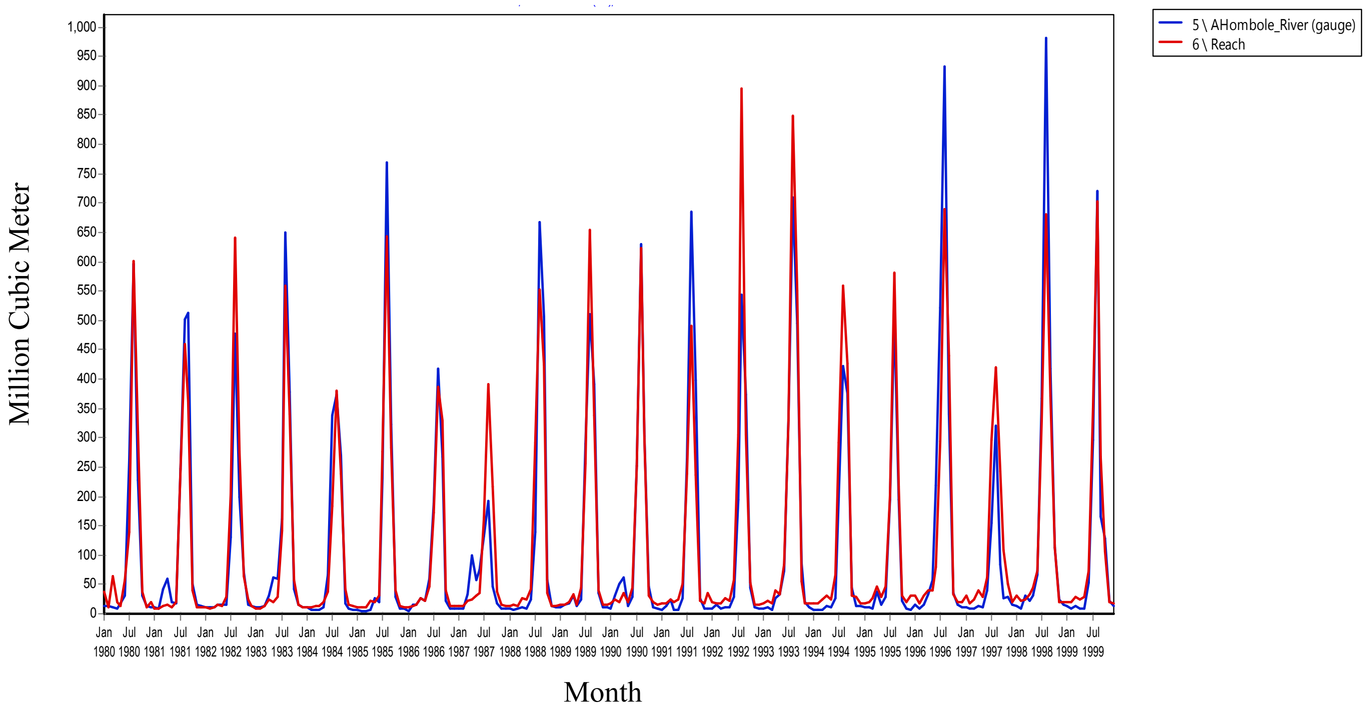
The trends of the model result to reproduce the observed values were also seen in Figures 5.2a-d. The relation between the monthly simulated and observed stream flow data's indicated that a high correlation whose coefficients vary from 0.85, 0.73, 0.89 and 0.91 for M/Kunture, Akaki Hombole and Mojo, respectively. These statistical results indicate very good model performance between the observed and simulated flow data trend of the basin.



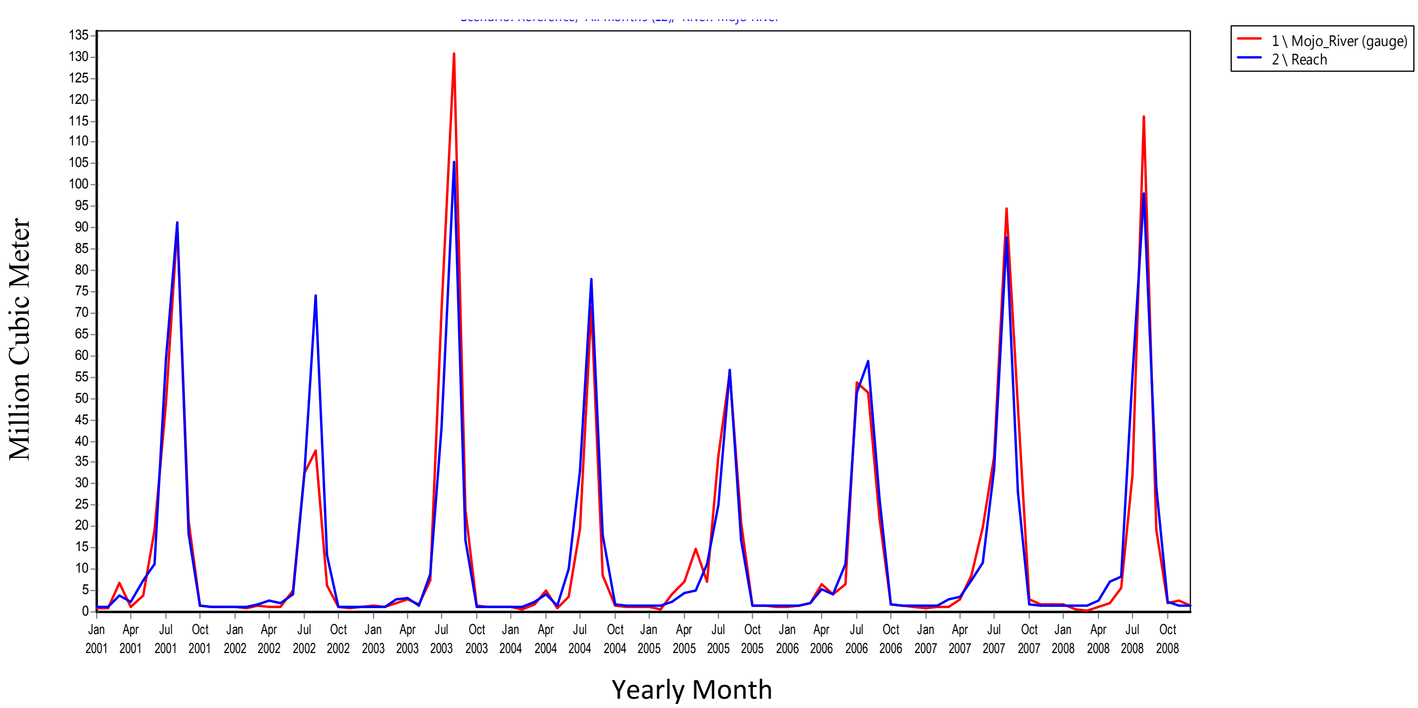
A. M/Kunture Stream-gauge



B. Akaki Stream-gauging

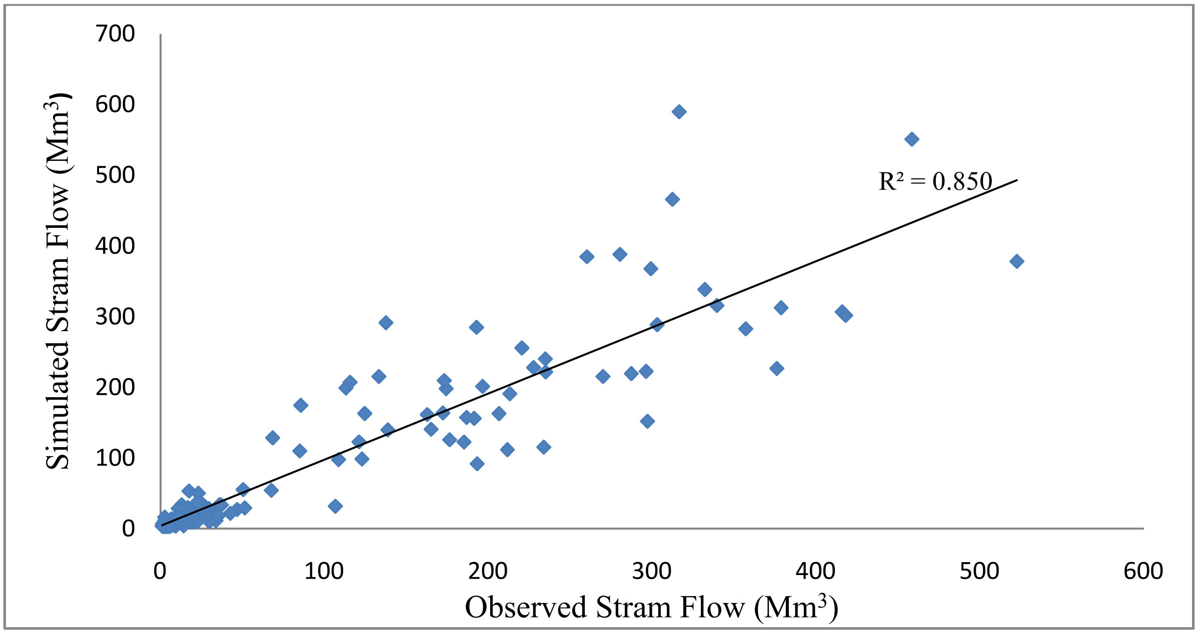


C. Hombole Stream-gauging

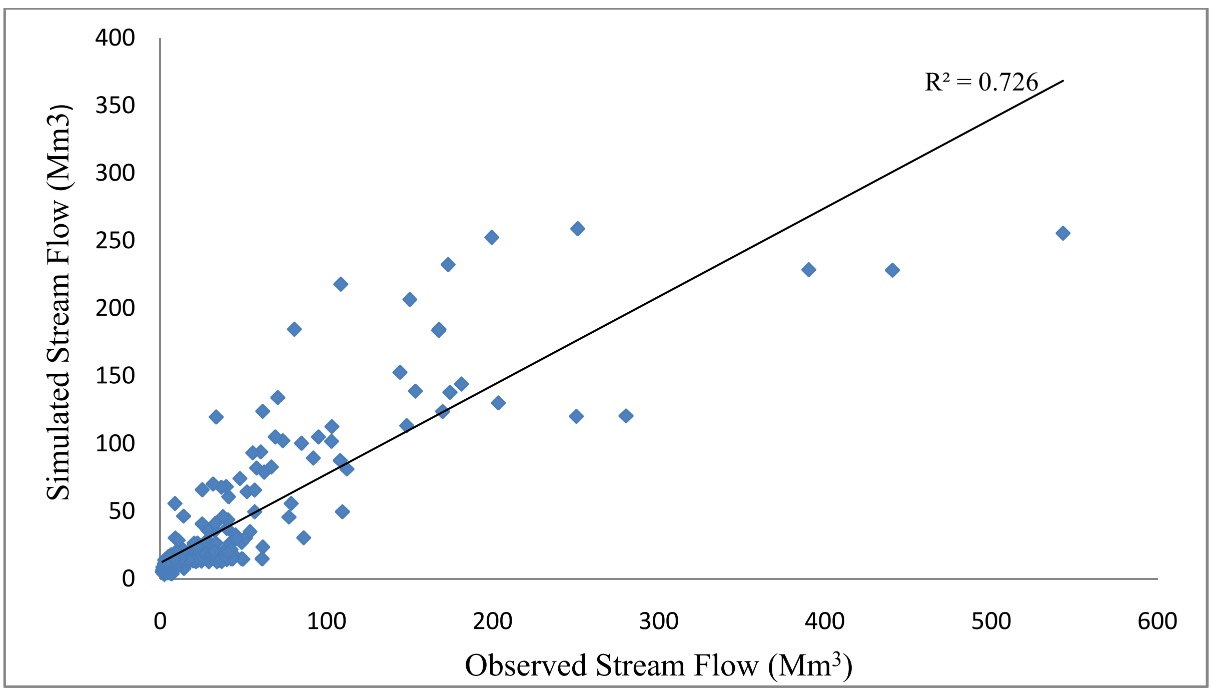


D. Mojo Stream-gauging

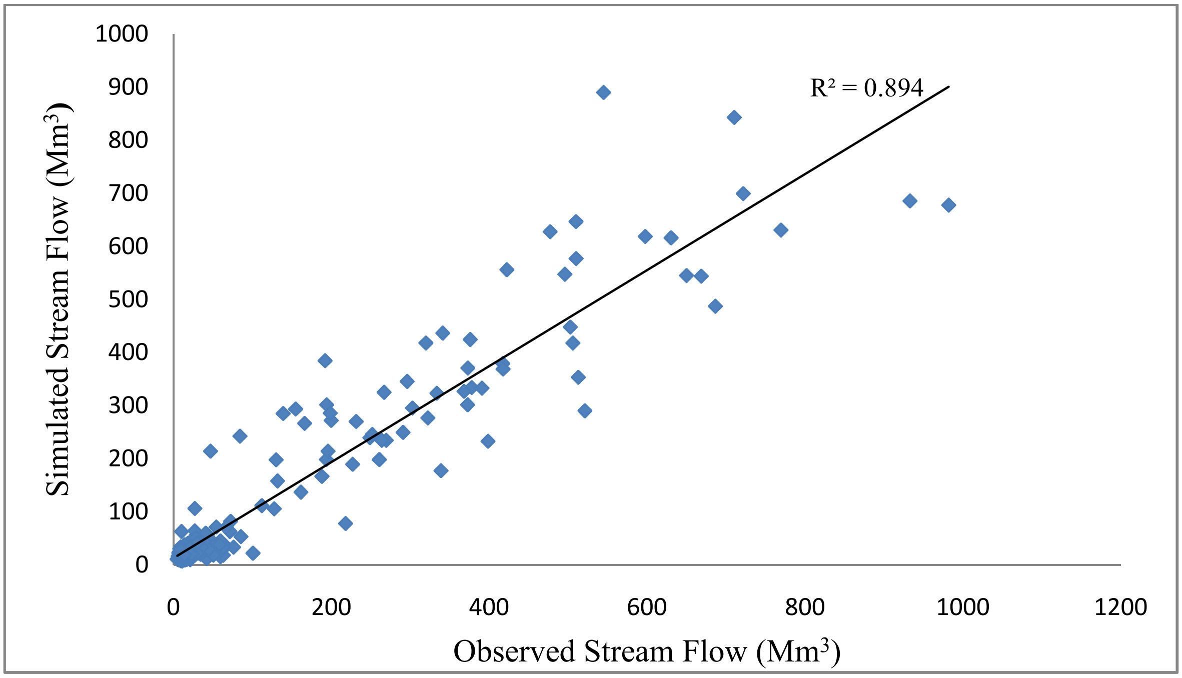
Figure 5. 1 Monthly observed and simulated stream flows at selected stations in the Upper Awash sub-basin. (a) M/Kunture, (b) Akaki, (c) Hombole, and (d) Mojo.



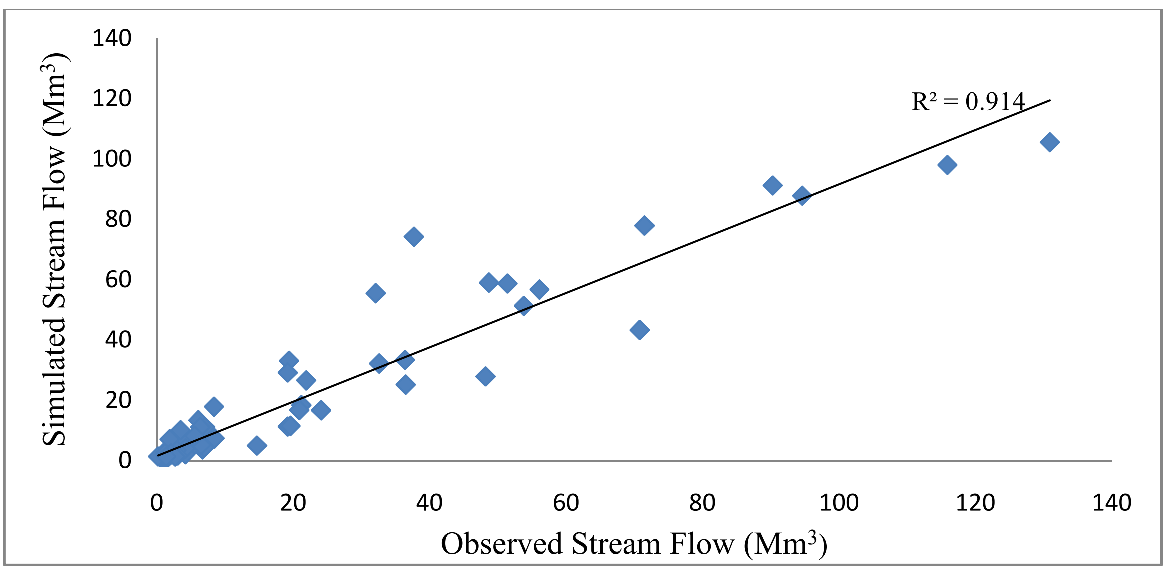
A) M/Kunture Stream-gauge



B) Akaki Stream-gauge



C) Hombole Stream-gauge

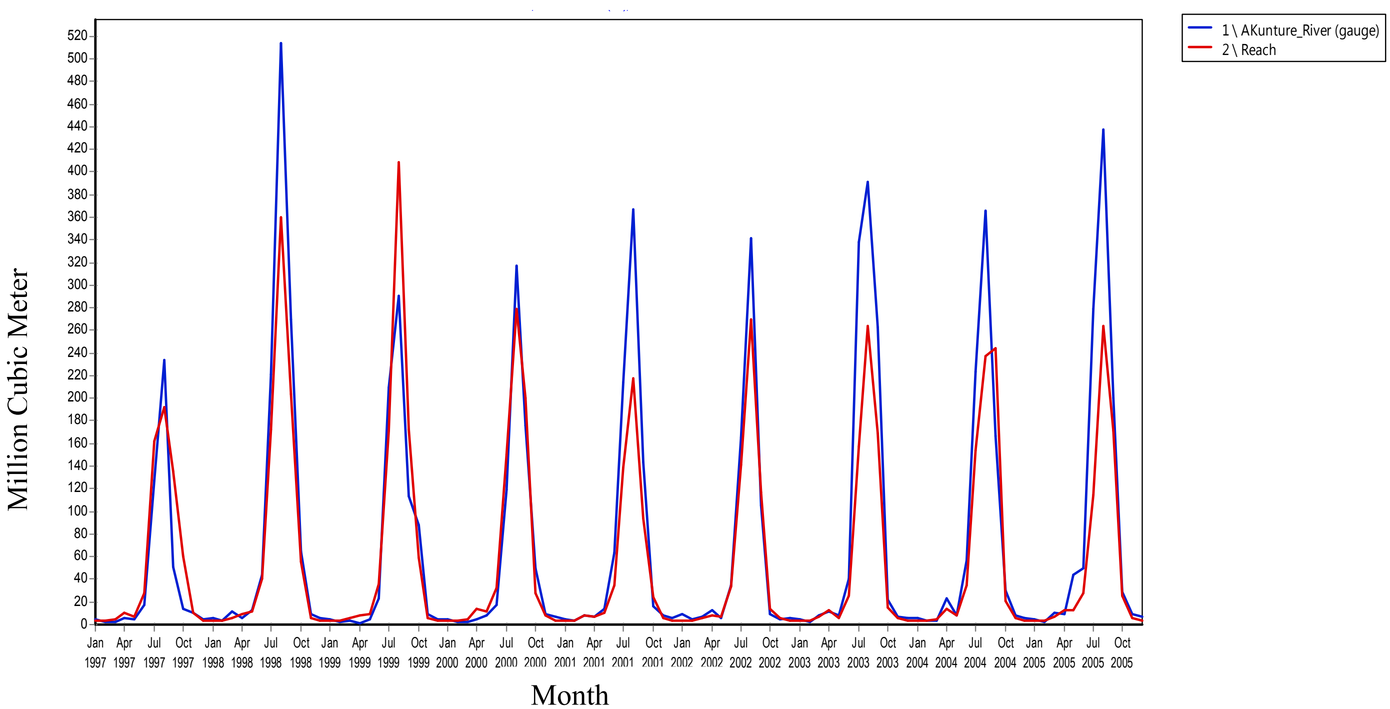


D) Mojo Stream-gauge

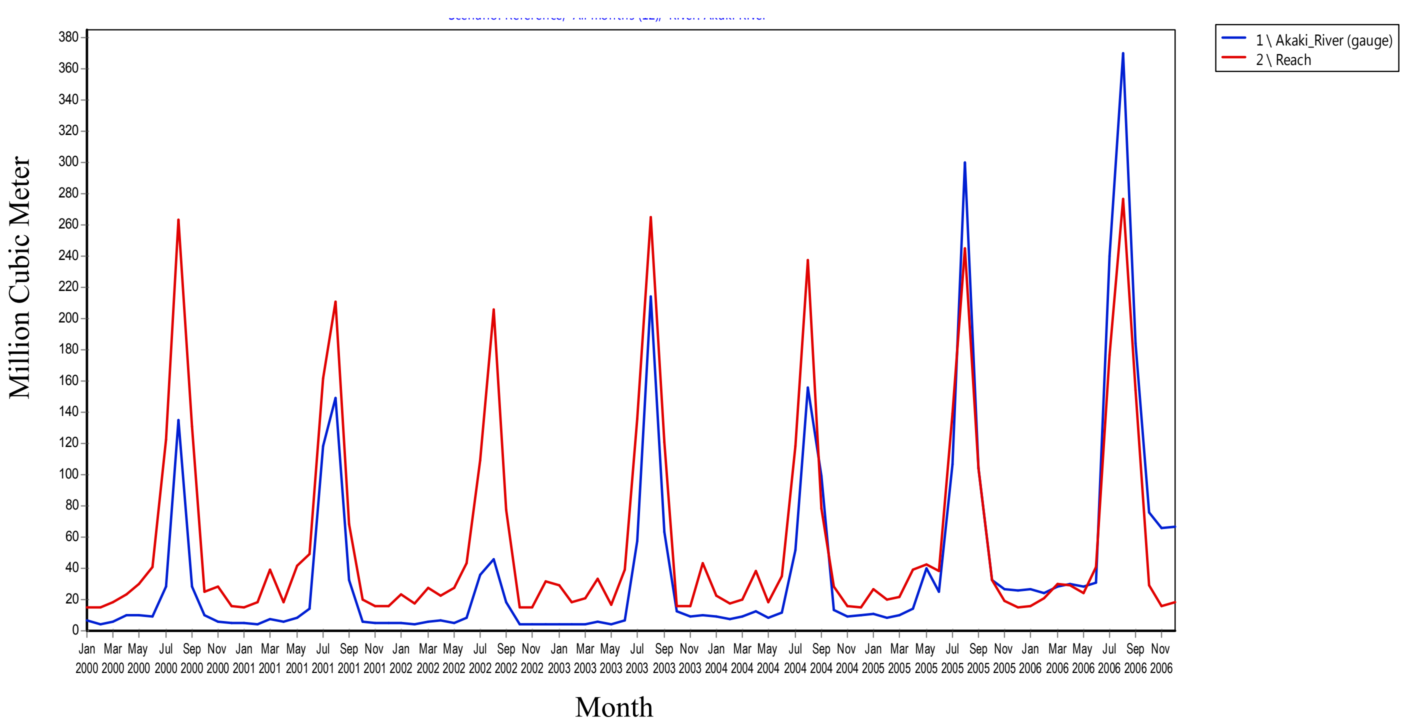
Figure 5. 2 Relationship between monthly observed and simulated stream flows in control stations: (a) M/Kunture, (b) Akaki, (c) Hombole, and (d) Mojo

5.1.2.2 Validation

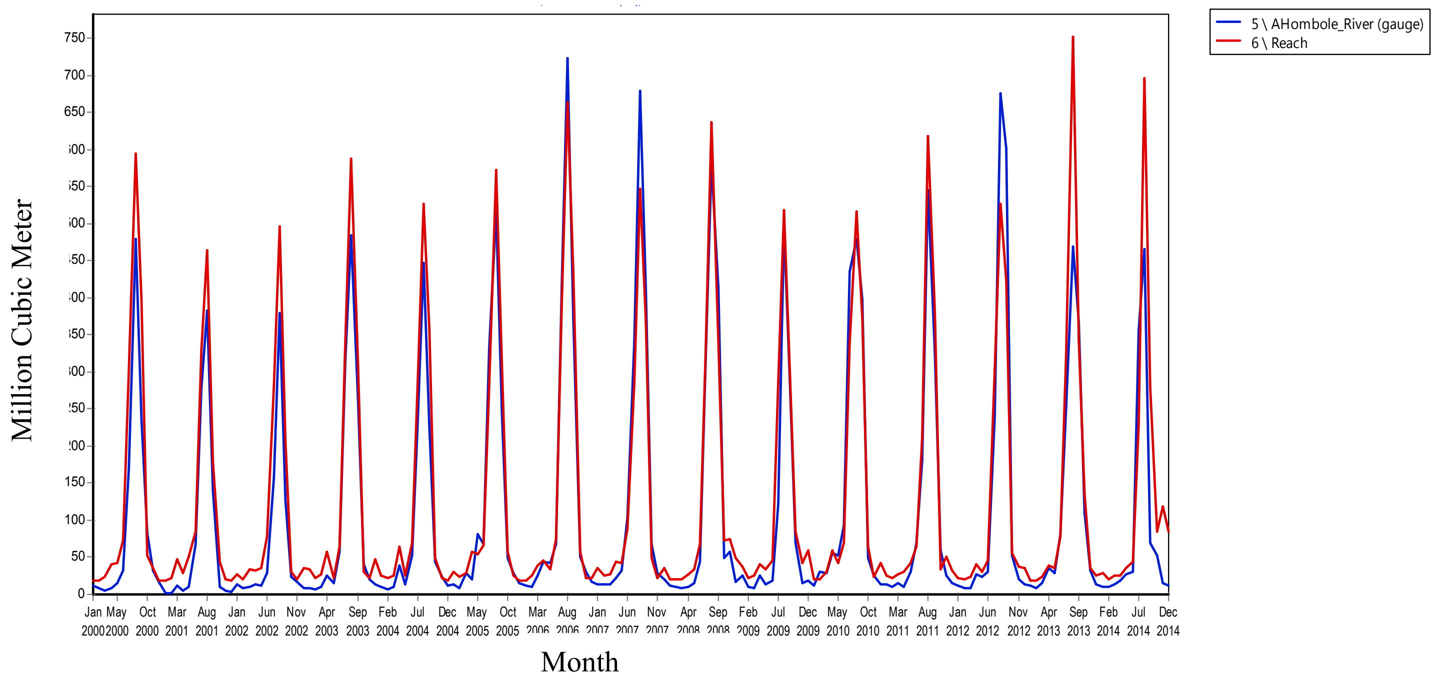
In order to validate the calibrated of the hydrological model, it was necessary to run the model out of the calibrated time range of data this is because of more represent the catchments characteristic than calibration to make sure the output results are valuable. The validation data range for each stream flow gauging stations are as follow. For the M/Kunture gauging station, data for the period (1997-2005) were used for validation; (2000-2006) for Akaki while (2000-2014) data were used to validate flow at Hombole and (2001-2014) for Mojo gauging station. The results of the model validation were presented in Figures 5.3a-d. For all the selected stations, simulated monthly flows were closed to the naturalized or observed flows. On the other hand the relationship between these flows data indicates a very good correlation for the selected stations. In general the model performance was well in simulating stream flow data by giving correlation coefficient of (R^2) values 0.86, 0.63, 0.91 and 0.54 for M/Kunture, Akaki, Hombole and Mojo stations respectively, but in case of Mojo gauging station the correlation value was much less than the other three stations because of the land use and land cove the of the sub-basin changed after 2000 years which was less amount of runoff generation. The correlation values were approaching to one as the scattered points are along the trend line. Now the model statistical validated result shows very good performance in reproducing all its outputs needed for analyzing the scenarios result.



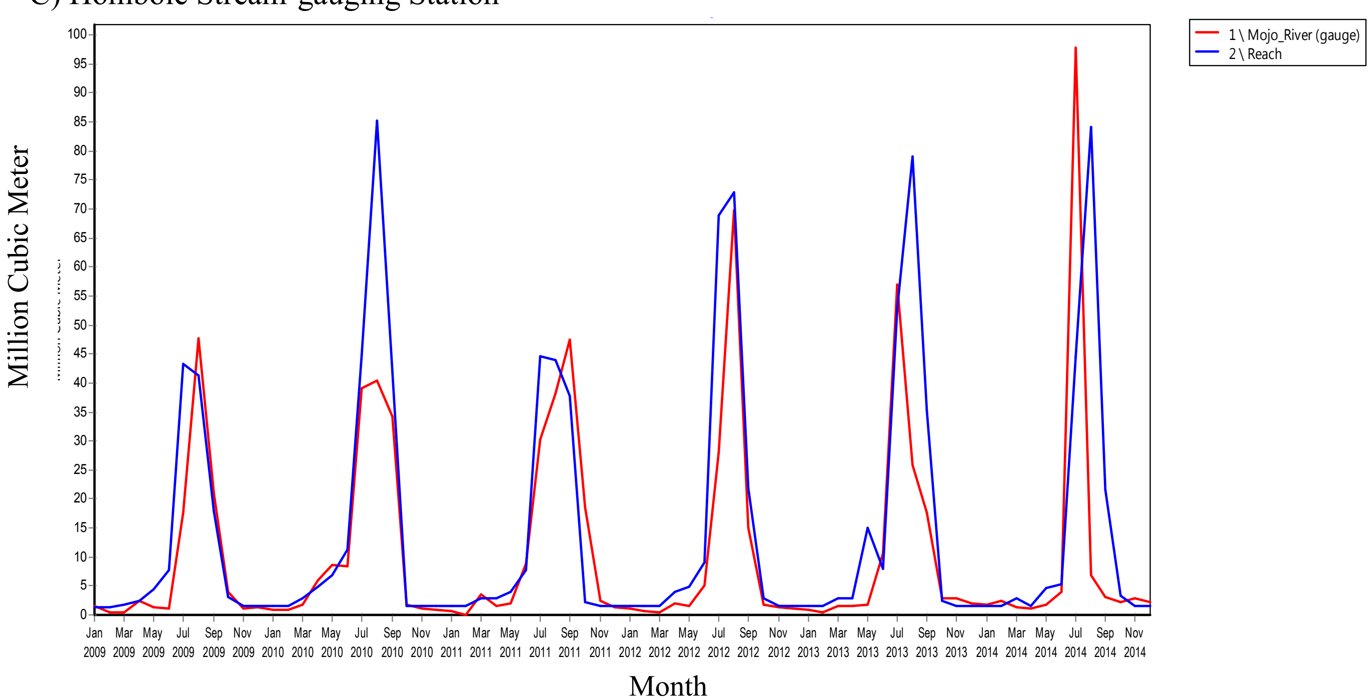
A) M/Kunture Stream - gauging Statıon



B) Akaki Stream-gauging Station

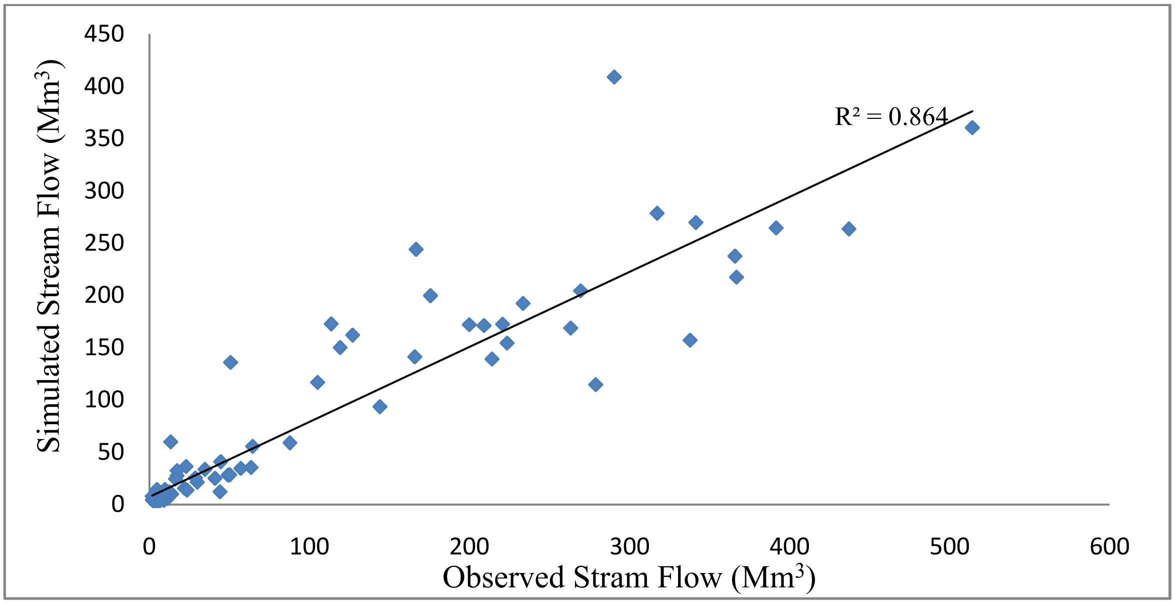


C) Hombole Stream-gauging Station

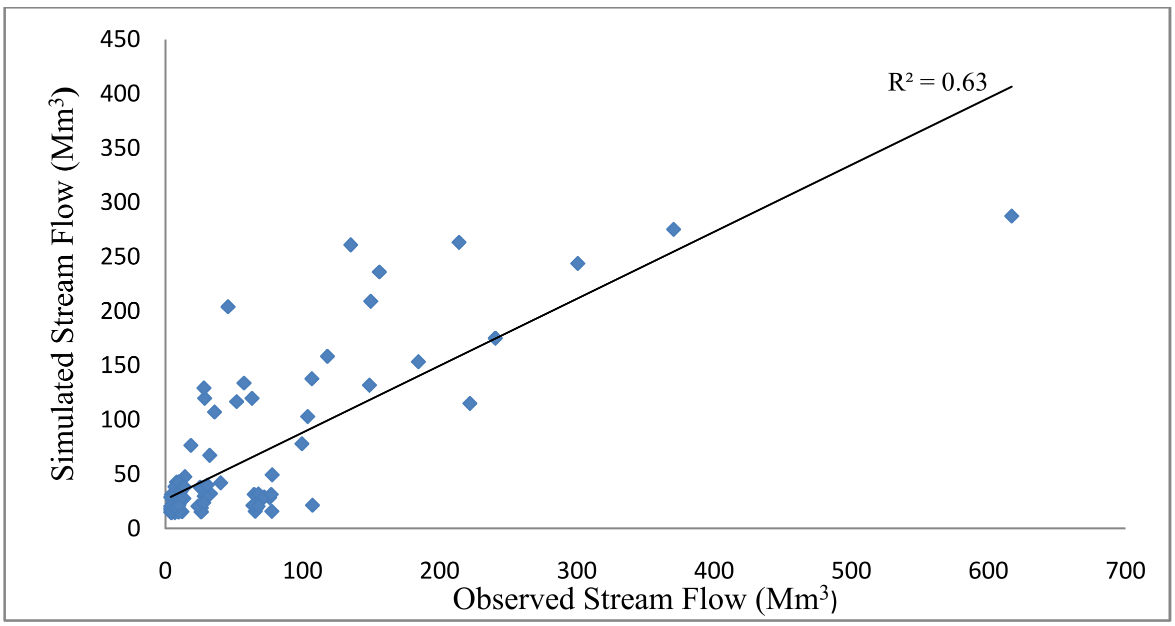


D) Mojo Stream - gauging Station

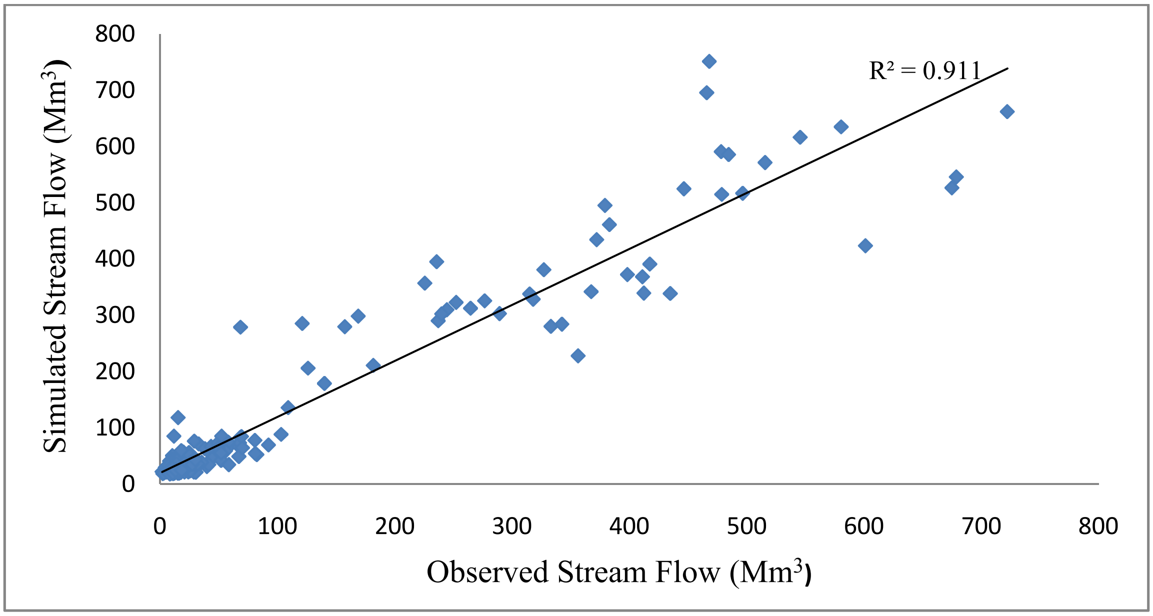
Figure 5. 3 Monthly variation of observed and simulated stream flows for the validation period; (a) M/Kunture, (b) Akaki, (c) Hombole, and (d) Mojo.



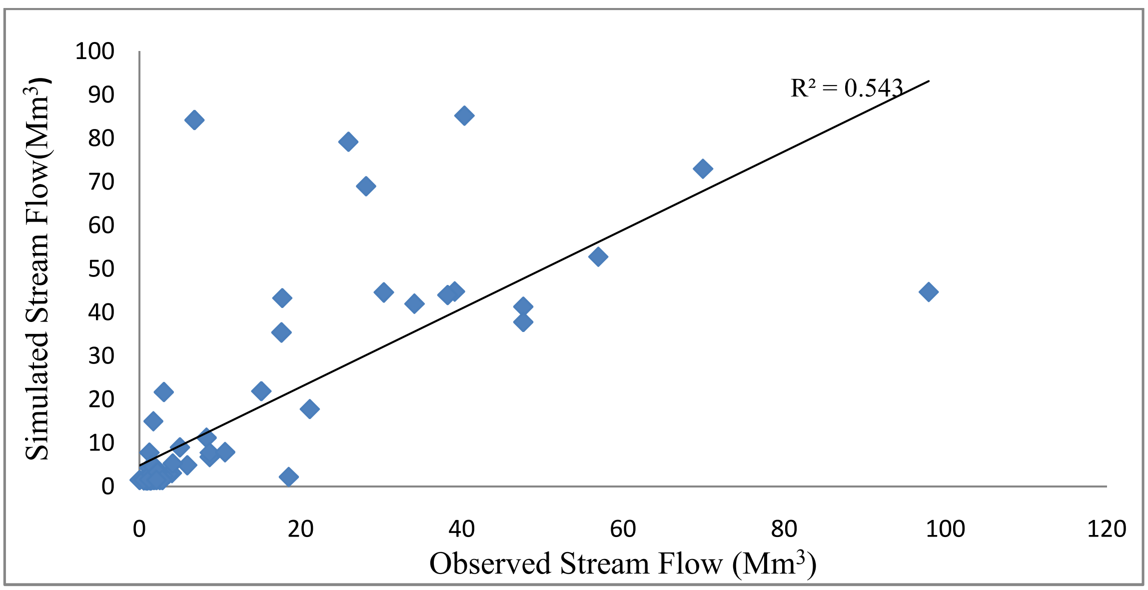
A) M/Kunture Stream-gauging Station



B) Akaki gauging station.



C) Hombole gauging station.



D) Mojo gauging station.

Figure 5. 4 Relationship between monthly observed and simulated streamflows for the validation period for the stations: (a) M/Kunture, (b) Akaki, (c) Hombole, and (d) Mojo.

5.1.2.3 Statistical analysis

Table 5.2 shows the statistical summary of the comparison between simulated and observed stream flow values for the calibration period. Little differences were observed on the correlation mean value of stream flows between M/Kunture, Hombole and Mojo stations in the calibration period. Here the Akaki stream flow statistical measure value was less than the other three stations due to land use and land cover change as the result of urbanization. Likewise, as it was mentioned above, the correlation coefficient (R2), and Nash-Sutcliffe Coefficient (NSE) were used to measure the variation between the model outputs and the observed flows. This behavior shows that the small differences between simulated and observed values of stream flow data.

Table 5. 2 Comparison of observed and simulated mean monthly stream flows for calibration period.

Gauging stations	Correlation Coefficient (R2)	Nash-Sutcliffe Coefficient (NSE)
M/Kunture	0.85	0.73
Akaki	0.73	0.65
Hombole	0.89	0.83
Mojo	0.91	0.85

Table 5.3, is statistical summary for the validation period, the Nash-Sutcliffe Coefficient (NSE) ranges from 0.50 to 0.84 indicating a good agreement between modeled and observed flows. On the other hand, the Correlation Coefficient ranges from 0.73 to 0.91 and from 0.54 to 0.91 for the calibration and validation period, respectively (Tables 5.2 and 5.3), showing a very good agreement between simulated and observed in calibration and validation data analysis period. Larger correlation coefficients exist in the basin stations located, at M/Kunture and Hombole. Uncertainties in the measured data, and the average climatology data used for each sub catchment, as well as the complex hydrological characteristics of the upper Awash basin, influences the relationship behavior of statistical measure of the data.

Table 5. 3 Comparison of observed and simulated mean monthly stream flows for validation period.

Gauging stations	Correlation Coefficient (R2)	Nash-Sutcliffe Coefficient (NSE)
M/Kunture	0.86	0.73
Akaki	0.63	0.50
Hombole	0.91	0.84
Mojo	0.54	0.68

In common, when it was seen each and every stations under calibration and validation period; the statistical correlation value measure of M/Kunture station shifted from 0.85 to 0.86 and no change in case of NSE value this shows that there is the change but in little amount of land use and land cover change. while the statistical measure value of Akaki steam flow gauging and simulated relation were seen 0.73 to 0.63 and 0.65 to 0.50 change were observed in correlation value and Nash-Sutcliffe Coefficient respectively. this is due to urbanization development of the sub-basin. In case of Hombole stream flow station the change not seen in both statistical measure value, from this what understanding is no significant change of land use. Now the significant change was seen in case of Mojo stream flow observed and simulated statistical value from 0.91 to 0.54 and 0.85 to 0.68 in terms of correlation coefficient and NSE values respectively. this change is the great change on land use and land cover of the sub-basin. However, there is the change in little significant and more significant on the sub-catchment land use still the statistical measure value indicates that the simulated result of the mode was the acceptable result due to the measure were in the range of acceptance.

5.2 Scenarios and results of WEAP Model Analysis

The scenarios result were structured and explained in terms of the following layout under climate change and irrigation expansion scenarios.

The results will be explained with regard to:

- Reservoir Capacity
- Evaporation from the reservoir
- Downstream water demand

5.2.1 Climate change scenarios

5.2.1.1 Basin temperature

The changes in climate also affect temperatures, as shown in Figure 5.5 Overall, it can be seen that there is an increase in the long-term average surface temperature of the catchment in the future scenarios in comparison to the baseline long-term average reservoir surface temperature. The average watershed temperature increases from 18.9^{o}C (baseline value) to 21.6^{o}C in 2015-2049, and to 24.6^{o}C in 2050-2084 time period.

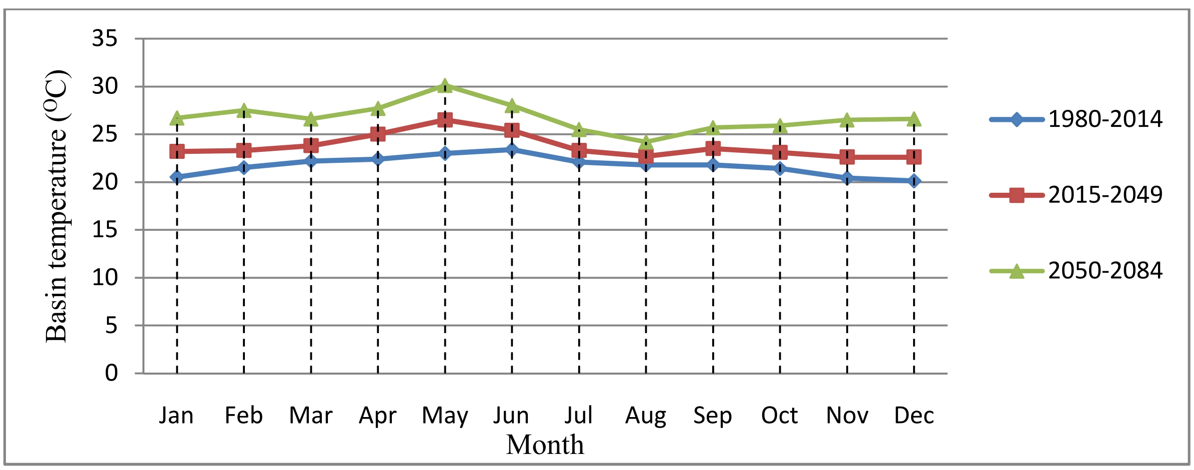


Figure 5. 5Mean Monthly upper basin temperature in deferent time period

The average monthly basin temperatures are expected to increase more significantly in May. For the 2015 - 2049 time periods, the increase was 2.7oC in relation to the baseline temperatures. For the 2050 - 2084 timeframe, the increase is even higher, at 5.7oC in comparison to the 1980 - 2014 temperatures. As with reservoir surface temperature, the average reservoir temperature is also expected to increase more significantly in spring than in the other seasons. Even small increases/decreases in this climatic variable will cause a significant change in evaporation.

5.2.1.2 Basin rainfall

The rainfall over the catchment shown in the figure 5.6 blow which look like fluctuating pattern but a little variation in the baseline year (1980-2014) after then a great variation for the future time period. The average rainfall of all over the upper awash catchment for the baseline period was 990.2mm. For the future rainfall of the watershed are 1622.6mm and 1559.3mm for the time period of 2015 to 2049 and 2050 to 2084 years respectively. In total there is an increase of rainfall on the watershed in the coming two consequent year when it is related to the current year but it is decreasing in (2050 - 2084) years when it is compared with the (2015 - 2049) period.

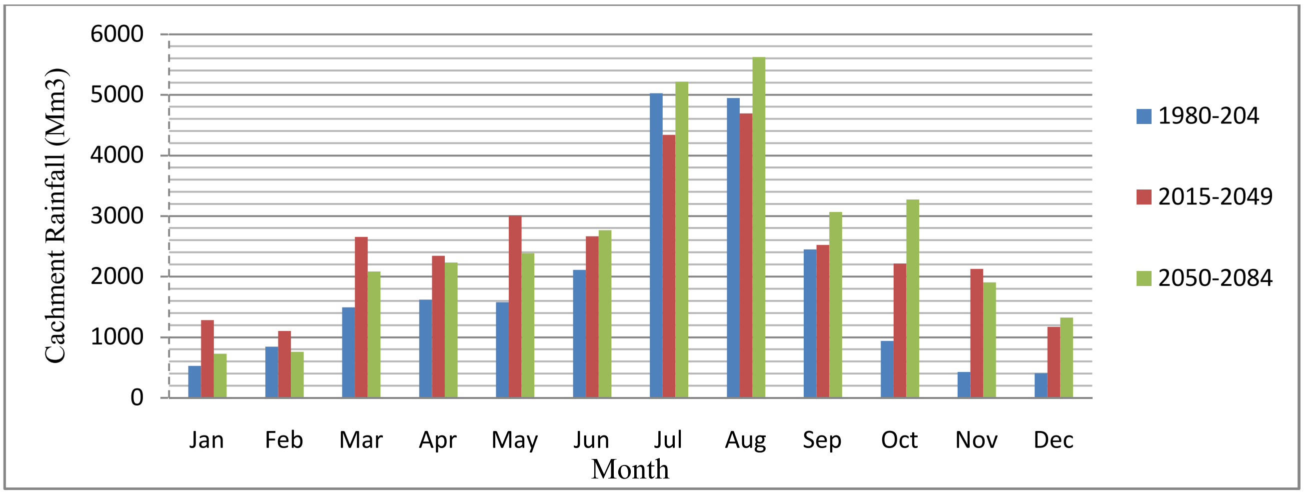


Figure 5. 6 Basin Monthly rainfall variables in deferent time period

5.2.1.3 Evaporation from the reservoir

This section describes the baseline scenario, giving emphasis to the driving forces of evaporation. The results of modeled reservoir evaporation in the present day scenario revealed that the reservoir has a variable trend. As it can be seen from Fig 5.7, the level in some months shows a rising while in some other a declining tendency. The maximum and minimum net evaporation rate were recorded for the month Oct and Aug with a value of 53.8 Mm3 and 16.3Mm3 the simulation period respectively and the annual evaporation was 404.5Mm3 for (1980-2014) years. Similarly The Koka reservoir monthly evaporation for future time period is shown in the same figure 5.7 and table5.4 blow, relative to the current baseline period. Compared to the baseline evaporation, the average annual evaporation in the period 2015-2049 will be 16.9Mm3 (4.2%) higher, and in the period of 2050-2084, is 22.3Mm3 (5.52 %) higher. In 2015-2049, annual evaporation is estimated to be 421.4Mm3, compared to the long-term annual evaporation in the present-day scenario of 404.5Mm3. When looking 2050-2084 periods the simulation of annual evaporation is 426.8Mm3. Generally the reservoir evaporation more in May, June and July months of the year this indicates that, the increase in temperature will also increases the average reservoir evaporation under the climate change scenario in more or less.

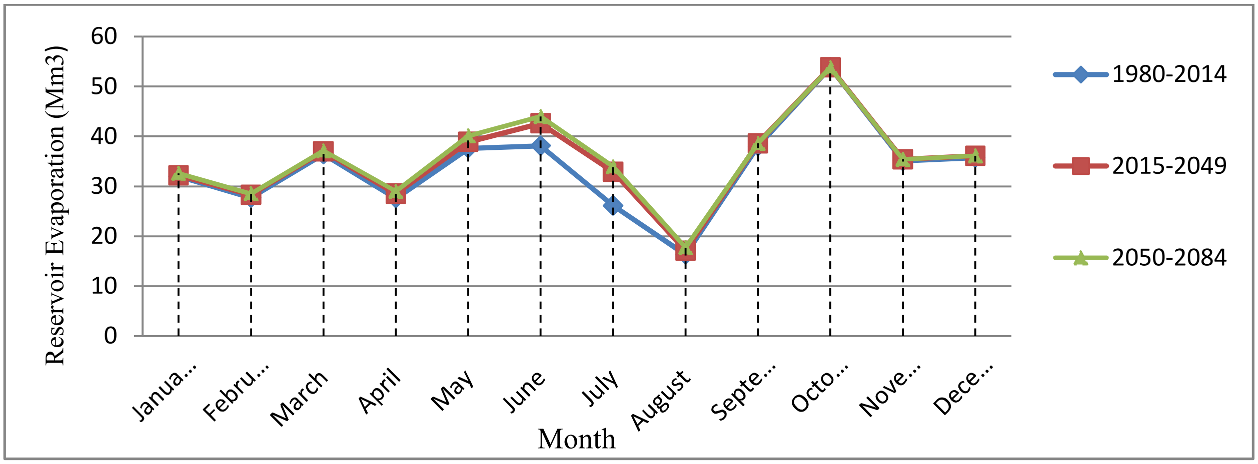


Figure 5. 7 Monthly evaporation of koka reservoir

Table 5. 4 Mean monthly evaporation of koka reservoir (Mm^3)

Period	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Annu
1980-2014	32	27.7	36.4	27.6	37.6	38.1	26.1	16.3	38	53.8	35.1	35.7	404.5
2015-2049	32.2	28.3	37	28.5	38.9	42.6	32.9	17.1	38.6	53.8	35.4	36.1	421.4
2050-2084	32.6	28.5	37.1	29	40.1	44	33.9	17.7	38.6	53.8	35.4	36.1	426.8

5.2.1.4 Reservoir inflows and outflows

Awash at Hombole and Mojo Rivers are major inflows for koka reservoir since the other rivers are the tributary of the two rivers. At the same time the areas downstream of the koka reservoirs are highly depends on the reservoir water release. The inflow of the reservoir has a fluctuating characteristic with the maximum at august and minimum at February while the total annual volume of inflow from upstream and the outflow volume to downstream of the reservoir were 1,638.6 Mm3 and 1,223.5 Mm3 respectively. In Jan, Feb, Mar, Apr, May, Oct, Nov and Dec there is no rainfall as the result the inflows less than the outflows and the reservoir volume decreased in those months but in Jun, July, Aug, and Sept the inflows greater than the out flows so the reservoir volume become increased. The table5.5 blow shows the monthly inflows and out flows of the Koka reservoir in the baseline year.

Table 5. 5 Monthly inflows and outflows of koka reservoir (Mm^3).

Flow	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Sum
Inflow	28.3	21.3	27.5	37.4	34.4	64.8	306.5	656.9	349.2	56.8	28.6	26.7	1,638.6
Outflow	84.0	72.6	80.4	77.8	80.1	74.5	80.4	164.8	270.4	80.5	77.8	80.4	1,223.5

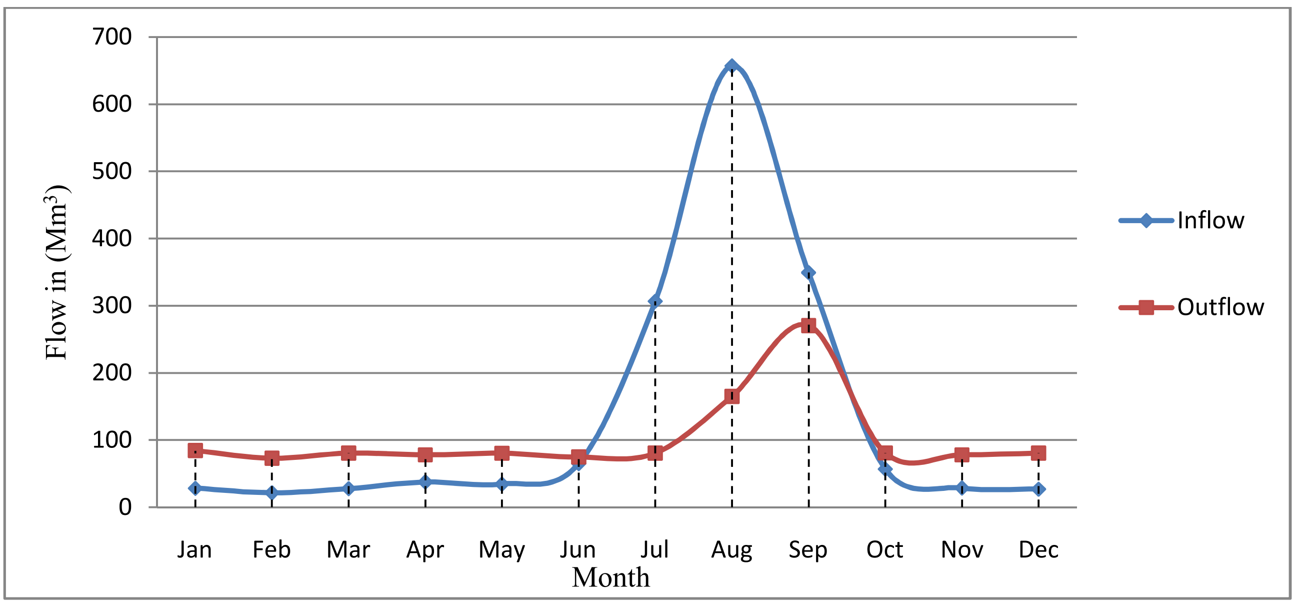


Figure 5. 8 Monthly Inflow and outflow of koka reservoir (Mm3) (1980 - 2014)

The above figure shows that the inflow and outflow of Koka reservoir in which the maximum inflow and outflow are at different position. Maximum inflow was in August, but for outflow it was in September, this is because of concentration time, a time which takes the runoff from remote place of the catchment to rich at outlet of the watershed. As the result of this the maximum outflow of the reservoir was during September.

5.2.1.4 Reservoir storage capacities

The results of reservoir storage capacity simulated show under climate change scenarios that some of the months are full, in the rainy months of August, September, and October but not in the other month. The minimum storage value was in June while the maximum reservoir storage was in the month of September. The annual average koka reservoir capacity under baseline year was 706.6Mm3 while, 804.2Mm3 and 832.2Mm3 in the coming 2015-2049 and 2050-2084 respectively within demand priority given to the reservoirs in the WEAP model was 3. Figure 5.9 shows the storages capacity of koka reservoirs operation.

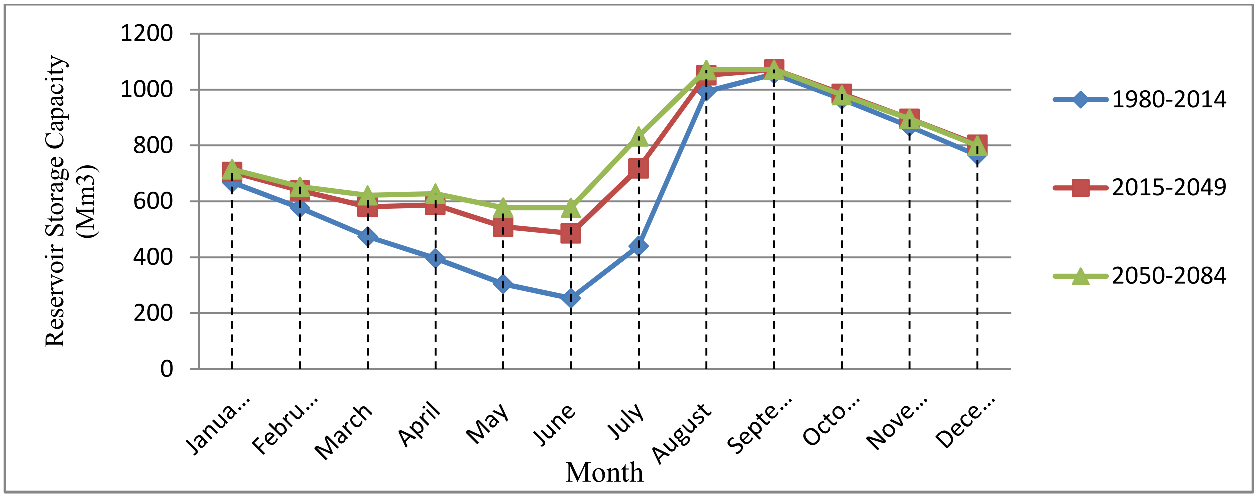


Figure 5. 9 Monthly Reservoirs storage capacity in million m3

Here the above result shows that the increments of the storage capacity of the reservoir between top of inactive and top of conservation zone due to temperature and rainfall increment on the catchment. It meam not that the reservoir can store beyond the maximum storage elevation (1590.7) msl , but seasonal average storage fluctuation of the reservoir due to the climate chenge ang irrigation exapansion scenarios between the minimum operational level and maximum out flow level of the reservoir as the result of the two scensrios. To make sure the reservoir operation in the future the following assumptions should be applicable: the dam height should be increased with minimum operational level gate height, the under sluice or bottom outlet should be in operational in order to scouring the silt deposited and upstream watershed should be conserved in order to minimize the silt deposition in the reservoir.

5.2.2 Irrigation expansion scenarios

5.2.2.1. Irrigation water demand

A key scenarios describing possible future irrigation situation in the lower Koka Basin have been defined. The starting point for the scenarios is an assumption that in line with the new Water Resources Management Strategy, the overriding policy is to prioritize the development of irrigation areas to their full potential. Working from this assumption, the Koka reservoir dam in the basin have been selected for simulation of irrigation water supply in downstream Irrigation Schemes. According to simulation results, the Reservoir had an average monthly capacity of 706.6MCM in the current scenarios.

The recent irrigation expansion coverage was 36,266ha while forecast potential irrigation area is 22,394 ha for upper awash, downstream of Koka, giving a total irrigable potential of 58,660ha (FAO Awash Water Audit document, 20013). The Scenario shows the utilization of the full irrigation potential with the Koka reservoir capacity water release.

The model result gives the monthly average water demand and annual summation demand for downstream Irrigation Scheme. The total net amount of water required to meet the irrigation demands of all the sites from 1980 to 2014 was 947.72Mm3 May, Jun and October months relatively with maximum demand requirements while July and August ware the minimum demand requirements than other months because of rain season.

Table 5. 6 Monthly average irrigation water demand for each site in current scenario (Mm3) (1980-2014)

Schemes	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Sum
Irr_AAwash	8.9	10.0	14.3	12.4	10.9	11.8	1.2	3.0	8.4	11.0	10.9	8.5	111.3
Irr_Arba	4.9	5.1	4.5	4.6	6.7	6.1	1.4	0.6	1.3	1.9	4.6	5.2	46.9
Irr_Fentale	13.2	10.3	6.0	10.3	15.0	15.1	16.7	26.1	41.1	25.3	14.0	14.1	207.4
Irr_Keleta	2.8	3.9	5.5	4.5	3.3	3.9	0.0	0.0	6.8	10.5	7.3	5.6	54.1
Irr_Metehara	20.3	19.7	18.9	19.7	23.2	25.1	12.0	10.6	19.4	22.3	19.4	20.4	231.1
Irr_Nurahera	8.6	7.9	7.9	7.4	8.8	8.0	0.0	0.0	5.1	8.7	9.1	8.6	80.0
Irr_Tibela	0.4	0.4	0.3	0.3	3.9	0.3	0.1	0.0	0.1	0.2	0.3	0.3	6.4
Irr_Wonji	18.1	17.6	17.5	18.1	21.1	21.9	16.5	13.1	11.8	19.9	17.2	18.0	210.7
Sum	77.1	74.7	74.9	77.2	92.9	92.2	47.8	53.4	94.0	100.0	82.8	80.7	947.7

According to 1980 to 2014 the total monthly water demand for the downstream koka Irrigation results comparison shown on Figure 5.10 blow for current water demand schemes.

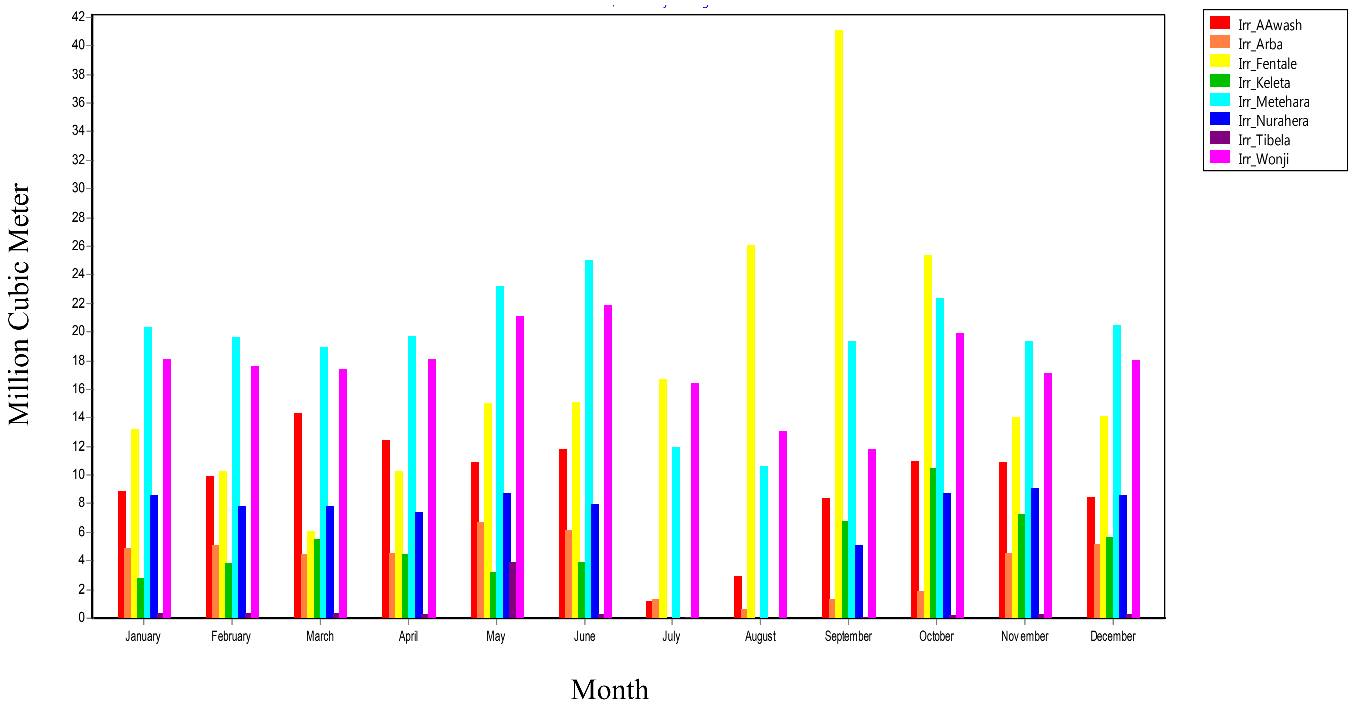


Figure 5. 10 Monthly average Current demands (without including losses)

5.2.2.2 Supply delivered

The total net amount of water delivered to the irrigation site from the water required to meet the irrigation demands of all the sites from 1980 to 2014 was 946.7 Mm^3. Similarity May, Jun and October months were with maximum demand delivered while July and August were the minimum demand than the other months, this difference between the amount of water demand and the amount of water delivered shows that there was the unmet demand.

Table 5. 7 Monthly average supplies delivered for each demand site in current scenario (Mm^3)

CommandAreas	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sept	Oct	Nov	Dec	Sum
Irr_AAwash	8.9	10	14.3	12.4	10.9	11.8	1.1	3	8.4	11	10.9	8.5	111.2
Irr_Arba	4.9	5.1	4.5	4.6	6.7	6.1	1.4	0.6	1.3	1.9	4.6	5.2	46.8
Irr_Fentale	13.2	10.3	6	10.3	15	15.1	16.7	26.1	41.1	25.3	14	14.1	207.4
Irr_Keleta	2.8	3.9	5.5	4.5	3.3	3.9	0	0	6.8	10	7.1	5.4	53.1
Irr_Metehara	20.3	19.7	18.9	19.7	23.2	25	11.9	10.6	19.4	22.3	19.4	20.4	231.1
Irr_Nurahera	8.6	7.9	7.9	7.4	8.8	8	0	0	5.1	8.7	9.1	8.6	80
Irr_Tibela	0.4	0.3	0.3	0.3	3.9	0.3	0.1	0	0.1	0.2	0.3	0.3	6.4
Irr_Wonji	18.1	17.6	17.4	18.1	21.1	21.9	16.5	13.1	11.8	19.9	17.2	18	210.7
Sum	77.1	74.7	74.8	77.2	92.9	92.2	47.7	53.4	94	99.5	82.6	80.5	946.7

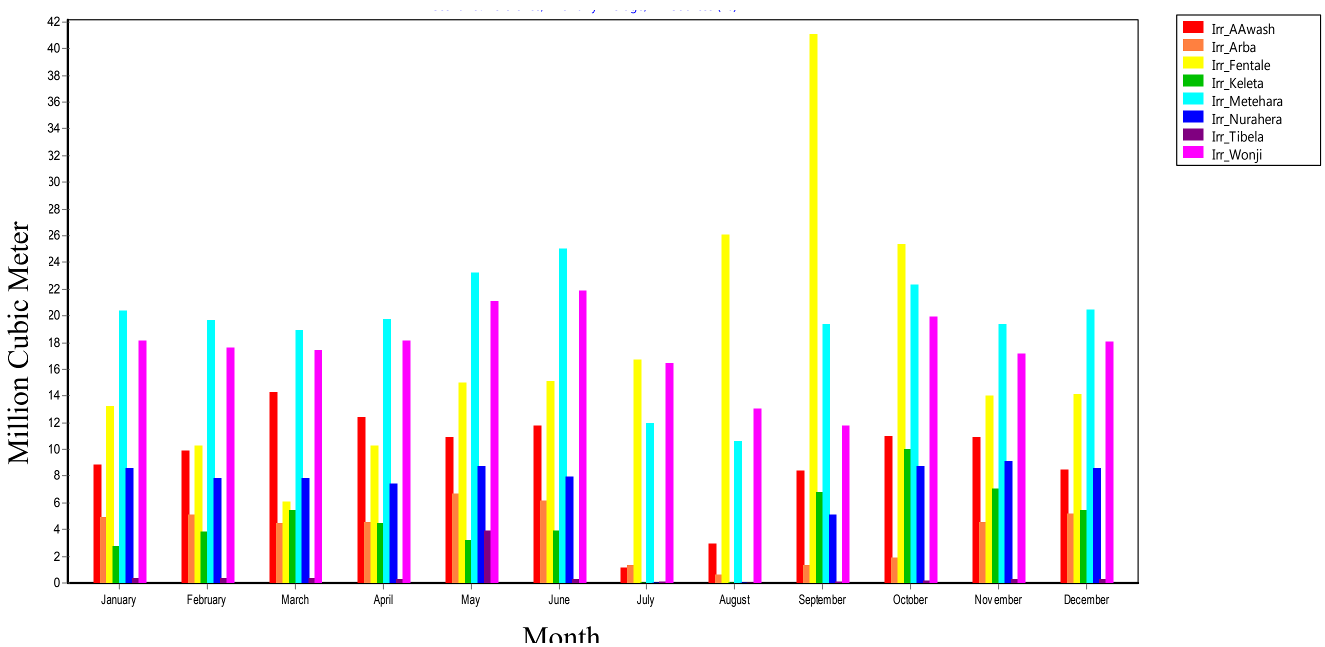


Figure 5. 11 Monthly average supplies delivered for all demand sites in current scenario

5.2.2.3 Unmet water demand

Unmet demand is the supply requirement that is not met. In other words unmet demand is the differences between supplies require and supply delivered at particular demand site and in the time duration. In this analysis the important quantity of unmet demand in the current and future were observed in some demand site of irrigation water supplies.

Among the total water requirement of the current scenario (947.7MMC), 1.0 MMC (0.1% of the total demand) was unmet from years 1980 to 2014 for all cumulative demands. Similarly in the coming future scenario analysis among the total water requirement (1659.1 MMC), the unmet demand observed is 9.8 MMC for the years 2015 to 2049. These situation shows that, the expected expansion of irrigation will not meet the demand required, in other ways the water release of the reservoir and the demand not matched in the coming future period even at present time the keleta Irrigation demand did not met. Table 5.8 and 5.9 with their respective figures below show the average monthly unmet demands of all sites in the current and future scenarios respectively.

Table 5. 8 Mean monthly unmet demands for each demand site (MMC) with respect to current scenario.

Command Areas	Jan	Feb	Mar	Apr	Ma	Jun	July	Aug	Sept	Oct	Nov	Dec	Sum
Irr_AAwash	0	0	0	0	0	0	0	0	0	0	0	0	0
Irr_Arba	0	0	0	0	0	0	0	0	0	0	0	0	0
Irr_Fentale	0	0	0	0	0	0	0	0	0	0	0	0	0
Irr_Keleta	0	0	0.1	0	0	0	0	0	0	0.5	0.2	0.2	1
Irr_Metehara	0	0	0	0	0	0	0	0	0	0	0	0	0
Irr_Nurahera	0	0	0	0	0	0	0	0	0	0	0	0	0
Irr_Tibela	0	0	0	0	0	0	0	0	0	0	0	0	0
Irr_Wonji	0	0	0	0	0	0	0	0	0	0	0	0	0
Sum	0	0	0.1	0	0	0	0	0	0	0.5	0.2	0.2	1

Table 5. 9 Mean monthly unmet demands for each demand site (MMC) with respect to future scenario (2015-2049)

Command Areas	Jan	Feb	Ma	Apr	Ma	Jun	July	Aug	Sep	Oct	Nov	Dec	Sum
Irr_AAwash	0	0	0	0	0.4	0.1	0	0	0	0	0	0	0.5
Irr_Arba	0	0	0	0	0	0	0	0	0	0	0	0	0
Irr_Fentale	0	0	0	0	1.4	0.3	0	0	0	0	0	0	1.7
Irr_Keleta	0	0	0	0	0.1	0	0	0	0	0	0	0	0.1
Irr_Metehara	0	0	0	0	0.8	0.2	0	0	0	0	0	0	1.0
Irr_Nurahera	0	0	0	0	0.3	0	0	0	0	0	0	0	0.4
Irr_Tibela	0	0	0	0	4.7	0.1	0	0	0	0	0	0	4.7
Irr_Wonji	0	0	0	0	1.2	0.2	0	0	0	0	0	0	1.4
Sum	0	0	0	0	9.0	0.9	0	0	0	0	0	0	9.8

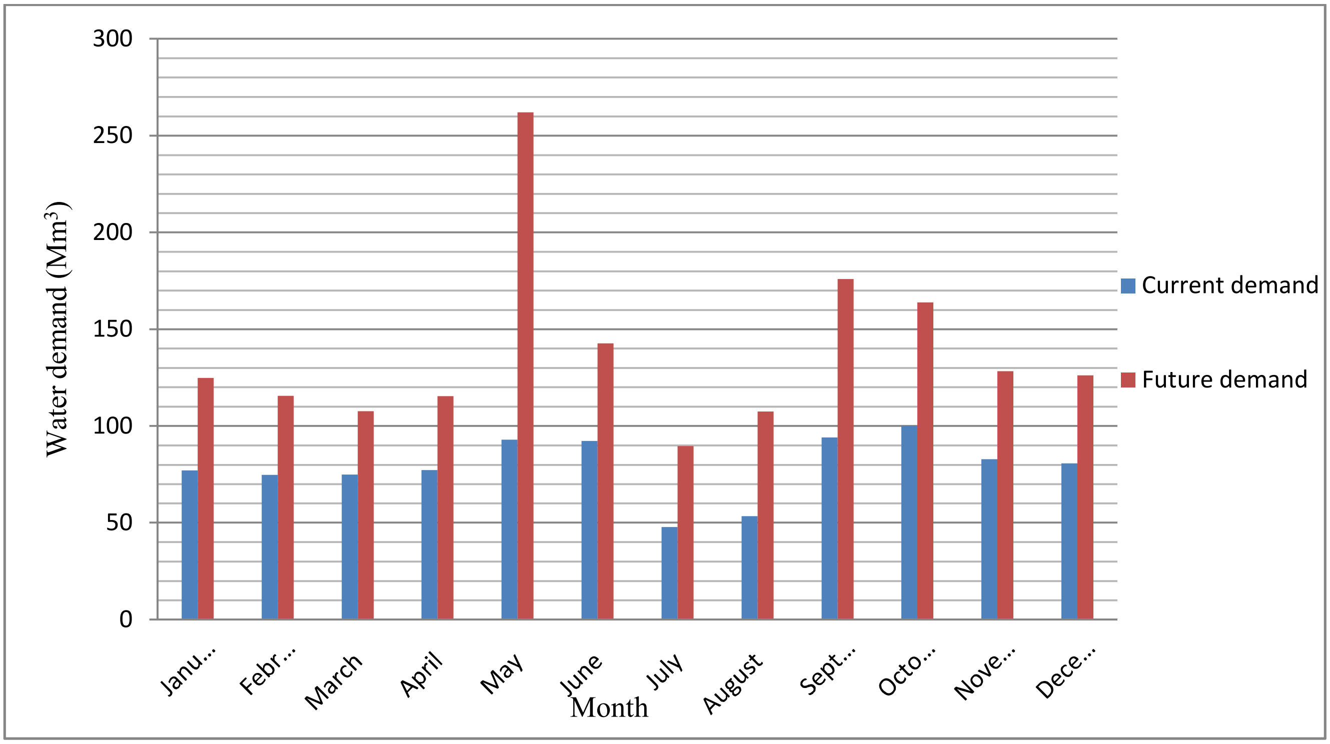


Figure 5. 12 Meam monthly current and future water demand

5.3 The two scenarios combination result

The combination effects of climate change and irrigation expansion scenarios together are seen blow. At the current scenario the exiting irrigation schemes are satisfied under the present climate condition. But in the future due to climate change scenario the reservoir storage volume increases even at June which is the minimum storage volume of the reservoir increase with 236.32Mm3 and 312.92 Mm3 in two consecutive 35 years. Although, the evaporation from the reservoir increased in the coming two 35 years, the amount of water stored in the reservoir will not deceased since the inflow to the reservoir increase with temperature increase and rainfall fluctuation in the upper catchments. This shows that the climate change scenario will not have negative effect on the reservoir storage volume rather than positive. In the future under the combination of the scenarios it will be unmet demand mainly in May and June by 8.9Mm3 on irrigation expansion if the current minimum flow requirement is applied in the future, but this scarcity can overcome by increasing the minimum flow requirement. This indicates the unmet demand is not the case of climate change it is due to the irrigation expansion which do not consider the water release of the reservoir to downstream. The following figure 5.13 shows the combination scenarios unmet demand result.

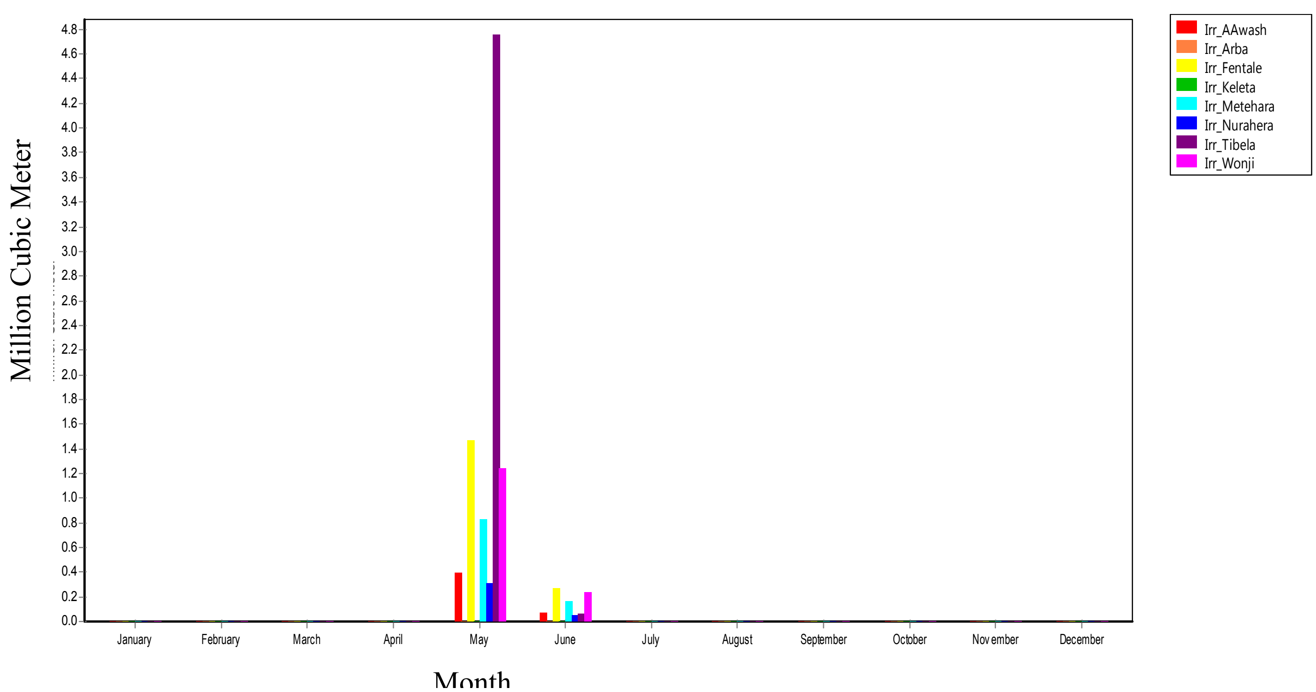


Figure 5. 13 combination scenarios unmet demand

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study analyzed the effects of climate change and irrigation expansion scenarios on koka reservoir water allocation using WEAP model. This thesis analyzed the effect of climate change on the reservoir and the downstream irrigation development which depend on the water release of Koka reservoir for its demand supply for the current and future development by considering the under sluice scouring is in operation and other development are insignificant. First the meteorological missed data due to misreading and failed of the gauging instruments were filled by multi-regression method. The filled data consistencies were then checked by double mass curve. For the RCM data the bias were checked and evaluated using R2, NSE, and PBIAS. The WEAP model also calibrated and validated using simulated and observed stream flow data of M/Kunture, Akaki, Hombole and Mojo gauging stations. The performance evaluation of the model confirmed that the statistical measure parameters were very good and the model can be used to simulate future stream flow with the climate change and irrigation development effect in the basin.

For the climate change scenario, the volume of reservoir evaporation in the (1980-2014) period was 404.5Mm3 and for the coming (2015-2049) and (2050-2084) the volume of evaporations are 421.4 and 426.8Mm3 respectively. While compared with the baseline period, the first 35 years the reservoir evaporation will increased by 16.9Mm3 and 22.3Mm3 for the second 35 years, even if the reservoir evaporation in the future become increase it has no effect on reservoir volume since the rainfall in the coming period increase in relative to the current scenario and shows the rainfall much greater than the evaporation.

Even though the Koka Reservoir water is available, the unmet demand is increased by 8.9Mm3 in all irrigation areas in the coming future time period; this is because of the current reservoir flow release is not proportional with irrigation expansion in the future, but unmet demand is not too much and it can be compensate with additional reservoir flow release.

At the end the Water Evaluation and Planning System (WEAP) Model has been found to be useful as an Integrated Water Resources Management tool for balancing water supply and demand for current and future scenarios in a priority ways of allocation.

6.2 Recommendations

Several recommendations can be derived from the results obtained and its analysis. They can be as the follow:

- Some stream flow gauging measurement are changed most of the time after 2005; this is because of land use and land cover change like that of Akaki and Mojo gauging stations which is due to urbanization and industrial development in case of Akaki which causes two problems. One, the development of high runoff generation due to land pavement, resulting downstream flooding or high amount of runoff generation. The second, result is high amount of CO_2 gas emission to atmosphere which contributes for the climate change in Ethiopia. These two things have to have optimized, in the ways of planting trees and developing watershed conserving structures beside of the development in order to minimize high runoff generation, sedimentation inflow to the reservoir and high concentrations of CO_2 emission to the atmosphere.
- The conservational measure structures on upper awash basin should be constructed like bunds; terraces, planting trees etc. and farmers should be encouraged on climate change adaptation measures through crop tolerating to water scarcity in the future should be cultivated.
- Additional reservoir flow release on the current minimum flow requirement or constructing reservoir or water harvesting structure for supplying the future unmet demand amount beside of the currently existing reservoir supply.
- The bottom outlet of the dam should be put in operation to help in scouring deposited silt in dam axis area and also to supply water for downstream uses. In addition to this increasing dam height with minimum operational gate opining height.

REFERENCES

Abayneh, A. (2011) Evaluation of Climate Change Impact on Extreme Evaluation of Climate Change Impact on Extreme Hydrological Event Addis Ababa University. Addis Ababa.

Abebe, D.; Jaap, E.; Seimon, L.; and Taye, A. (2011). Irrigation practice and policy in the low lands of the Horn Africa contribution to FAO Expert Meeting 24-25 November 2011, Nairobi.

Agizew, N. and Geremew, S. 2015. Climate Modeling of the Impact of Climate Change on Sugarcane and Cotton for Project on 'a Climate Resilient Production of Cotton and Sugar in Ethiopia'. Ethipian development Research Institute, Addis Ababa, Ethiopia February 2015.

Ahmed, S.P. and Sayed Nawal S. 2015. Efficient allocation of scarce water resources and irrigation water management in Egypt. ISSN 2375 - 0693 Vol. 3 (1), pp.176-184.

Awulachew, S. B.; Yilma, A. D.; Loulseged, M.; Loiskandl, W., Ayana, M.; Alamirew, T. (2007). Water Resources and Irrigation Development in Ethiopia. Colombo, Sri Lanka: International Water Management Institute. 78p. (Working Paper 123).

Azman, B. (2007) Impact of Climate Change on Water Resources Availability in the Komati River Basin Using WEAP21 Model. At the UNESCO-IHE Institute for Water Education, Delft, the Netherlands.

Birhanu, A. (2008). Water Allocation Study of Upper Awash Valley for Existing and Future Demands, Addis Ababa University. Addis Ababa.

Daniel, A. (2011) Water Use and Operation Analysis of Water Resource Systems in Omo Gibe River Basin. Addis Ababa University. Addis Ababa.

Emerta, A. (2013) climate change, growth, and poverty in Ethiopia. The Roberts. Strauss center, working paper No.3.

Endalkachew, G. (2012) Climate Change Impact on Surface Water Sources of Addis Abab case study Legedadi-Dire-Gefersa Catchments and Reservoirsa. Addis Ababa institute of Technology, Addis Ababa.

FAO and MoWIE (2013) Developing a Water Audit for Awash River Basin. GCP/INT/072/ITA Addis Ababa, Ethiopia.

G. H. Fang, J. Yang, Y. N. Chen1, and C. Zammit (2014) Comparing bias correction methods in downscaling meteorological variables for hydrologic impact study in an arid area in China. EuropeanGeosciencesUnion. doi:10.5194/hessd-11-12659-2014

Habtom, M. (2009) Evaluation of Climate Change Impact on Upper Blue Nile Basin Reservoir,Arba Minch University. Arba Minch.

Hague, S. (2013) Issues Paper Water Governance Capacity Awash Basin, Central Ethiopia.

H.Y. Gebretsadik, N. Schütze, R. Müller, (2016) 7th International Water Resources Management Conference of ICWRS, 18–20 May 2016, Bochum, Ger many, IWRM 2016-95-2.

Haileyesus, B. (2011) Evaluation of Climate Change impacts on hydrology on selected catchments of Abbay Basin. Addis Ababa University. Addis Ababa.

IPCC (2000): A Special Report of IPCC Working Group III Summary for Policymakers. ISBN: 92-9169-113-5

IPCC (2001): the scientific basis technical summary of the working group I report. Cambridge university press, New York, 94pp.

IPCC (2007): Technical paper VI Climate change and Water.

IPCC (2014) Summary for Policymakers integrated view of climate change as the final part of the IPCC's Fifth Assessment Report (AR5).

Kenneth, D.; Frederick, Senior, F. (1997) Water Resources and Climate Change, Washington, DC.

Kinfe, H. (1999) Impact of climate change on water resource of Awash River basin. Clim Res, Vol .12: 91-96, National Meteorological Services Agency, Addis Ababa.

Marius, k. (2009) Assessment report for a community-level Project. Bread for all, in Guduru, Oromiya, Ethiopia.

OWWDSE (2014) Upper Awash Sub Basin Integrated Land Use Planning Study. Addis Ababa.

Reuben, N. (2007) Application of the WEAp Model in Integrated Water Resources Management of the Nyando River Basin, Kenya. Jomo Kenyatta University.

Stockholm Environment Institute (SEI), (2015). WEAP: Water Evaluation and Planning System-User Guide. Stockholm Environment Institute, Boston, USA.

Tigist,T. (2009) Water Resource Utilization and Its Related Effects Lake Abiyata and the Surrounding. Addis Ababa University, Addis Ababa Ethiopia.

WWDSE (2015) Walenchiti Feasibility Report On Climate & Hydrological Study. Addis Ababa Ethiopia.

Zemade, A. (2011) Assessing pathways, synergies & tradeoffs in alleviating poverty through sustainable ecosystem services in Sub-Saharan Africa; Situational Analysis 3 Ethiopia & the River Awash Basin. Ripple Office Addis Ababa (Ethiopia).

APPENDIX-1 Hydrological Data

Station name: M/Kunture

Element: Monthly total stream flow (m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	1.13	1.28	1.79	1.32	0.93	6.79	79.09	140.41	53.12	6.28	1.60	1.02	294.8
1981	1.10	0.86	3.15	7.91	2.35	2.64	65.12	126.80	114.36	13.46	3.01	2.30	343.1
1982	1.64	2.13	1.62	2.77	3.18	4.62	32.01	116.69	51.41	25.31	3.27	2.13	246.8
1983	1.20	1.79	2.84	5.02	12.66	12.83	40.60	141.41	90.75	8.65	2.78	1.83	322.4
1984	1.44	0.85	0.93	0.50	1.02	18.06	69.17	85.01	68.10	4.86	1.36	0.91	252.2
1985	0.61	0.44	0.47	1.15	1.49	10.11	60.77	155.36	66.51	6.22	1.58	1.00	305.7
1986	0.59	0.75	1.56	2.67	3.19	14.39	45.27	100.86	66.83	11.07	1.51	0.99	249.7
1987	0.73	1.02	4.74	11.51	8.82	16.53	31.82	87.69	26.48	4.54	1.53	1.02	196.4
1988	0.73	0.67	0.53	1.21	1.12	6.06	42.29	156.12	110.88	13.22	2.22	1.41	336.5
1989	1.53	2.31	1.80	4.24	1.23	4.21	69.77	97.22	82.28	7.39	2.09	1.61	275.7
1990	1.11	3.87	3.70	6.59	1.36	6.03	51.85	124.08	73.89	10.63	2.06	1.38	286.6
1991	1.16	1.23	3.68	0.87	0.79	4.77	61.68	133.36	90.23	5.31	1.54	1.40	306.0
1992	1.23	2.45	1.20	2.33	2.11	9.47	43.25	118.22	79.76	10.12	2.35	1.82	274.3
1993	1.55	2.21	1.02	7.21	7.57	19.54	73.41	171.21	108.23	19.28	3.56	2.14	416.9
1994	1.64	1.05	1.21	1.82	1.53	8.67	46.57	111.73	74.46	10.26	2.74	1.72	263.4
1995	1.25	1.11	0.85	4.40	3.60	7.29	45.91	113.21	74.58	4.63	1.88	1.22	259.9
1996	2.17	0.76	3.51	7.24	8.53	41.22	110.99	195.16	85.09	7.74	2.87	2.03	467.3
1997	1.82	1.14	0.86	2.28	1.63	6.73	47.40	87.18	19.56	5.01	3.98	1.67	179.3
1998	2.37	1.49	4.22	2.08	4.75	17.19	82.37	191.98	103.97	24.07	3.57	2.15	440.2
1999	1.60	0.92	1.38	0.65	1.83	8.83	78.03	108.42	43.83	32.78	3.45	1.76	283.5
2000	1.54	0.95	0.73	1.84	2.86	6.70	44.50	118.46	67.75	18.38	3.73	2.42	269.9
2001	1.66	1.41	2.97	2.48	5.23	24.51	79.92	136.95	55.56	6.10	2.96	2.21	322.0
2002	3.42	1.89	2.38	4.85	2.01	13.43	61.91	127.48	40.56	3.63	1.70	1.99	265.3
2003	1.79	0.95	2.90	4.58	3.22	15.82	126.13	146.19	101.58	8.19	2.78	2.16	416.3
2004	2.08	1.29	1.34	9.05	2.90	22.04	83.42	136.62	64.26	11.17	3.12	1.99	339.3
2005	1.84	0.86	3.70	3.74	16.48	19.36	104.11	163.21	77.11	10.72	3.37	2.60	407.1
2006	1.59	1.18	6.67	9.15	18.46	22.03	143.22	302.08	104.68	7.15	3.04	1.99	621.2
2007	1.39	1.83	1.49	2.61	4.64	41.97	113.91	205.13	144.02	15.22	2.83	1.87	536.9
2008	1.26	0.84	0.54	1.00	2.01	9.98	128.52	215.81	104.25	5.97	8.19	2.62	481.0
2009	-	-	-	-	-	-	-	-	-	-	-	-	0.0
2010	-	-	-	-	-	-	-	-	-	-	-	-	0.0
2011	-	-	-	-	-	-	-	-	-	-	-	-	0.0
2012	-	-	-	-	-	-	-	-	-	-	-	-	0.0
2013	-	-	-	-	-	-	-	-	-	-	-	-	0.0
2014	-	-	-	-	-	-	-	-	-	-	-	-	0.0
Mean	1.49	1.36	2.20	3.90	4.40	13.86	71.14	141.86	77.38	10.94	2.78	1.77	275.98

Station name Akaki

Element: Monthly total stream flow (m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	-	-	-	-	-	-	-	-	-	-	-	-	0.0
1981	0.95	1.02	2.66	2.42	0.74	0.85	16.24	40.39	42.29	2.62	1.39	1.33	112.9
1982	1.74	1.58	1.13	1.74	1.96	1.28	11.33	27.50	12.62	1.68	1.03	0.89	64.5
1983	0.75	0.81	0.47	0.51	2.03	2.10	8.34	57.30	21.92	1.81	0.80	0.55	97.4
1984	0.63	0.81	0.48	0.52	1.27	5.51	32.22	25.85	15.71	1.18	0.85	0.61	85.6
1985	0.81	0.88	0.58	1.65	2.81	1.79	14.98	62.59	20.13	3.26	1.17	1.51	112.2
1986	1.19	1.33	2.13	3.21	1.53	3.44	10.70	26.37	15.86	4.36	1.89	0.66	72.7
1987	0.73	0.90	2.60	4.25	3.87	3.17	9.41	12.55	3.44	0.95	1.03	1.05	44.0
1988	1.48	1.44	1.08	1.98	1.15	1.68	9.44	30.12	23.76	3.48	2.29	1.35	79.3
1989	0.97	1.25	1.01	2.75	1.66	2.42	17.92	56.05	23.35	2.35	1.49	1.63	112.9
1990	1.44	3.53	3.34	6.50	1.89	2.39	14.84	64.67	21.46	4.45	1.67	1.55	127.7
1991	1.43	1.72	1.92	1.61	1.13	3.67	21.21	55.35	43.34	4.30	3.24	3.37	142.3
1992	2.65	3.21	1.84	2.07	2.16	2.50	13.72	40.55	32.78	3.99	2.05	2.14	109.7
1993	1.78	2.55	1.49	5.44	3.92	8.65	35.56	93.79	108.09	23.04	14.23	13.28	311.8
1994	12.73	12.13	12.99	13.37	13.65	16.27	38.47	53.86	35.55	9.26	8.38	8.05	234.7
1995	7.94	9.54	8.66	11.52	9.41	9.78	21.64	74.45	25.78	8.41	7.61	7.62	202.4
1996	7.68	7.05	8.46	8.79	10.30	29.86	93.45	202.76	67.20	22.89	19.18	18.30	495.9
1997	18.29	16.52	16.42	15.83	14.38	17.44	38.52	62.61	24.10	14.11	12.80	11.59	262.6
1998	12.51	12.41	12.05	12.50	19.14	17.71	63.42	145.68	78.45	29.37	16.80	15.85	435.9
1999	16.02	14.99	15.89	15.02	15.20	20.83	67.67	164.47	12.27	5.28	4.84	3.29	355.8
2000	2.65	1.77	2.21	4.22	4.07	3.95	13.04	71.08	13.24	3.85	2.35	1.83	124.3
2001	1.72	1.64	2.91	2.22	3.35	6.30	62.88	80.52	16.14	2.31	1.87	1.80	183.7
2002	1.94	1.70	2.10	2.53	1.82	3.40	17.65	21.74	8.52	1.64	1.43	1.59	66.1
2003	1.44	1.65	1.47	2.38	1.55	2.68	21.42	79.89	24.40	4.57	3.53	3.63	148.6
2004	3.36	3.12	3.30	4.78	3.06	4.37	19.40	58.25	38.37	5.09	3.59	3.66	150.4
2005	1.39	1.31	1.35	1.60	2.56	2.12	4.33	8.76	4.47	2.40	2.20	2.15	34.6
2006	2.16	2.16	2.23	2.35	2.19	2.35	7.27	10.19	6.55	3.84	3.60	3.55	48.4
2007	3.50	3.68	3.59	3.67	3.72	3.96	5.67	14.85	7.54	4.66	3.97	3.88	62.7
2008	4.22	4.14	4.05	4.10	4.37	5.30	9.55	16.34	16.12	0.00	0.00	4.90	73.1
2009	-	-	-	-	-	-	-	-	-	-	-	-	0.0
2010	-	-	-	-	-	-	-	-	-	-	-	-	0.0
2011	-	-	-	-	-	-	-	-	-	-	-	-	0.0
2012	-	-	-	-	-	-	-	-	-	-	-	-	0.0
2013	-	-	-	-	-	-	-	-	-	-	-	-	0.0
2014	-	-	-	-	-	-	-	-	-	-	-	-	0.0
Mean	4.08	4.10	4.23	4.98	4.82	6.63	25.01	59.23	27.27	6.26	4.47	4.34	124.34

Station name Mojo

Element: Monthly total stream flow (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	0.2	0.1	0.2	0.2	2.1	9.3	14.6	18.7	4.2	0.5	0.2	0.2	50.4
1981	-	-	-	-	-	-	-	-	-	-	-	-	0.0
1982	-	-	-	-	-	-	-	360.2	-	-	-	-	360.2
1983	0.2	0.3	19.4	0.4	11.7	13.0	44.5	158.4	57.5	0.3	0.2	0.2	306.0
1984	0.2	0.2	0.2	0.1	0.4	16.8	75.5	86.7	24.8	0.3	0.3	0.3	205.8
1985	0.2	0.2	0.1	0.3	12.0	0.4	62.0	186.0	61.1	0.3	0.4	0.4	323.3
1986	0.4	0.4	0.4	4.6	0.6	69.9	51.9	97.5	60.8	0.3	0.2	0.3	287.2
1987	0.3	0.3	1.0	0.8	30.7	12.0	4.6	32.9	0.9	0.3	0.2	0.2	84.3
1988	0.3	0.4	0.2	0.4	0.5	1.3	78.9	141.7	106.7	1.0	0.1	0.3	331.5
1989	0.3	0.3	0.3	0.5	0.1	0.1	29.2	62.6	87.3	0.5	0.3	0.3	181.8
1990	0.3	4.6	0.5	8.5	0.2	0.4	54.6	102.3	45.5	0.4	0.2	0.3	217.9
1991	0.3	0.4	0.6	0.3	0.2	0.4	80.4	146.1	70.3	0.4	0.4	0.7	300.4
1992	0.6	0.7	0.4	0.7	0.3	5.4	21.5	112.1	87.1	0.5	0.3	0.3	229.7
1993	0.3	0.3	0.2	6.2	9.4	0.5	72.4	130.3	113.5	8.0	0.4	0.3	341.8
1994	0.2	0.2	0.3	0.3	0.4	0.8	39.6	117.1	53.2	0.5	0.4	0.3	213.2
1995	0.3	0.4	0.5	0.6	45.8	97.3	57.1	109.7	73.6	126.7	131.6	132.4	776.0
1996	132.9	131.2	135.0	129.9	137.1	160.0	191.7	215.6	63.5	0.5	0.4	0.3	1298.2
1997	0.5	0.3	0.4	4.4	0.3	14.0	69.8	107.9	1.3	4.8	0.5	0.4	204.4
1998	0.4	0.6	0.6	8.8	0.5	17.8	101.3	216.5	81.2	26.5	0.5	0.5	455.2
1999	0.5	0.4	0.5	0.4	0.4	14.7	111.9	172.7	25.8	4.5	0.4	0.3	332.5
2000	0.4	0.3	0.3	0.3	0.4	8.9	82.0	91.1	16.7	0.6	0.4	0.4	201.7
2001	0.4	0.3	2.5	0.4	1.4	7.4	18.2	33.7	8.2	0.5	0.5	0.5	74.0
2002	0.5	0.4	0.5	0.4	0.5	1.9	12.2	14.1	2.3	0.5	0.4	0.5	34.0
2003	0.6	0.5	0.8	1.2	0.6	2.8	26.4	48.9	9.3	0.6	0.4	0.5	92.5
2004	0.4	0.2	0.7	1.9	0.3	1.4	7.3	26.7	3.3	0.6	0.4	0.4	43.5
2005	0.5	0.2	1.6	2.7	5.5	2.7	13.6	21.0	8.1	0.6	0.6	0.5	57.4
2006	0.4	0.6	0.8	2.5	1.6	2.5	20.1	19.2	8.5	0.7	0.5	0.5	57.8
2007	0.4	0.5	0.5	1.1	3.2	7.6	13.6	35.3	18.6	1.2	0.7	0.7	83.2
2008	0.7	0.2	0.1	0.5	0.7	2.2	12.0	43.3	7.4	0.8	1.0	0.5	69.4
2009	0.5	0.2	0.2	0.9	0.5	0.5	6.6	17.8	8.1	1.5	0.4	0.5	37.7
2010	0.3	0.3	0.7	2.3	3.2	3.2	14.6	15.1	13.2	0.7	0.5	0.4	54.4
2011	0.2	0.0	1.3	0.6	0.8	3.4	11.3	14.3	18.4	6.9	1.0	0.5	58.7
2012	0.5	0.3	0.2	0.7	0.6	1.9	10.5	26.1	5.8	0.6	0.5	0.4	48.0
2013	0.3	0.2	0.6	0.6	0.7	4.1	21.2	9.7	6.8	1.1	1.1	0.8	47.1
2014	0.6	1.0	0.5	0.5	0.6	1.6	36.6	2.6	1.2	0.8	1.1	0.8	47.8
Mean	4.4	4.4	5.2	5.6	8.3	14.7	44.5	88.0	35.0	5.9	4.4	4.4	214.5

Station name Hombole

Element: Monthly total stream flow (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	5.01	5.23	3.72	3.12	6.52	11.67	97.29	223.06	87.46	11.93	4.80	4.30	464.1
1981	4.07	3.97	15.63	22.83	7.80	6.50	92.84	187.64	197.80	19.28	6.27	5.31	569.9
1982	4.48	4.59	3.75	5.91	5.39	6.39	48.43	178.05	76.99	26.60	6.04	4.90	371.5
1983	3.91	4.18	5.23	11.59	23.46	22.93	60.20	242.53	145.73	15.99	5.68	4.13	545.6
1984	3.79	2.90	2.81	2.19	4.09	25.51	126.44	139.22	103.86	6.76	3.22	2.80	423.6
1985	2.65	2.28	1.65	2.73	9.94	7.46	86.28	287.25	124.28	10.99	3.69	3.70	542.9
1986	2.04	6.19	5.67	10.08	8.04	22.83	70.12	155.72	102.87	8.37	3.58	3.27	398.8
1987	2.95	3.67	12.79	38.75	21.70	29.26	49.15	71.68	17.95	6.44	3.72	2.98	261.0
1988	3.21	3.19	3.04	4.29	3.18	9.60	51.74	249.58	195.08	21.70	4.93	3.84	553.4
1989	4.26	6.07	6.74	11.70	5.13	9.05	108.51	190.28	150.65	13.05	4.12	4.18	513.7
1990	3.46	12.87	18.79	24.16	4.84	11.11	93.95	235.25	116.77	17.06	4.01	2.94	545.2
1991	2.77	5.07	9.10	2.72	2.51	10.41	98.44	256.24	153.72	9.59	3.63	3.29	557.5
1992	3.43	6.39	3.37	4.40	4.14	10.92	72.44	203.37	143.71	16.43	4.20	3.23	476.0
1993	2.92	4.89	2.50	10.28	12.17	27.87	124.47	265.19	191.22	31.80	8.01	4.06	685.4
1994	2.81	2.32	2.43	4.75	4.26	10.36	74.05	157.57	144.96	16.53	5.02	4.84	429.9
1995	4.26	4.52	3.09	14.91	5.49	10.69	72.22	190.29	75.46	7.88	3.28	2.85	394.9
1996	5.42	4.08	5.87	12.49	21.65	84.08	194.51	348.31	131.52	13.22	5.97	3.99	831.1
1997	4.05	3.27	2.97	5.50	4.10	15.70	57.72	119.31	32.38	10.03	10.70	6.10	271.8
1998	5.01	3.69	11.16	8.21	11.31	25.62	137.40	366.62	161.07	41.72	9.09	5.45	786.4
1999	4.98	4.10	4.58	3.41	3.46	20.80	110.46	269.34	63.95	47.58	8.64	5.12	546.4
2000	4.15	3.73	1.98	3.15	5.67	12.66	63.10	178.60	90.99	30.78	12.48	6.04	413.3
2001	0.88	0.71	4.17	1.76	3.91	26.36	103.35	143.07	54.08	3.76	1.93	1.11	345.1
2002	5.01	3.46	4.09	4.91	4.37	11.27	58.82	141.59	48.69	8.77	6.75	3.06	300.8
2003	2.86	2.48	4.07	9.54	5.89	22.03	117.64	180.98	102.17	14.92	8.03	5.20	475.8
2004	3.68	2.85	3.89	14.74	5.29	20.49	88.59	166.73	87.11	16.74	9.33	4.49	423.9
2005	5.13	3.79	10.43	7.71	30.29	26.01	124.39	192.58	94.34	18.21	11.14	5.63	529.7
2006	4.31	4.00	9.73	17.12	15.50	26.20	155.89	269.65	143.56	18.66	11.81	6.01	682.4
2007	5.00	5.47	5.15	8.22	11.83	39.81	127.92	253.47	158.64	25.10	11.11	7.49	659.2
2008	4.66	4.16	3.31	3.72	5.64	16.80	118.76	216.79	159.12	18.41	22.48	6.08	579.9
2009	9.51	4.25	3.43	9.52	5.31	7.42	45.25	185.45	111.66	25.88	6.16	6.77	420.6
2010	4.54	12.56	10.97	21.57	19.45	35.68	162.37	178.77	153.67	18.51	9.99	5.36	633.4
2011	4.87	3.96	5.49	3.78	11.09	27.06	67.85	203.71	126.23	21.89	9.78	5.80	491.5
2012	4.25	3.76	3.15	10.77	8.79	11.44	89.62	251.98	232.02	19.44	7.80	5.26	648.3
2013	4.26	3.41	5.96	13.69	11.04	31.20	94.29	174.83	141.82	40.82	12.37	4.99	538.7
2014	3.92	4.44	4.96	7.10	10.28	11.61	133.05	174.02	26.48	19.57	5.92	4.41	405.8
Mean	4.07	4.47	5.88	9.75	9.24	20.14	96.50	207.11	118.51	18.70	7.31	4.54	506.22

Station name Keleta

Element: Monthly total stream flow (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	-	-	-	-	-	-	-	-	-	-	-	-	0.0
1981	-	-	-	-	-	-	-	-	-	-	-	-	0.0
1982	-	-	-	-	-	-	-	-	-	-	-	-	0.0
1983	-	-	-	-	-	-	-	-	-	-	-	-	0.0
1984	-	-	-	-	-	-	-	-	-	-	-	-	0.0
1985	-	-	-	-	-	-	-	-	-	-	-	-	0.0
1986	-	-	-	-	-	-	-	-	-	-	-	-	0.0
1987	-	-	-	-	-	-	-	-	-	-	-	-	0.0
1988	-	-	-	-	-	-	-	-	-	-	-	-	0.0
1989	-	-	-	-	-	-	-	-	-	-	-	-	0.0
1990	0.41	6.98	6.76	9.63	1.22	0.95	6.38	16.92	27.07	4.75	1.45	1.23	83.8
1991	1.13	1.31	3.56	1.95	1.67	2.09	7.60	18.53	8.41	2.34	1.31	1.26	51.2
1992	1.59	2.45	1.43	2.30	1.97	2.49	5.95	30.63	35.54	14.04	3.33	2.60	104.3
1993	2.87	4.00	1.83	4.09	6.52	2.37	12.44	20.89	18.34	6.09	1.57	0.89	81.9
1994	0.75	0.72	0.97	1.04	1.23	5.49	49.50	23.98	9.76	1.71	1.86	1.15	98.2
1995	0.95	1.12	2.83	3.53	3.46	1.92	16.38	21.62	7.37	1.07	0.63	0.65	61.5
1996	1.17	0.60	1.12	-	-	-	1.43	24.31	31.97	1.66	0.49	0.40	63.2
1997	0.87	0.36	0.40	0.58	0.77	1.25	14.94	5.35	1.93	0.76	0.99	0.08	28.3
1998	0.32	0.21	0.71	0.03	0.37	0.28	3.27	13.44	8.39	3.53	0.02	0.00	30.6
1999	1.32	1.25	1.44	1.24	1.52	2.19	7.91	13.07	7.29	13.79	2.09	1.35	54.5
2000	1.31	1.23	1.20	1.38	2.79	2.59	4.53	14.22	7.21	14.14	1.92	1.21	53.7
2001	0.34	0.32	1.01	0.68	3.31	3.55	6.66	10.77	5.69	2.37	1.45	1.24	37.4
2002	1.49	1.27	1.41	1.44	1.64	1.48	2.09	6.84	4.25	1.89	1.37	1.47	26.6
2003	1.40	1.94	1.62	4.00	1.22	2.28	5.77	9.45	7.69	1.38	0.50	0.66	37.9
2004	0.47	0.46	0.48	1.15	0.87	1.24	4.39	6.14	6.78	1.68	0.65	0.38	24.7
2005	0.48	0.46	0.64	1.25	3.67	1.43	5.22	11.90	9.51	2.81	1.77	1.76	40.9
2006	2.06	2.08	1.34	2.64	1.71	3.10	10.98	11.31	7.26	1.44	0.59	1.15	45.7
2007	0.62	0.70	1.66	1.18	1.73	4.11	5.30	9.90	10.45	5.93	4.01	3.12	48.7
2008	3.04	2.90	2.83	3.43	5.32	6.39	11.50	12.55	12.53	6.72	7.52	3.86	78.6
2009	3.89	3.76	3.79	4.19	4.06	3.91	8.08	9.05	6.98	6.55	2.40	2.35	59.0
2010	-	-	-	-	-	-	-	-	-	-	-	-	0.0
2011	-	-	-	-	-	-	-	-	-	-	-	-	0.0
2012	-	-	-	-	-	-	-	-	-	-	-	-	0.0
2013	-	-	-	-	-	-	-	-	-	-	-	-	0.0
2014	-	-	-	-	-	-	-	-	-	-	-	-	0.0
Mean	1.32	1.71	1.85	2.41	2.37	2.58	9.52	14.54	11.72	4.73	1.80	1.34	31.73

Estimated of Koka Reservoir Evaporation (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Koka/Reservoir	218.6	201.9	267.6	203.9	276.1	302.4	238.9	117.3	240.2	335.2	220.8	224.8	2847.7

Average Kc values of defferent land uses/cover types of upper Awash River Basin

Land use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Forest	0.65	0.66	0.77	0.77	0.78	0.78	0.78	0.78	0.78	0.78	0.77	0.70
Grass Land	0.69	0.81	0.91	091	0.91	0.91	0.91	0.91	0.91	0.89	0.66	0.66
IrrigatedCultivated	0.82	0.85	0.88	0.92	0.91	0.74	0.81	0.96	0.87	0.68	0.90	1.01
Rainfed Cultivated					0.35	0.64	1.00	1.06	1.04	0.52		
Shrub Lnd	0.65	0.66	0.77	0.77	0.78	0.78	0.78	0.78	0.78	0.78	0.77	0.70
Urban or Exposed rock	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Water Body	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05

APPENDIX-2 Meteorological Data

Station name: Ginchi

Element: Monthly total rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	32.1	42.5	65.3	114.3	150.4	87.8	224.5	212.3	164.7	42.6	0.0	0.0	1136.5
1981	32.1	42.5	65.3	114.3	150.4	87.8	224.5	212.3	164.7	42.6	0.0	0.0	1136.5
1982	46.0	62.6	59.9	40.6	84.9	39.5	181.0	251.2	68.0	78.5	68.2	0.0	980.4
1983	36.1	41.3	79.1	192.5	229.8	115.5	259.3	197.2	211.6	49.5	3.7	31.5	1447.1
1984	14.1	0.0	21.6	7.0	121.5	189.3	185.0	126.7	95.1	3.8	15.5	13.3	792.9
1985	5.1	0.0	26.6	116.3	162.3	54.1	297.4	299.5	171.4	7.3	5.7	4.1	1149.8
1986	0.0	98.4	103.0	92.2	141.7	270.2	276.0	236.6	159.1	67.7	0.0	0.0	1444.9
1987	16.0	50.8	219.9	97.1	249.3	105.6	216.4	179.4	97.2	58.4	2.2	5.9	1298.2
1988	35.9	108.2	51.1	74.8	21.6	135.2	274.8	375.9	287.4	49.8	0.0	2.7	1417.4
1989	12.6	120.2	151.1	126.1	14.5	134.1	334.7	253.8	157.0	86.5	10.2	85.6	1486.4
1990	0.0	184.2	101.8	65.6	69.9	126.1	134.1	279.9	141.2	22.1	10.9	5.0	1140.8
1991	11.7	39.7	27.8	9.0	54.5	163.6	201.5	262.5	130.6	0.0	0.0	4.2	905.1
1992	21.1	112.9	43.6	60.7	70.7	127.5	243.8	180.4	93.1	54.5	15.3	0.0	1023.6
1993	22.8	87.8	33.0	157.0	153.5	137.5	208.9	374.5	264.6	23.4	0.0	0.0	1463.0
1994	0.0	0.0	98.3	77.5	91.9	138.6	214.8	361.1	167.0	12.3	12.0	0.0	1173.5
1995	3.5	30.2	14.9	280.7	84.1	61.8	171.6	210.4	106.8	0.0	0.0	27.8	991.8
1996	27.9	2.9	116.8	90.6	108.5	151.5	254.7	285.1	190.9	19.7	1.2	0.0	1249.8
1997	64.4	0.0	0.0	131.3	47.1	118.2	199.6	188.2	101.7	101.0	74.9	2.8	1029.2
1998	71.5	18.8	99.4	25.7	79.8	172.2	242.7	267.0	182.8	66.6	0.0	0.0	1226.5
1999	16.3	0.0	26.5	163.4	72.1	150.3	226.4	196.0	101.6	178.7	4.2	0.0	1135.5
2000	0.0	0.0	8.3	129.4	85.8	159.4	141.6	236.2	146.3	45.7	37.0	3.5	993.2
2001	7.1	40.3	118.6	33.8	113.0	270.7	238.0	151.0	96.5	31.1	2.5	0.0	1102.6
2002	112.7	76.5	88.7	40.5	38.2	182.0	209.4	158.1	79.9	0.0	0.0	61.4	1047.4
2003	19.6	61.2	107.0	162.5	15.4	147.6	227.8	207.0	117.7	0.0	2.1	14.9	1082.8
2004	107.8	6.7	21.4	214.1	57.9	123.6	198.4	200.4	178.0	19.1	4.9	1.0	1133.3
2005	65.6	2.5	119.5	45.6	85.5	116.4	260.5	241.6	185.8	12.8	12.5	0.0	1148.3
2006	0.0	15.3	320.4	191.5	133.5	237.8	434.2	629.2	157.1	19.5	0.0	14.1	2152.6
2007	19.9	24.1	37.3	31.6	157.4	248.1	232.3	182.6	122.1	35.3	0.0	0.0	1090.7
2008	0.0	5.7	0.0	18.1	100.6	152.7	294.9	236.6	111.2	41.7	62.6	0.0	1024.1
2009	57.5	5.3	11.4	50.9	43.6	101.1	210.6	274.2	144.8	0.0	0.0	41.0	940.4
2010	45.5	74.5	90.5	136.5	68.0	161.7	262.3	213.5	103.5	17.5	0.0	37.9	1211.4
2011	8.5	12.3	60.4	11.2	94.5	182.1	144.1	185.3	52.9	0.0	52.3	0.0	803.6
2012	0.0	1.4	5.0	67.7	22.7	101.8	221.3	188.8	215.1	0.0	0.0	0.0	823.8
2013	496.0	0.0	0.0	102.6	119.3	145.5	232.4	257.9	144.5	145.5	0.0	0.0	1643.7
2014	0.0	56.4	53.4	47.5	169.3	111.8	156.0	232.1	93.4	41.2	0.0	0.0	961.1
Mean	40.3	40.7	69.9	94.9	98.9	143.1	229.6	244.1	143.0	39.3	11.4	10.2	1165.4

Station name: Addis Alem

Element: Monthly total rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	33.0	48.0	63.0	89.0	71.0	168.0	223.5	242.0	138.0	1.7	8.1	6.0	1091.3
1981	33.0	48.0	63.0	89.0	71.0	168.0	223.5	242.0	138.0	1.7	8.1	6.0	1091.3
1982	52.0	49.0	42.5	65.5	69.0	72.2	237.0	267.0	72.0	64.0	112.0	40.0	1142.2
1983	18.0	65.0	29.0	102.0	151.2	110.3	190.1	272.0	140.6	29.6	14.5	42.5	1164.8
1984	2.5	0.0	32.0	12.0	138.0	157.6	155.4	150.5	107.5	3.0	2.0	8.0	768.5
1985	10.0	0.0	8.0	59.2	50.0	98.5	170.6	168.5	80.9	61.1	11.0	0.0	717.8
1986	2.5	64.3	105.0	96.0	155.0	138.0	193.0	179.0	121.0	16.0	3.0	4.5	1077.3
1987	0.0	44.0	106.0	59.0	132.0	89.0	129.0	124.0	90.0	13.0	0.0	5.5	791.5
1988	11.0	35.5	9.0	55.0	13.9	117.0	259.5	252.0	133.7	21.0	0.0	0.0	907.6
1989	32.0	61.0	80.0	104.0	38.9	126.2	250.2	256.0	210.0	10.5	0.0	24.0	1192.8
1990	9.6	131.6	55.0	55.8	99.1	111.5	189.9	342.8	196.5	13.0	0.0	0.0	1204.8
1991	0.0	79.8	102.6	43.9	16.8	144.6	370.4	353.8	193.6	0.0	0.0	24.1	1329.6
1992	41.0	50.7	72.4	85.5	32.7	75.1	323.1	385.4	234.3	36.3	5.4	8.2	1350.1
1993	10.2	12.5	13.4	116.8	88.9	168.6	359.7	367.3	168.1	44.3	0.0	0.0	1349.8
1994	0.0	0.0	34.5	46.1	43.0	218.0	250.4	228.1	155.6	0.0	17.5	8.0	1001.2
1995	0.0	39.5	47.1	144.9	94.5	245.1	402.5	352.3	136.8	6.4	0.0	7.6	1476.7
1996	46.1	7.9	129.5	70.1	160.4	163.2	371.9	326.6	123.0	6.2	0.0	2.2	1407.1
1997	23.5	0.0	17.6	70.1	23.7	88.1	243.1	164.1	86.1	58.8	81.5	0.0	856.6
1998	61.1	86.8	107.4	67.3	101.1	208.1	289.5	251.0	154.0	53.9	21.9	0.0	1402.1
1999	29.5	3.3	28.6	13.5	74.6	197.5	255.0	262.2	51.8	116.6	0.0	0.0	1032.6
2000	0.0	0.0	12.5	103.1	135.4	168.1	266.6	238.2	186.8	33.6	17.4	29.2	1190.9
2001	0.0	0.0	169.4	28.2	127.9	233.9	309.7	265.0	43.3	21.4	0.0	0.0	1198.8
2002	51.6	84.1	77.8	26.4	35.0	174.5	333.1	264.6	38.8	0.0	0.0	62.4	1148.3
2003	0.0	65.8	109.6	84.1	0.0	173.1	226.0	232.1	165.3	11.0	6.6	6.3	1079.9
2004	17.5	27.6	70.5	140.6	62.9	143.1	190.4	212.5	172.5	33.6	1.3	38.8	1111.3
2005	14.2	15.2	148.2	45.1	96.9	90.4	142.7	224.0	99.0	21.9	12.7	0.0	910.3
2006	0.0	83.5	101.0	61.1	83.2	148.9	334.3	265.4	135.5	75.7	0.0	12.1	1300.7
2007	12.1	59.3	120.1	94.9	123.4	170.1	237.3	204.3	75.0	23.1	0.0	2.3	1121.9
2008	1.9	12.5	14.6	36.9	125.6	145.1	291.5	268.1	85.6	46.9	85.4	70.3	1184.4
2009	43.2	2.8	48.6	11.3	51.5	96.1	297.6	146.5	108.3	70.3	68.0	81.7	1026.0
2010	83.0	84.2	95.5	106.0	89.2	113.0	143.2	129.7	96.8	75.2	68.0	80.8	1164.6
2011	72.7	66.9	87.1	71.2	96.6	118.7	110.4	121.8	82.7	70.3	82.6	70.3	1051.2
2012	70.3	66.2	71.7	86.9	76.6	96.3	131.8	122.8	127.8	70.3	68.0	70.3	1059.1
2013	496.0	63.5	70.3	96.6	103.5	108.5	134.9	142.0	108.2	110.8	68.0	70.3	1572.6
2014	70.3	79.2	85.2	81.2	117.4	99.1	113.7	134.8	94.0	81.8	68.0	70.3	1095.0
Mean	38.5	43.9	69.4	71.9	84.3	141.2	238.6	233.1	124.3	37.2	23.7	24.3	1130.6

Station name: Holota

Element: Monthly total rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	80.5	79.2	90.9	103.9	117.5	95.6	140.6	136.8	119.7	83.8	68.2	70.4	1187.1
1981	80.5	79.2	90.9	103.9	117.5	95.6	140.6	136.8	119.7	83.8	68.2	70.4	1187.1
1982	84.8	83.2	89.2	80.9	97.0	80.5	127.0	149.0	89.4	95.0	89.5	70.4	1136.0
1983	81.7	76.5	95.2	128.4	142.3	104.3	151.5	132.1	134.3	85.9	69.3	80.3	1281.9
1984	74.9	65.9	77.2	70.4	108.4	127.4	128.3	110.1	97.9	71.6	73.0	74.6	1079.7
1985	72.0	63.6	78.8	104.5	121.2	85.1	163.4	164.1	121.8	72.7	70.0	71.7	1189.0
1986	70.4	94.4	102.7	97.0	114.8	152.7	156.7	144.4	117.9	91.6	68.2	70.4	1281.3
1987	6.9	55.9	141.6	142.3	181.9	103.8	182.0	261.8	142.2	60.6	60.5	94.8	1434.4
1988	30.3	80.7	26.0	99.6	27.4	108.0	291.6	283.7	239.9	31.9	0.0	15.9	1235.1
1989	57.1	121.0	78.0	69.8	8.3	74.9	242.7	279.3	117.5	3.0	59.4	186.8	1297.8
1990	64.1	169.7	74.9	97.7	55.5	141.5	262.4	333.2	155.4	64.8	69.3	69.1	1557.6
1991	21.1	74.8	117.8	21.3	61.9	87.9	232.1	201.3	109.0	2.6	61.7	5.8	997.2
1992	47.4	33.5	58.8	95.0	34.6	115.4	183.2	315.2	118.9	36.3	0.6	77.8	1116.7
1993	77.6	91.1	80.8	117.3	118.4	111.2	135.8	187.5	150.9	77.8	68.2	70.4	1286.9
1994	70.4	63.6	101.2	92.4	99.2	111.5	137.6	183.4	120.4	74.3	71.9	70.4	1196.4
1995	71.5	73.1	75.1	155.9	96.7	87.5	124.1	136.2	101.6	70.4	68.2	79.1	1139.6
1996	79.2	66.8	107.0	96.5	104.4	115.5	150.1	159.6	127.9	76.6	68.5	70.4	1222.5
1997	90.6	63.6	70.4	109.2	85.2	105.1	132.9	129.3	100.0	102.0	91.6	71.3	1151.3
1998	92.8	69.5	101.5	76.2	95.4	122.0	146.3	153.9	125.3	91.3	68.2	70.4	1213.0
1999	75.5	63.6	78.7	119.3	93.0	115.2	141.2	131.7	99.9	126.3	69.5	70.4	1184.5
2000	70.4	65.9	73.0	108.6	97.3	118.0	114.7	144.3	113.9	84.7	79.7	71.5	1142.3
2001	72.7	76.2	107.5	78.7	105.8	152.8	144.9	117.7	98.3	80.2	69.0	70.4	1174.2
2002	105.7	87.5	98.2	80.8	82.4	125.1	135.9	119.9	93.2	70.4	68.2	89.6	1157.0
2003	76.6	82.8	103.9	119.0	75.3	114.3	141.7	135.2	105.0	70.4	68.8	75.1	1168.0
2004	104.2	68.0	77.1	135.1	88.6	106.8	132.5	133.1	123.8	76.4	69.7	70.8	1186.1
2005	91.0	64.4	107.8	82.4	97.2	104.6	151.9	146.0	126.3	74.4	72.1	70.4	1188.5
2006	70.4	68.4	170.6	128.1	112.2	142.5	206.2	267.2	117.3	76.5	68.2	74.9	1502.6
2007	76.7	71.2	82.1	78.1	119.7	145.8	143.1	127.5	106.4	81.5	68.2	70.4	1170.5
2008	70.4	67.7	70.4	73.8	101.9	115.9	162.7	144.4	102.9	83.5	87.7	70.4	1152.0
2009	88.4	65.3	74.0	84.1	84.1	99.8	136.3	156.2	113.5	70.4	68.2	83.3	1123.5
2010	2.3	42.5	90.2	74.3	79.2	96.7	280.1	250.6	188.6	2.3	26.4	19.1	1152.1
2011	2.3	41.1	44.9	34.9	78.1	146.8	242.2	272.7	170.4	2.3	17.2	2.3	1055.0
2012	2.3	2.7	8.2	99.0	46.1	59.3	285.3	199.5	226.1	2.3	2.3	8.0	941.0
2013	496.0	63.6	70.4	100.3	107.8	113.7	143.1	151.1	113.4	115.9	68.2	70.4	1613.9
2014	70.4	81.3	87.1	83.0	123.4	103.1	119.2	143.0	97.4	83.3	68.2	70.4	1130.0
Mean	78.0	71.9	85.8	95.5	93.7	111.0	168.9	178.2	125.9	67.9	61.9	68.0	1206.6

Station name: Tulubolo

Element: Monthly total rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	49.5	29.8	62.0	57.2	14.7	154.3	404.0	358.0	86.0	22.5	0.0	0.0	1238.0
1981	49.5	29.8	62.0	57.2	14.7	154.3	404.0	358.0	86.0	22.5	0.0	0.0	1238.0
1982	20.5	20.0	39.0	39.5	37.5	178.7	406.1	520.9	211.7	58.6	8.5	12.3	1553.3
1983	5.0	21.4	145.3	59.3	70.5	114.4	116.0	295.2	131.1	71.3	56.4	71.0	1157.0
1984	27.8	50.2	66.3	56.4	114.1	153.3	247.8	228.6	62.7	55.2	55.5	4.5	1122.3
1985	57.2	12.2	6.6	58.5	87.5	149.6	325.4	268.7	87.8	19.8	0.0	54.4	1127.8
1986	10.6	43.3	71.6	99.7	86.7	204.2	193.0	146.2	144.6	4.4	0.0	4.2	1008.5
1987	3.7	31.6	137.0	71.8	140.4	137.4	177.7	173.9	52.3	11.3	0.0	23.0	960.1
1988	2.5	18.6	0.0	41.4	270.7	195.8	379.8	157.1	58.5	4.4	0.0	0.0	1128.8
1989	6.0	68.8	87.3	95.8	0.0	218.6	238.0	334.0	91.4	20.3	0.0	9.2	1169.4
1990	0.0	27.6	17.7	81.6	29.0	150.1	255.2	199.8	36.6	0.0	0.0	0.0	797.6
1991	9.2	7.2	70.8	11.2	129.0	187.0	191.9	167.4	4.1	0.0	0.0	0.0	777.8
1992	14.1	71.6	62.2	37.3	42.8	336.9	441.7	635.0	65.7	8.2	4.7	2.8	1723.0
1993	12.4	26.3	13.9	113.8	193.5	548.9	440.4	563.7	326.1	19.2	0.0	0.0	2258.2
1994	0.0	0.0	86.6	46.9	69.0	284.4	339.4	316.6	232.8	0.0	58.9	0.0	1434.6
1995	0.0	8.3	43.1	49.7	95.2	134.8	90.1	221.6	0.0	3.1	0.0	14.7	660.6
1996	17.5	3.1	39.8	65.5	87.8	226.1	243.9	338.2	191.2	0.0	4.3	0.0	1217.4
1997	0.0	0.0	36.3	60.7	42.1	203.0	343.2	134.3	78.8	63.3	37.1	0.0	998.8
1998	0.0	18.3	0.0	90.4	155.3	317.0	343.6	340.9	113.8	68.9	0.0	53.6	1501.8
1999	15.7	0.0	56.0	0.0	79.1	270.1	356.7	449.0	140.3	5.5	0.0	0.0	1372.4
2000	53.6	0.0	1.8	160.8	131.9	222.0	320.7	226.7	114.3	6.3	26.4	4.6	1269.1
2001	0.0	3.2	98.1	36.4	72.3	186.5	224.0	160.1	35.6	6.9	0.0	0.0	823.1
2002	46.3	9.1	41.7	60.6	43.3	224.9	236.8	241.0	77.2	0.0	0.0	40.6	1021.5
2003	40.0	11.7	49.1	94.3	23.8	127.1	315.1	219.1	91.5	0.0	0.0	7.7	979.4
2004	52.5	0.0	10.8	92.9	44.7	270.9	330.6	185.0	163.8	0.0	2.2	5.2	1158.6
2005	26.0	0.0	53.9	180.9	165.0	208.4	179.6	203.2	83.8	18.3	5.5	0.0	1124.6
2006	0.0	13.3	106.4	63.2	91.4	197.9	260.8	138.2	162.0	5.5	0.0	0.3	1039.0
2007	6.8	12.9	40.6	49.4	121.5	257.6	206.2	143.7	147.2	13.1	0.0	0.0	999.0
2008	0.0	0.0	7.4	48.4	124.4	234.1	281.0	306.0	90.8	47.0	0.0	0.0	1139.1
2009	41.4	0.0	16.2	9.4	67.1	59.2	264.1	147.0	109.3	72.0	69.7	83.2	938.5
2010	0.0	103.9	81.6	82.2	186.3	289.9	349.2	157.4	108.1	0.0	10.2	34.0	1402.8
2011	3.4	17.8	53.1	14.5	75.5	188.8	111.1	237.1	152.4	0.0	0.0	0.0	853.7
2012	0.0	0.0	23.0	90.6	97.7	107.2	218.2	253.0	122.4	57.4	55.6	58.6	1083.8
2013	496.0	0.0	34.1	71.7	128.9	252.0	411.9	454.0	217.1	111.9	0.0	2.0	2179.6
2014	0.0	32.1	53.6	22.0	77.5	95.2	310.9	333.9	79.8	14.2	0.0	44.1	1063.3
Mean	30.5	19.8	50.7	64.9	91.7	206.9	284.5	274.6	113.0	23.2	11.3	15.1	1186.3

Station name: Sendafa

Element: Monthly total rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	0.0	66.4	37.2	64.2	41.2	88.8	336.6	364.6	71.9	28.0	7.1	0.0	1106.0
1981	0.0	66.4	37.2	64.2	41.2	88.8	336.6	364.6	71.9	28.0	7.1	0.0	1106.0
1982	39.4	84.7	54.8	31.7	64.5	31.3	232.6	282.9	89.6	42.7	14.5	14.1	982.8
1983	1.4	25.4	43.1	91.6	167.6	71.1	247.1	430.4	124.0	4.7	0.0	0.0	1206.4
1984	0.0	0.0	45.2	0.0	78.4	169.1	340.3	184.9	109.3	0.0	0.0	1.2	928.4
1985	9.5	1.3	38.6	158.9	157.9	76.4	394.1	451.5	106.0	10.8	0.0	0.0	1405.0
1986	0.0	28.1	117.3	193.7	32.3	164.7	270.9	244.5	143.2	0.0	0.0	0.0	1194.7
1987	0.2	33.1	128.9	80.5	110.1	55.7	223.6	143.6	105.3	8.7	0.0	0.0	889.7
1988	0.0	32.9	0.9	132.9	22.1	104.6	451.1	330.2	237.6	5.2	0.0	0.0	1317.5
1989	18.0	10.1	43.3	112.0	21.4	46.3	357.5	339.4	139.9	10.2	0.4	0.6	1099.1
1990	21.5	190.4	35.7	148.4	38.2	87.8	282.7	469.9	142.9	3.8	2.4	0.0	1423.7
1991	15.9	20.5	118.1	0.5	34.5	72.7	216.8	9.4	134.5	38.8	0.0	5.6	667.3
1992	10.7	46.5	1.0	53.1	56.3	69.6	253.2	357.9	151.6	55.5	0.0	0.0	1055.4
1993	4.3	105.2	0.0	119.9	81.3	132.4	457.2	353.2	153.8	13.7	0.0	0.0	1421.0
1994	0.0	0.0	0.0	64.1	11.0	130.7	337.7	184.1	122.0	0.0	6.4	0.0	856.0
1995	0.0	11.4	106.2	116.7	42.4	22.5	230.8	388.8	101.7	1.4	0.0	0.0	1021.9
1996	69.4	5.6	99.3	87.5	102.8	187.2	339.2	338.6	121.4	0.0	0.0	0.0	1351.0
1997	44.5	0.0	29.4	60.0	44.8	149.7	303.8	251.1	84.7	72.0	34.6	0.0	1074.6
1998	28.9	23.3	5.8	27.0	38.2	68.8	359.1	289.7	152.0	98.9	0.0	0.0	1091.7
1999	0.0	1.2	56.3	11.8	25.4	144.7	441.6	237.7	80.5	77.1	0.0	0.0	1076.4
2000	0.0	0.0	35.5	44.0	87.9	166.0	352.2	373.4	113.9	5.0	10.0	0.0	1187.9
2001	0.0	35.3	154.1	9.2	134.9	149.5	335.5	276.8	27.4	9.8	0.0	0.0	1132.5
2002	21.2	3.4	67.2	20.6	60.9	144.4	246.8	289.1	85.4	0.0	0.0	27.4	966.4
2003	75.5	0.0	29.7	122.9	1.7	120.6	304.4	373.4	122.4	0.0	0.0	19.7	1170.3
2004	15.2	7.1	2.2	118.9	0.0	69.8	315.0	319.0	30.6	0.0	0.0	0.0	877.8
2005	24.5	22.3	12.3	136.1	150.2	57.7	381.3	282.9	73.3	34.6	0.0	0.0	1175.2
2006	0.0	46.4	86.5	77.2	31.1	126.2	455.8	398.7	160.0	0.0	0.0	0.0	1381.8
2007	38.0	45.0	8.2	92.9	24.2	162.0	288.8	343.4	114.1	0.0	0.0	44.8	1161.4
2008	0.0	0.0	0.0	0.0	0.0	87.9	290.3	306.2	175.3	24.7	63.7	47.7	995.8
2009	66.6	41.2	49.0	85.7	74.1	84.4	237.4	239.6	93.8	66.8	45.7	66.4	1150.6
2010	0.0	12.5	18.0	205.3	76.4	106.7	317.9	295.8	65.6	1.5	0.0	44.9	1144.6
2011	38.1	35.1	66.2	71.5	136.7	86.8	216.8	328.6	138.3	44.8	55.5	44.9	1263.3
2012	34.5	32.3	55.8	85.4	67.1	98.4	220.5	233.3	134.8	45.4	43.4	47.3	1098.3
2013	496.0	3.4	1.2	44.7	45.3	274.7	374.6	449.0	27.5	0.0	0.0	5.9	1722.3
2014	43.4	11.3	42.4	0.0	73.8	79.1	211.5	731.3	139.0	6.4	97.1	0.0	1435.3
Mean	31.9	29.9	46.5	78.1	62.2	107.9	313.2	321.6	112.7	21.1	11.1	10.6	1146.8

Station name: Addis Ababa

Element: Monthly total rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	23.2	38.4	45.3	88.5	54.2	126.2	385.1	297.4	111.9	51.5	0.0	0.0	1221.7
1981	23.2	38.4	45.3	88.5	54.2	126.2	385.1	297.4	111.9	51.5	0.0	0.0	1221.7
1982	48.7	80.9	57.8	103.7	115.9	31.9	259.3	257.9	133.8	64.4	43.2	12.8	1210.3
1983	18.3	21.7	48.7	117.0	237.0	109.3	199.3	244.7	160.9	26.3	0.0	8.8	1192.0
1984	0.0	8.0	8.8	8.4	127.8	220.8	296.1	295.6	142.4	0.0	4.4	16.3	1128.6
1985	14.2	0.0	17.5	96.3	83.7	112.2	270.4	327.7	205.9	58.0	3.3	1.2	1190.4
1986	0.0	35.7	88.0	197.6	125.4	179.5	180.1	269.5	127.8	36.1	0.0	1.7	1241.4
1987	0.5	63.4	248.9	82.4	241.3	92.9	196.5	254.4	115.2	21.3	0.8	0.3	1317.9
1988	9.7	53.4	5.3	144.6	16.6	106.2	277.9	299.3	229.7	59.9	0.0	0.0	1202.6
1989	0.8	75.9	75.7	154.4	0.5	120.9	357.7	325.3	187.7	14.8	0.0	7.6	1321.3
1990	0.8	155.9	59.2	106.4	20.0	88.8	218.7	268.6	184.0	16.2	6.0	0.0	1124.6
1991	0.0	74.5	106.6	34.7	60.3	197.8	248.9	262.6	126.4	3.4	0.0	50.0	1165.2
1992	20.2	33.7	20.2	41.0	52.0	109.1	248.5	294.7	209.4	69.7	0.0	2.9	1101.4
1993	10.8	67.2	16.1	157.9	97.2	208.3	274.0	426.5	243.3	62.1	0.0	4.5	1567.9
1994	0.0	0.0	82.4	82.3	63.3	123.4	308.9	225.0	142.0	0.5	14.7	0.0	1042.5
1995	0.0	69.0	41.5	174.4	68.2	102.9	190.2	314.9	136.1	0.0	0.0	52.6	1149.8
1996	28.1	5.2	106.8	128.2	122.0	258.5	266.4	338.7	294.2	0.2	0.2	1.7	1550.2
1997	39.2	0.0	24.5	51.3	38.5	104.0	272.6	194.3	112.2	62.4	50.3	1.5	950.8
1998	55.2	20.5	49.0	48.5	154.2	124.4	285.4	260.0	213.6	126.9	0.0	0.0	1337.7
1999	2.9	0.3	28.8	16.3	23.8	119.6	276.3	305.3	88.4	75.4	0.0	0.0	937.1
2000	0.0	0.0	17.6	49.9	110.0	144.5	244.8	306.2	250.6	46.4	21.1	0.0	1191.1
2001	0.0	12.2	210.8	25.0	168.0	216.2	428.0	246.4	131.7	13.7	0.0	0.0	1452.0
2002	14.7	21.0	90.2	56.3	63.1	172.5	256.9	215.9	108.8	0.2	0.0	16.5	1016.1
2003	10.5	53.3	62.6	99.3	20.2	151.8	291.8	233.3	193.3	0.8	1.5	54.9	1173.3
2004	24.8	20.3	49.5	139.9	30.1	141.9	238.5	272.6	164.0	76.9	0.0	0.0	1158.5
2005	45.9	51.6	83.2	160.9	133.7	179.8	246.0	315.2	162.5	55.2	4.4	0.0	1438.4
2006	0.7	11.2	129.5	78.9	74.6	150.1	356.3	243.6	239.1	54.0	0.3	8.0	1346.3
2007	51.3	19.1	59.8	73.8	120.1	171.5	261.8	381.2	147.6	24.8	0.0	0.0	1311.0
2008	0.0	5.1	0.0	35.1	59.1	84.4	300.2	233.9	140.7	57.8	67.9	52.0	1036.1
2009	33.2	2.7	28.4	80.6	58.9	82.6	349.9	388.3	114.8	47.9	4.4	65.0	1256.6
2010	15.0	2.6	89.1	55.5	99.5	72.9	279.6	313.9	202.5	239.5	1.8	27.7	1399.5
2011	14.1	13.1	44.3	22.8	66.1	182.0	180.9	340.8	146.0	0.0	42.3	0.0	1052.4
2012	0.0	0.0	15.8	75.8	50.2	69.4	324.2	298.0	215.5	2.3	0.0	9.8	1061.0
2013	496.0	0.0	48.6	92.3	85.0	153.2	234.6	353.2	0.0	199.7	58.4	24.0	1744.9
2014	35.0	1.7	0.0	1.7	54.4	52.6	31.2	93.6	66.7	219.9	249.2	266.4	1072.4
Mean	29.6	30.2	60.2	84.9	84.3	134.0	269.2	285.6	158.9	52.6	16.4	19.6	1225.3

Station name: Chafe-dorsa

Element: Monthly total rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	0.0	66.4	37.2	64.2	41.2	88.8	336.6	364.6	71.9	28.0	7.1	0.0	1106.0
1981	0.0	66.4	37.2	64.2	41.2	88.8	336.6	364.6	71.9	28.0	7.1	0.0	1106.0
1982	39.4	84.7	54.8	31.7	64.5	31.3	232.6	282.9	89.6	42.7	14.5	14.1	982.8
1983	1.4	25.4	43.1	91.6	167.6	71.1	247.1	430.4	124.0	4.7	0.0	0.0	1206.4
1984	0.0	0.0	45.2	0.0	78.4	169.1	340.3	184.9	109.3	0.0	0.0	1.2	928.4
1985	9.5	1.3	38.6	158.9	157.9	76.4	394.1	451.5	106.0	10.8	0.0	0.0	1405.0
1986	0.0	28.1	117.3	193.7	32.3	164.7	270.9	244.5	143.2	0.0	0.0	0.0	1194.7
1987	0.2	33.1	128.9	80.5	110.1	55.7	223.6	143.6	105.3	8.7	0.0	0.0	889.7
1988	0.0	32.9	0.9	132.9	22.1	104.6	451.1	330.2	237.6	5.2	0.0	0.0	1317.5
1989	18.0	10.1	43.3	112.0	21.4	46.3	357.5	339.4	139.9	10.2	0.4	0.6	1099.1
1990	21.5	190.4	35.7	148.4	38.2	87.8	282.7	469.9	142.9	3.8	2.4	0.0	1423.7
1991	15.9	20.5	118.1	0.5	34.5	72.7	216.8	9.4	134.5	38.8	0.0	5.6	667.3
1992	10.7	46.5	1.0	53.1	56.3	69.6	253.2	357.9	151.6	55.5	0.0	0.0	1055.4
1993	4.3	105.2	0.0	119.9	81.3	132.4	457.2	353.2	153.8	13.7	0.0	0.0	1421.0
1994	0.0	0.0	0.0	64.1	11.0	130.7	337.7	184.1	122.0	0.0	6.4	0.0	856.0
1995	0.0	11.4	106.2	116.7	42.4	22.5	230.8	388.8	101.7	1.4	0.0	0.0	1021.9
1996	69.4	5.6	99.3	87.5	102.8	187.2	339.2	338.6	121.4	0.0	0.0	0.0	1351.0
1997	44.5	0.0	29.4	60.0	44.8	149.7	303.8	251.1	84.7	72.0	34.6	0.0	1074.6
1998	28.9	23.3	5.8	27.0	38.2	68.8	359.1	289.7	152.0	98.9	0.0	0.0	1091.7
1999	0.0	1.2	56.3	11.8	25.4	144.7	441.6	237.7	80.5	77.1	0.0	0.0	1076.4
2000	0.0	0.0	35.5	44.0	87.9	166.0	352.2	373.4	113.9	5.0	10.0	0.0	1187.9
2001	0.0	35.3	154.1	9.2	134.9	149.5	335.5	276.8	27.4	9.8	0.0	0.0	1132.5
2002	21.2	3.4	67.2	20.6	60.9	144.4	246.8	289.1	85.4	0.0	0.0	27.4	966.4
2003	75.5	0.0	29.7	122.9	1.7	120.6	304.4	373.4	122.4	0.0	0.0	19.7	1170.3
2004	15.2	7.1	2.2	118.9	0.0	69.8	315.0	319.0	30.6	0.0	0.0	0.0	877.8
2005	24.5	22.3	12.3	136.1	150.2	57.7	381.3	282.9	73.3	34.6	0.0	0.0	1175.2
2006	0.0	46.4	86.5	77.2	31.1	126.2	455.8	398.7	160.0	0.0	0.0	0.0	1381.8
2007	38.0	45.0	8.2	92.9	24.2	162.0	288.8	343.4	114.1	0.0	0.0	44.8	1161.4
2008	0.0	0.0	0.0	0.0	0.0	87.9	290.3	306.2	175.3	24.7	63.7	47.7	995.8
2009	66.6	41.2	49.0	85.7	74.1	84.4	237.4	239.6	93.8	66.8	45.7	66.4	1150.6
2010	0.0	12.5	18.0	205.3	76.4	106.7	317.9	295.8	65.6	1.5	0.0	44.9	1144.6
2011	38.1	35.1	66.2	71.5	136.7	86.8	216.8	328.6	138.3	44.8	55.5	44.9	1263.3
2012	34.5	32.3	55.8	85.4	67.1	98.4	220.5	233.3	134.8	45.4	43.4	47.3	1098.3
2013	496.0	3.4	1.2	44.7	45.3	274.7	374.6	449.0	27.5	0.0	0.0	5.9	1722.3
2014	43.4	11.3	42.4	0.0	73.8	79.1	211.5	731.3	139.0	6.4	97.1	0.0	1435.3
Mean	31.9	29.9	46.5	78.1	62.2	107.9	313.2	321.6	112.7	21.1	11.1	10.6	1146.8

Station name: Akaki

Element: Monthly total rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	28.5	36.8	54.7	59.0	56.8	99.6	393.2	364.4	43.7	34.8	0.0	0.0	1171.5
1981	28.5	36.8	54.7	59.0	56.8	99.6	393.2	364.4	43.7	34.8	0.0	0.0	1171.5
1982	12.1	35.4	39.5	94.6	75.2	63.5	238.8	255.9	125.2	25.8	11.0	8.1	985.1
1983	1.8	33.3	20.2	142.1	175.0	83.0	237.7	275.3	146.7	0.0	0.0	0.0	1115.1
1984	0.0	0.0	40.4	5.1	130.0	215.3	277.9	227.1	71.7	0.0	0.0	1.9	969.4
1985	3.6	0.0	32.4	71.8	96.6	96.5	303.0	324.1	164.3	1.6	0.0	0.0	1093.9
1986	0.0	95.4	67.7	148.7	83.2	143.4	189.4	216.5	86.1	9.4	0.0	0.0	1039.8
1987	0.0	65.6	181.9	81.2	187.7	69.3	202.0	246.9	82.5	4.4	0.0	0.0	1121.5
1988	0.0	44.5	0.0	96.0	23.8	124.6	255.9	278.1	253.5	35.4	0.0	0.0	1111.8
1989	2.1	63.8	53.8	226.3	7.1	58.6	264.2	301.0	170.9	37.9	0.0	0.0	1185.7
1990	7.7	120.6	48.4	159.1	37.3	78.9	280.7	222.9	107.3	5.8	1.2	0.0	1069.9
1991	0.0	37.6	62.4	11.6	45.6	90.4	263.7	308.5	113.3	4.4	0.0	56.5	994.0
1992	33.5	24.2	30.5	15.5	25.6	100.4	218.4	276.0	86.7	43.3	0.2	0.0	854.3
1993	1.2	53.9	5.6	118.4	54.6	116.5	218.0	251.5	118.3	20.5	0.0	0.0	958.5
1994	0.0	0.0	62.7	72.2	20.2	131.2	219.3	181.0	94.5	0.0	11.0	0.0	792.1
1995	0.0	25.4	62.7	102.1	20.9	95.7	279.0	242.3	79.5	0.0	0.0	4.8	912.4
1996	15.3	0.3	79.7	38.8	90.5	240.1	292.5	234.1	119.0	1.9	0.0	0.0	1112.2
1997	27.6	0.0	29.5	102.7	25.2	57.0	203.6	203.4	83.4	114.9	10.3	0.0	857.6
1998	32.7	30.2	19.6	69.3	159.9	116.9	207.8	280.0	118.5	36.9	0.0	0.0	1071.8
1999	1.3	1.8	91.8	12.1	45.4	92.8	282.6	300.7	61.7	65.0	0.0	0.0	955.2
2000	0.0	0.0	29.1	93.0	64.9	100.1	188.9	210.0	124.1	17.2	23.4	3.8	854.5
2001	0.0	20.7	121.2	23.6	118.0	142.6	257.5	145.0	64.9	2.2	0.0	0.0	895.7
2002	31.1	10.5	87.8	53.9	76.6	108.0	167.1	166.3	52.3	0.0	0.0	17.7	771.3
2003	19.6	24.8	23.9	114.0	1.4	125.4	325.1	307.4	113.4	0.0	0.0	40.8	1095.8
2004	15.6	15.8	61.4	154.5	15.4	95.2	150.3	189.1	80.9	4.8	3.4	0.7	787.1
2005	28.8	7.3	47.9	112.2	140.7	139.9	218.7	231.4	152.7	9.1	15.2	0.0	1103.9
2006	2.6	44.2	56.3	79.7	22.0	84.3	276.4	262.6	148.1	38.0	0.0	3.2	1017.4
2007	34.2	24.7	25.6	96.8	64.6	132.7	254.2	221.8	148.5	14.3	1.3	0.0	1018.7
2008	0.0	0.0	0.6	34.2	62.4	140.2	253.5	252.3	194.7	7.2	64.8	0.0	1009.9
2009	60.2	0.0	10.0	118.7	47.7	63.5	235.3	322.4	71.3	32.8	4.0	16.8	982.7
2010	0.0	63.8	126.2	170.0	95.2	164.8	334.4	169.8	154.1	5.2	14.8	7.8	1306.1
2011	0.0	2.5	45.2	20.7	128.7	60.0	204.3	304.0	194.5	0.0	4.7	0.1	964.7
2012	0.0	0.0	65.7	61.0	28.6	80.6	228.0	243.9	122.9	0.0	0.0	0.0	830.7
2013	496.0	0.0	77.0	89.1	73.4	111.5	179.6	242.4	142.5	20.6	0.0	0.2	1432.3
2014	0.0	39.4	76.0	13.9	67.8	52.6	176.8	281.6	115.3	52.3	0.0	0.0	875.7
Mean	25.3	27.4	54.1	83.5	69.3	107.8	247.7	254.4	115.7	19.4	4.7	4.6	1014.0

Station name: Bishoftu

Element: Monthly total rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	20.0	10.1	32.3	24.2	69.4	75.1	242.4	215.5	58.1	40.7	0.0	0.0	787.8
1981	20.0	10.1	32.3	24.2	69.4	75.1	242.4	215.5	58.1	40.7	0.0	0.0	787.8
1982	20.8	75.4	34.5	47.3	57.7	91.0	123.9	233.6	46.1	25.5	9.4	0.0	765.2
1983	0.0	10.2	62.8	105.2	209.5	149.4	128.8	344.8	88.6	23.4	0.0	0.0	1122.7
1984	0.0	0.0	19.3	0.0	108.7	80.7	220.5	217.3	85.0	0.0	0.0	3.6	735.1
1985	3.5	0.0	14.5	63.6	111.4	74.0	307.3	292.7	130.0	1.1	0.0	0.0	998.1
1986	55.1	62.9	63.1	67.2	62.8	96.1	81.8	116.9	120.6	11.3	0.0	0.0	737.7
1987	0.0	61.4	138.2	90.1	161.7	65.0	83.3	155.9	80.9	6.4	0.0	0.0	842.9
1988	8.0	15.9	6.0	44.6	38.6	104.3	148.0	236.8	121.4	25.3	0.0	0.0	748.9
1989	0.6	12.2	35.1	47.0	2.2	59.0	183.7	171.5	135.2	21.2	0.0	3.3	671.0
1990	0.0	125.1	58.2	93.4	36.5	76.0	235.8	177.7	104.9	1.8	1.8	0.0	911.2
1991	55.1	57.0	89.5	54.3	58.3	66.2	132.3	103.1	74.9	55.1	53.3	55.1	854.4
1992	64.7	52.8	57.4	64.7	58.4	73.5	97.9	122.2	72.7	61.5	55.8	55.6	837.3
1993	55.6	54.3	55.1	72.8	72.2	67.6	122.1	105.8	72.5	56.4	53.3	55.1	842.8
1994	55.1	0.0	33.9	19.5	19.6	74.5	232.8	187.3	108.6	0.0	10.2	0.0	741.5
1995	0.0	2.4	7.8	34.0	5.5	92.5	188.4	169.6	78.7	0.0	0.0	11.9	590.8
1996	16.4	0.0	103.1	55.3	105.4	261.5	164.1	275.6	90.0	0.1	5.9	0.0	1077.4
1997	27.8	0.0	26.7	74.8	13.6	121.7	235.8	171.8	69.2	99.9	10.9	0.0	852.2
1998	32.0	51.4	13.9	77.2	41.8	77.7	206.3	293.5	97.6	93.3	0.0	0.0	984.7
1999	0.5	0.0	36.6	0.0	10.0	176.8	298.7	258.6	48.7	92.7	0.0	0.0	922.6
2000	0.0	1.8	8.6	50.4	65.4	77.4	244.3	186.5	139.4	41.8	23.4	3.4	842.3
2001	0.0	4.6	166.4	21.8	104.0	79.5	242.3	143.4	64.3	38.2	0.0	0.0	864.5
2002	8.6	0.0	48.0	34.6	11.0	109.1	179.3	178.0	58.4	0.0	0.0	21.3	648.3
2003	38.3	55.4	64.4	100.3	21.1	81.4	277.9	285.5	120.0	6.0	3.6	35.4	1089.3
2004	58.7	51.6	67.8	119.9	2.0	133.5	172.5	209.1	73.6	22.6	10.3	0.0	921.6
2005	21.8	0.0	122.1	77.3	86.5	96.7	168.0	186.7	153.3	0.0	2.9	0.0	915.3
2006	55.5	108.8	0.0	52.2	32.2	108.2	329.0	141.4	122.8	78.3	5.2	16.1	1049.7
2007	5.8	0.0	0.0	57.9	92.0	77.4	326.8	155.1	123.2	13.2	55.3	55.6	962.3
2008	0.0	0.0	0.0	41.1	47.6	55.5	226.3	253.5	148.6	3.2	45.2	0.0	821.0
2009	40.9	0.0	13.9	29.0	16.8	38.0	125.1	243.9	45.5	67.5	0.6	20.9	642.1
2010	0.0	36.2	87.0	129.7	37.2	100.7	197.9	204.9	125.5	0.0	0.0	0.0	919.1
2011	0.0	49.8	85.2	25.2	64.8	83.4	239.9	287.7	147.3	70.6	0.0	3.4	1057.2
2012	0.0	0.0	110.2	39.2	26.9	73.4	175.6	193.7	91.4	1.6	0.0	0.0	712.0
2013	496.0	0.0	32.3	51.2	50.8	161.9	153.3	109.4	69.5	63.6	53.3	55.1	1296.6
2014	55.1	53.7	67.2	54.0	56.9	59.7	116.1	115.3	89.4	77.6	53.3	55.1	853.5
Mean	34.7	27.5	51.2	55.5	57.9	94.1	195.7	198.9	94.7	32.6	13.0	12.9	868.8

Station name: Mojo

Element: Monthly total rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	32.1	42.5	65.3	114.3	150.4	87.8	224.5	212.3	164.7	42.6	0.0	0.0	1136.5
1981	32.1	42.5	65.3	114.3	150.4	87.8	224.5	212.3	164.7	42.6	0.0	0.0	1136.5
1982	46.0	62.6	59.9	40.6	84.9	39.5	181.0	251.2	68.0	78.5	68.2	0.0	980.4
1983	36.1	41.3	79.1	192.5	229.8	115.5	259.3	197.2	211.6	49.5	3.7	31.5	1447.1
1984	14.1	0.0	21.6	7.0	121.5	189.3	185.0	126.7	95.1	3.8	15.5	13.3	792.9
1985	5.1	0.0	26.6	116.3	162.3	54.1	297.4	299.5	171.4	7.3	5.7	4.1	1149.8
1986	0.0	98.4	103.0	92.2	141.7	270.2	276.0	236.6	159.1	67.7	0.0	0.0	1444.9
1987	16.0	50.8	219.9	97.1	249.3	105.6	216.4	179.4	97.2	58.4	2.2	5.9	1298.2
1988	35.9	108.2	51.1	74.8	21.6	135.2	274.8	375.9	287.4	49.8	0.0	2.7	1417.4
1989	12.6	120.2	151.1	126.1	14.5	134.1	334.7	253.8	157.0	86.5	10.2	85.6	1486.4
1990	0.0	184.2	101.8	65.6	69.9	126.1	134.1	279.9	141.2	22.1	10.9	5.0	1140.8
1991	11.7	39.7	27.8	9.0	54.5	163.6	201.5	262.5	130.6	0.0	0.0	4.2	905.1
1992	21.1	112.9	43.6	60.7	70.7	127.5	243.8	180.4	93.1	54.5	15.3	0.0	1023.6
1993	22.8	87.8	33.0	157.0	153.5	137.5	208.9	374.5	264.6	23.4	0.0	0.0	1463.0
1994	0.0	0.0	98.3	77.5	91.9	138.6	214.8	361.1	167.0	12.3	12.0	0.0	1173.5
1995	3.5	30.2	14.9	280.7	84.1	61.8	171.6	210.4	106.8	0.0	0.0	27.8	991.8
1996	27.9	2.9	116.8	90.6	108.5	151.5	254.7	285.1	190.9	19.7	1.2	0.0	1249.8
1997	64.4	0.0	0.0	131.3	47.1	118.2	199.6	188.2	101.7	101.0	74.9	2.8	1029.2
1998	71.5	18.8	99.4	25.7	79.8	172.2	242.7	267.0	182.8	66.6	0.0	0.0	1226.5
1999	16.3	0.0	26.5	163.4	72.1	150.3	226.4	196.0	101.6	178.7	4.2	0.0	1135.5
2000	0.0	0.0	8.3	129.4	85.8	159.4	141.6	236.2	146.3	45.7	37.0	3.5	993.2
2001	7.1	40.3	118.6	33.8	113.0	270.7	238.0	151.0	96.5	31.1	2.5	0.0	1102.6
2002	112.7	76.5	88.7	40.5	38.2	182.0	209.4	158.1	79.9	0.0	0.0	61.4	1047.4
2003	19.6	61.2	107.0	162.5	15.4	147.6	227.8	207.0	117.7	0.0	2.1	14.9	1082.8
2004	107.8	6.7	21.4	214.1	57.9	123.6	198.4	200.4	178.0	19.1	4.9	1.0	1133.3
2005	65.6	2.5	119.5	45.6	85.5	116.4	260.5	241.6	185.8	12.8	12.5	0.0	1148.3
2006	0.0	15.3	320.4	191.5	133.5	237.8	434.2	629.2	157.1	19.5	0.0	14.1	2152.6
2007	19.9	24.1	37.3	31.6	157.4	248.1	232.3	182.6	122.1	35.3	0.0	0.0	1090.7
2008	0.0	5.7	0.0	18.1	100.6	152.7	294.9	236.6	111.2	41.7	62.6	0.0	1024.1
2009	57.5	5.3	11.4	50.9	43.6	101.1	210.6	274.2	144.8	0.0	0.0	41.0	940.4
2010	45.5	74.5	90.5	136.5	68.0	161.7	262.3	213.5	103.5	17.5	0.0	37.9	1211.4
2011	8.5	12.3	60.4	11.2	94.5	182.1	144.1	185.3	52.9	0.0	52.3	0.0	803.6
2012	0.0	1.4	5.0	67.7	22.7	101.8	221.3	188.8	215.1	0.0	0.0	0.0	823.8
2013	496.0	0.0	0.0	102.6	119.3	145.5	232.4	257.9	144.5	145.5	0.0	0.0	1643.7
2014	0.0	56.4	53.4	47.5	169.3	111.8	156.0	232.1	93.4	41.2	0.0	0.0	961.1
Mean	40.3	40.7	69.9	94.9	98.9	143.1	229.6	244.1	143.0	39.3	11.4	10.2	1165.4

Station name: Hombole

Element: Monthly total rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	7.6	11.3	8.1	24.1	22.5	75.7	150.9	189.8	36.7	64.6	0.6	0.0	591.9
1981	7.6	11.3	8.1	24.1	22.5	75.7	150.9	189.8	36.7	64.6	0.6	0.0	591.9
1982	6.8	46.4	96.9	40.8	169.8	59.3	74.0	306.1	51.9	55.9	29.2	3.6	940.7
1983	8.5	44.9	55.0	178.4	174.7	300.0	234.0	429.2	151.1	29.4	0.0	0.0	1605.2
1984	0.0	0.0	18.0	13.2	138.9	375.7	267.2	148.0	152.3	0.0	0.0	42.6	1155.9
1985	40.9	36.3	44.7	66.8	83.7	82.5	779.0	601.1	97.1	0.0	0.0	0.0	1832.2
1986	59.4	63.1	33.2	63.3	34.1	133.6	73.4	114.7	111.3	0.3	0.0	0.0	686.4
1987	0.0	44.4	157.2	13.2	115.0	0.0	65.6	81.9	57.2	0.0	0.0	0.0	534.5
1988	0.0	15.6	0.0	73.1	12.7	38.4	183.1	211.5	155.9	0.0	0.0	0.0	690.3
1989	0.0	40.3	108.6	64.5	0.0	54.1	147.9	208.4	89.8	12.4	0.0	4.4	730.4
1990	0.0	203.5	69.2	80.3	55.2	79.4	331.9	159.2	88.2	40.7	0.0	40.2	1147.7
1991	0.0	39.8	145.8	14.7	4.4	80.9	249.5	358.4	68.9	8.9	0.0	16.2	987.5
1992	17.8	96.0	3.5	65.2	38.5	91.7	230.8	312.4	74.2	54.2	0.0	0.0	984.3
1993	2.6	72.3	0.0	38.1	73.0	67.8	134.6	114.5	73.9	53.5	50.2	51.9	732.5
1994	51.9	36.3	52.8	52.5	60.1	75.6	149.7	108.1	92.4	40.2	50.6	40.8	811.1
1995	42.8	47.7	50.7	63.7	48.9	66.4	124.7	110.6	72.6	41.6	38.9	42.7	751.2
1996	47.1	43.8	85.4	67.9	93.0	145.9	128.0	151.6	77.0	40.2	40.9	40.2	961.1
1997	53.4	36.3	54.9	58.8	46.9	96.0	120.7	127.6	47.9	22.0	3.0	0.0	667.5
1998	17.6	26.3	52.0	43.8	38.0	66.4	224.6	284.3	57.0	62.1	0.0	0.0	872.1
1999	3.4	0.0	8.6	4.2	3.4	93.9	200.9	188.8	42.2	116.5	0.0	0.0	661.9
2000	40.2	38.0	44.9	52.0	62.0	86.0	194.3	158.4	115.8	16.9	0.0	0.0	808.5
2001	0.0	16.4	116.5	63.8	123.8	158.7	187.7	102.8	26.6	0.0	0.0	0.0	796.3
2002	42.0	36.3	52.5	32.3	38.2	48.4	220.5	47.6	16.7	0.0	0.0	15.6	550.1
2003	15.2	14.8	58.3	150.9	13.7	107.5	326.1	160.9	28.9	0.0	0.0	18.3	894.6
2004	56.4	0.0	28.9	144.9	0.0	101.2	119.9	147.6	60.2	12.0	0.0	0.0	671.1
2005	47.8	41.2	104.5	65.2	105.3	81.0	188.1	196.4	45.3	43.7	42.1	40.2	1000.8
2006	52.4	45.4	112.3	58.9	51.6	89.6	215.4	120.0	89.5	0.0	0.0	19.9	855.0
2007	40.2	3.8	43.4	26.7	113.5	180.4	135.0	159.2	106.6	15.5	0.0	0.0	824.3
2008	0.0	0.0	0.0	0.0	56.8	69.4	233.9	202.6	91.2	0.0	133.2	0.0	787.1
2009	58.3	37.7	49.4	60.1	46.8	69.8	117.9	92.1	79.5	93.3	0.0	45.1	750.0
2010	0.0	61.4	96.4	132.4	74.7	95.7	165.4	127.9	137.9	40.2	39.2	40.2	1011.4
2011	0.0	0.0	46.7	45.0	41.2	68.8	189.9	174.4	103.7	0.0	14.1	0.0	683.8
2012	0.0	0.0	71.8	61.1	29.7	55.8	411.9	100.7	97.2	48.0	40.9	40.7	957.7
2013	496.0	0.0	67.6	57.6	80.0	96.9	173.2	119.0	70.2	62.4	0.0	51.9	1274.8
2014	0.0	1.2	30.4	22.1	53.1	6.0	185.6	126.2	94.8	79.7	0.0	0.0	599.1
Mean	34.7	34.6	56.5	57.8	60.7	96.4	202.5	183.8	80.0	32.0	13.8	15.8	868.6

Station name: Koka Dam

Element: Monthly total rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	41.5	40.4	50.6	54.5	61.6	75.1	146.7	140.5	68.1	56.2	35.3	35.4	805.9
1981	41.5	40.4	50.6	54.5	61.6	75.1	146.7	140.5	68.1	56.2	35.3	35.4	805.9
1982	15.6	9.9	14.7	17.2	72.4	11.7	54.8	130.6	33.7	46.0	12.6	44.0	463.2
1983	0.0	29.6	2.2	53.0	31.9	7.6	20.5	138.0	84.3	14.5	0.0	4.4	386.0
1984	0.0	0.0	2.0	0.0	43.0	21.2	53.9	34.4	13.5	0.0	0.0	4.2	172.2
1985	0.0	0.0	0.0	19.1	89.5	0.0	127.0	129.2	26.0	0.0	0.0	0.0	390.8
1986	0.0	10.8	11.7	3.2	6.5	26.8	72.8	24.6	12.9	0.0	0.0	0.0	169.3
1987	0.0	0.0	17.9	16.6	103.8	14.3	70.7	77.8	12.8	0.0	0.0	0.0	313.9
1988	16.4	21.2	15.0	64.0	8.5	48.7	237.0	244.8	132.4	29.9	0.0	1.0	818.9
1989	0.5	22.8	64.9	185.9	2.7	55.2	107.1	283.7	95.7	14.0	0.0	0.5	833.0
1990	0.0	152.8	292.0	151.2	0.5	5.0	225.1	213.4	168.4	0.0	0.0	0.0	1208.4
1991	0.0	8.8	43.7	0.0	0.0	0.0	164.4	220.9	73.0	43.2	40.5	44.2	638.8
1992	54.5	54.3	44.8	168.2	90.4	249.1	499.7	666.8	410.6	56.4	43.2	42.4	2380.3
1993	47.0	133.0	72.1	293.0	143.0	75.0	289.4	698.4	122.4	36.8	14.3	0.0	1924.4
1994	0.0	0.0	19.0	52.4	60.3	46.6	113.6	109.4	51.7	0.0	10.2	0.0	463.1
1995	43.4	29.2	51.2	63.1	49.4	9.2	225.4	88.2	9.5	0.0	0.0	42.6	611.2
1996	46.9	44.6	81.2	66.1	10.2	39.0	116.2	260.6	49.3	0.0	0.0	40.7	754.8
1997	25.7	0.0	67.8	39.3	46.9	145.4	210.9	259.2	50.3	66.6	24.7	0.0	936.7
1998	31.0	37.6	17.9	27.2	130.3	65.8	245.4	399.1	71.5	167.9	0.0	0.0	1193.7
1999	15.6	0.0	3.5	0.0	10.0	110.2	219.3	211.4	67.0	177.6	0.0	0.0	814.6
2000	0.0	0.0	1.6	57.9	122.7	90.6	337.0	264.9	212.1	0.0	67.8	10.1	1164.7
2001	0.0	40.7	141.2	40.9	154.7	178.3	501.0	436.0	119.0	13.3	5.9	21.7	1652.7
2002	19.8	32.3	13.1	58.3	8.9	13.0	217.0	175.6	63.1	0.6	0.0	13.9	615.6
2003	46.1	65.6	104.2	28.2	1.3	121.3	274.7	273.4	33.2	0.0	3.8	55.7	1007.5
2004	6.3	0.0	68.8	84.5	0.0	103.4	153.9	272.1	47.5	35.7	4.2	0.0	776.4
2005	47.9	0.0	34.8	30.4	10.6	66.8	92.8	141.7	61.2	0.0	5.8	0.0	492.0
2006	0.3	11.0	38.1	68.3	62.0	131.3	234.5	171.4	86.6	4.5	0.0	25.0	833.0
2007	44.7	8.5	83.2	37.2	101.8	69.1	151.7	179.6	140.2	23.0	1.3	0.0	840.3
2008	5.1	0.0	0.0	26.5	100.3	94.2	302.3	292.0	165.7	59.0	77.0	1.1	1123.2
2009	29.1	1.3	3.3	34.1	28.8	80.1	193.0	78.9	78.8	62.2	35.6	44.5	669.8
2010	0.0	69.7	90.1	80.4	80.2	87.5	236.8	272.3	201.7	0.0	1.4	0.0	1120.1
2011	0.0	0.0	72.1	18.2	51.4	81.9	256.8	96.2	214.7	0.0	37.6	35.9	864.8
2012	0.0	1.1	0.0	41.6	42.2	38.4	501.0	91.1	94.3	48.8	41.5	41.3	941.4
2013	496.0	0.0	36.7	12.6	56.2	55.2	297.9	172.7	115.6	17.5	1.6	0.0	1262.0
2014	0.0	3.5	87.3	0.5	54.9	5.3	260.5	195.9	91.9	76.9	40.5	41.9	859.2
Mean	30.7	24.8	48.5	55.7	54.2	65.6	210.2	216.7	95.6	31.6	15.4	16.7	865.9

Station name: Adama

Element: Monthly total rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	17.0	30.0	52.3	54.4	50.3	61.9	187.2	205.7	142.5	39.4	4.3	0.0	845.0
1981	17.0	30.0	52.3	54.4	50.3	61.9	187.2	205.7	142.5	39.4	4.3	0.0	845.0
1982	8.8	41.6	35.5	29.7	79.1	31.7	210.1	259.8	47.6	104.5	31.3	10.9	890.6
1983	5.3	43.4	33.8	79.3	188.0	24.7	214.8	221.3	72.4	14.3	0.0	0.0	897.3
1984	0.0	0.0	4.3	0.4	173.1	84.6	202.7	148.3	66.9	0.0	0.0	19.8	700.1
1985	3.0	29.2	23.1	189.9	67.3	8.0	399.4	327.4	174.0	0.0	0.0	0.0	1221.3
1986	0.0	96.5	41.0	6.2	54.4	152.4	263.3	99.5	20.4	0.6	0.0	0.0	734.4
1987	0.0	11.2	80.2	81.1	259.6	0.0	161.6	243.4	30.8	0.0	0.0	0.0	867.9
1988	34.0	31.3	6.8	50.9	9.4	50.3	185.4	171.4	186.9	52.9	0.0	0.0	779.3
1989	0.0	29.9	21.7	95.4	0.0	54.7	182.5	281.2	80.3	5.7	0.0	3.5	754.9
1990	0.7	183.9	83.0	114.7	13.3	12.0	337.8	168.7	153.7	7.0	0.0	0.0	1074.8
1991	0.0	29.9	111.0	13.5	41.3	76.1	322.0	232.8	89.0	13.7	0.0	1.7	931.1
1992	41.2	27.8	0.0	46.9	8.6	68.6	239.1	214.8	160.3	44.2	0.0	4.5	856.0
1993	15.7	51.9	0.0	102.6	72.7	64.1	345.2	142.4	79.3	20.0	0.0	0.0	893.9
1994	0.0	0.0	2.6	49.1	26.5	70.1	229.6	171.5	173.8	13.8	35.6	51.0	823.6
1995	0.0	36.5	46.9	127.2	33.0	46.5	203.1	251.4	88.2	14.7	0.0	2.8	850.3
1996	27.2	0.0	111.5	65.1	115.2	120.2	220.2	250.0	93.9	0.0	7.9	0.0	1011.2
1997	14.4	0.0	75.3	28.5	6.9	94.0	193.1	240.9	74.7	116.5	31.5	0.0	875.8
1998	11.8	25.6	105.2	19.8	49.3	55.3	196.5	220.6	144.7	132.8	0.0	0.0	961.6
1999	9.2	0.0	34.6	1.2	18.6	74.0	283.2	194.4	66.3	164.7	3.1	0.0	849.3
2000	0.0	0.0	20.2	16.1	51.5	60.8	355.1	269.0	133.6	85.7	57.8	12.9	1062.7
2001	0.0	6.2	108.3	28.7	177.0	51.2	216.8	145.3	107.8	1.7	0.0	6.6	849.6
2002	20.9	11.1	27.1	51.3	22.5	50.2	129.9	205.7	65.3	1.1	0.0	34.5	619.6
2003	46.5	69.1	151.2	88.9	3.6	75.2	235.6	279.7	122.8	0.0	5.3	48.8	1126.7
2004	28.8	3.3	77.4	53.1	1.9	63.3	114.4	227.3	77.1	58.6	12.8	1.6	719.6
2005	72.5	6.3	90.1	41.3	71.1	50.2	144.3	165.0	68.4	6.0	5.3	0.0	720.5
2006	17.6	88.4	64.6	88.7	27.8	58.7	173.5	225.0	128.8	10.1	0.5	28.5	912.2
2007	23.1	31.6	82.1	101.7	64.7	62.8	225.7	344.4	138.0	25.6	7.5	0.0	1107.2
2008	9.6	0.0	0.0	82.4	71.3	71.3	357.1	302.2	100.3	37.5	69.5	0.0	1101.1
2009	62.6	0.0	3.1	2.3	22.1	50.0	156.1	113.3	34.0	132.7	7.7	4.9	588.8
2010	0.0	97.3	88.8	27.4	68.1	100.6	227.8	242.9	164.7	0.0	17.6	0.3	1035.5
2011	0.0	0.0	10.4	17.6	68.7	54.8	215.1	155.8	192.1	0.0	30.2	0.0	744.7
2012	0.5	0.0	2.8	78.2	17.7	33.0	508.9	313.0	130.2	1.4	0.5	3.9	1090.1
2013	496.0	0.2	69.2	35.1	36.0	38.9	443.2	105.2	132.8	34.0	5.2	0.0	1395.8
2014	0.0	4.8	123.0	7.1	62.3	7.7	211.7	180.0	150.6	91.7	8.9	0.0	847.8
Mean	28.1	29.1	52.6	55.1	59.5	58.3	242.3	215.0	109.6	36.3	9.9	6.7	902.4

Station name: Wonji

Element: Monthly total rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	0.0	0.5	4.7	0.0	0.0	0.0	118.6	0.0	0.0	22.7	0.0	0.0	146.5
1981	0.0	0.5	4.7	0.0	0.0	0.0	118.6	0.0	0.0	22.7	0.0	0.0	146.5
1982	8.4	36.9	31.4	35.1	68.7	38.6	102.2	242.1	35.2	85.9	51.1	9.6	745.2
1983	0.0	33.2	31.5	40.0	139.7	55.4	216.1	232.5	146.8	13.2	18.0	0.0	926.4
1984	0.0	0.0	17.3	0.2	151.2	73.1	202.0	137.4	67.2	0.0	0.0	6.0	654.4
1985	1.2	0.0	18.8	56.8	106.8	14.0	271.7	311.4	85.3	1.0	3.0	0.0	870.0
1986	0.0	71.1	67.9	45.9	46.3	161.4	170.7	138.5	67.9	12.0	0.0	0.8	782.5
1987	0.0	13.5	84.9	39.1	215.1	7.1	142.4	214.0	60.8	9.0	0.0	0.0	785.9
1988	46.4	46.8	9.0	50.2	21.4	60.4	168.4	278.6	137.7	38.2	0.0	4.8	861.9
1989	0.0	18.2	70.7	91.7	7.1	68.5	187.4	318.7	91.2	0.0	0.0	1.7	855.2
1990	0.0	280.6	126.6	175.0	18.3	8.1	240.7	259.1	234.5	3.6	0.0	0.0	1346.4
1991	0.0	31.4	188.5	0.7	63.0	82.9	177.0	355.2	85.7	7.5	0.0	2.6	994.4
1992	62.9	42.4	0.0	71.5	13.1	104.6	364.8	327.7	244.5	67.5	0.0	6.9	1305.9
1993	4.7	68.4	0.0	145.0	80.8	63.0	326.1	107.6	76.2	44.6	0.0	0.0	916.4
1994	0.0	0.0	4.0	74.9	40.4	106.9	350.3	261.6	265.1	21.1	54.3	77.8	1256.5
1995	0.0	55.7	71.5	194.1	50.3	70.9	309.8	383.5	134.6	22.4	0.0	4.3	1297.2
1996	41.5	0.0	170.1	99.3	175.7	183.4	335.9	381.4	143.3	0.0	12.1	0.0	1542.6
1997	22.0	0.0	114.9	43.5	10.5	143.4	294.6	367.5	114.0	177.7	48.1	0.0	1336.1
1998	18.0	39.1	160.5	30.2	75.2	84.4	299.8	336.5	220.7	202.6	0.0	0.0	1467.0
1999	14.0	0.0	52.8	1.8	28.4	112.9	432.0	296.6	101.1	251.3	4.7	0.0	1295.7
2000	0.0	0.0	30.8	24.6	78.6	92.8	541.7	410.4	203.8	130.7	88.2	19.7	1621.2
2001	0.0	9.5	165.2	43.8	270.0	78.1	330.7	221.7	164.5	2.6	0.0	10.1	1296.1
2002	31.9	16.9	41.4	78.3	34.3	76.6	198.2	313.8	99.6	1.7	0.0	52.6	945.3
2003	70.9	105.4	230.7	135.6	5.5	114.7	359.4	426.7	187.3	0.0	8.1	74.4	1718.9
2004	43.9	5.0	118.1	81.0	2.9	96.6	174.5	346.8	117.6	89.4	19.5	2.4	1097.8
2005	110.6	9.6	137.5	63.0	108.5	76.6	220.1	251.7	104.3	9.2	8.1	0.0	1099.2
2006	26.8	134.9	98.6	135.3	42.4	89.6	264.7	343.3	196.5	15.4	0.8	43.5	1391.6
2007	35.2	48.2	125.2	155.1	98.7	95.8	344.3	525.4	210.5	39.1	11.4	0.0	1689.1
2008	14.6	0.0	0.0	125.7	108.8	108.8	544.7	461.0	153.0	57.2	106.0	0.0	1679.9
2009	95.5	0.0	4.7	3.5	33.7	76.3	238.1	172.8	51.9	202.4	11.7	7.5	898.2
2010	0.0	148.4	135.5	41.8	103.9	153.5	347.5	370.6	251.3	0.0	26.8	0.5	1579.7
2011	0.0	0.0	15.9	26.8	104.8	83.6	328.1	237.7	293.1	0.0	46.1	0.0	1136.1
2012	0.8	0.0	4.3	119.3	27.0	50.3	776.4	477.5	198.6	2.1	0.8	5.9	1663.0
2013	496.0	0.3	105.6	53.5	54.9	59.3	676.1	160.5	202.6	51.9	7.9	0.0	1868.7
2014	0.0	7.3	187.6	10.8	95.0	11.7	323.0	274.6	229.7	139.9	13.6	0.0	1293.4
Mean	32.7	35.0	75.2	65.5	70.9	77.2	299.9	284.1	142.2	49.8	15.4	9.5	1157.5

Station name: Itaya

Element: Monthly total rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	89.5	92.1	110.7	109.2	109.4	113.7	195.8	202.2	161.9	103.7	79.3	79.3	1446.9
1981	89.5	92.1	110.7	109.2	109.4	113.7	195.8	202.2	161.9	103.7	79.3	79.3	1446.9
1982	84.9	97.9	101.8	95.9	129.3	97.2	208.9	244.1	106.6	145.1	97.5	86.2	1495.3
1983	82.5	98.9	100.7	125.7	197.2	93.7	216.2	220.7	125.8	88.4	77.5	79.3	1506.5
1984	79.3	74.2	82.6	77.0	188.7	130.2	208.4	173.4	119.4	79.3	76.7	91.4	1380.5
1985	81.1	89.1	93.8	192.5	123.7	82.1	328.7	287.3	184.1	79.3	76.9	79.3	1697.9
1986	79.3	132.1	106.5	82.3	113.6	174.2	243.4	144.3	91.6	80.1	76.7	79.3	1403.4
1987	79.3	78.9	106.4	50.3	222.9	57.6	194.2	94.2	76.1	2.6	2.6	4.8	969.6
1988	11.9	85.9	2.6	83.2	37.1	38.9	245.5	160.6	167.4	57.1	2.6	9.1	901.6
1989	9.6	21.6	84.3	104.9	32.0	113.1	187.1	272.7	112.9	5.6	2.6	4.4	950.4
1990	2.6	160.1	50.3	95.7	35.6	31.8	201.4	191.6	79.1	2.6	2.6	6.8	859.8
1991	5.4	38.9	163.7	21.0	33.9	44.6	189.2	108.0	5.0	2.9	2.6	10.9	625.9
1992	106.4	92.5	79.3	107.6	85.0	121.9	236.6	220.6	182.2	108.4	76.7	82.3	1499.4
1993	22.2	0.0	17.2	64.6	48.8	81.7	183.8	297.0	157.1	116.6	2.6	5.6	997.0
1994	5.1	35.0	2.6	127.2	39.3	21.8	209.3	311.3	136.4	16.5	2.6	112.9	1019.7
1995	2.6	5.6	66.6	59.4	147.7	135.7	129.4	93.8	91.5	5.0	56.1	3.9	797.0
1996	2.6	35.4	95.0	99.8	94.0	89.3	183.2	228.4	114.0	28.6	2.6	2.6	975.3
1997	24.1	0.9	89.2	60.4	194.7	106.2	127.0	164.5	147.7	2.6	2.6	2.6	922.2
1998	59.9	2.6	50.8	63.1	78.3	122.3	252.7	121.3	213.5	80.2	59.1	2.6	1106.0
1999	44.0	80.4	96.5	58.1	90.1	83.1	273.0	418.7	230.4	152.1	5.1	2.6	1533.7
2000	2.6	5.1	58.8	45.0	71.7	103.8	151.1	114.2	119.3	212.6	2.6	2.6	889.0
2001	2.6	0.0	2.6	77.2	122.4	104.5	204.7	192.0	303.2	187.4	60.9	3.5	1260.6
2002	13.9	2.6	220.2	25.0	228.1	276.3	340.6	330.7	221.4	10.2	6.7	2.6	1677.8
2003	97.6	4.9	152.1	46.6	75.7	148.0	253.1	293.5	199.3	5.0	2.6	17.9	1295.9
2004	84.9	61.1	65.8	104.5	27.5	133.2	280.8	291.5	301.5	6.6	2.6	41.1	1400.7
2005	45.0	0.8	77.1	240.1	9.7	93.6	218.3	129.0	177.6	98.9	13.7	7.6	1111.0
2006	66.2	57.7	70.3	158.8	136.5	90.7	142.3	87.3	30.9	20.7	40.8	7.6	909.5
2007	9.0	2.6	42.3	136.6	41.2	166.2	197.9	121.8	87.9	11.8	2.6	2.6	822.3
2008	26.8	26.7	90.3	63.8	145.0	229.8	348.9	118.2	42.2	14.2	101.6	2.6	1209.8
2009	15.9	71.6	3.7	71.6	82.6	145.3	182.0	319.1	125.7	112.4	101.6	2.6	1233.8
2010	2.6	49.6	88.6	52.4	178.5	136.2	580.7	206.6	259.8	2.6	5.3	7.1	1569.6
2011	2.6	13.6	51.4	23.8	164.4	155.1	120.8	169.3	125.8	2.6	22.6	2.6	854.2
2012	2.7	2.6	85.4	64.4	91.1	87.2	269.0	166.4	182.8	19.9	7.9	3.8	983.1
2013	496.0	2.6	89.9	28.9	164.5	95.9	235.3	62.6	127.1	68.1	19.7	2.6	1393.0
2014	2.6	12.9	38.0	18.9	79.2	43.0	164.3	153.7	141.0	84.8	2.6	2.6	743.2
Mean	52.3	46.5	78.5	84.1	106.5	110.3	225.7	197.5	146.0	60.5	33.6	26.7	1168.2

Station name: Abomsa

Element: Monthly total rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	56.7	55.4	63.0	60.9	62.0	62.1	99.3	86.6	74.9	63.3	53.0	54.1	791.3
1981	56.7	55.4	63.0	60.9	62.0	62.1	99.3	86.6	74.9	63.3	53.0	54.1	791.3
1982	56.5	60.3	63.8	61.6	75.6	62.4	100.8	127.0	64.5	81.9	64.0	57.0	875.4
1983	54.9	60.1	63.5	70.1	102.2	63.5	116.5	119.6	83.0	58.0	54.7	54.1	900.2
1984	54.1	50.6	57.0	52.4	101.3	75.3	112.7	95.6	71.7	54.1	52.3	58.0	835.0
1985	54.7	53.4	60.2	89.9	78.7	55.4	153.0	146.8	91.1	54.2	52.7	54.1	944.1
1986	54.1	73.4	69.5	59.3	68.7	97.6	118.2	88.0	64.5	55.7	52.3	54.2	855.5
1987	54.1	52.4	76.3	65.3	122.1	52.0	99.2	111.6	63.8	50.2	47.5	49.2	843.6
1988	33.8	67.2	3.1	93.6	12.1	79.0	182.8	211.4	179.2	58.6	0.0	6.4	927.2
1989	0.0	50.2	61.4	119.2	28.4	90.3	136.7	192.4	120.7	49.1	10.6	33.8	892.8
1990	7.4	347.4	186.1	183.5	42.4	22.0	220.8	115.8	106.9	8.3	3.1	4.0	1247.7
1991	2.0	69.6	100.2	45.3	58.3	69.8	171.0	185.1	46.1	21.0	1.1	5.2	774.7
1992	46.6	52.0	5.6	146.3	46.9	50.5	142.0	169.7	197.7	158.7	19.7	55.0	1090.8
1993	189.9	38.3	0.0	204.2	82.8	19.7	118.3	128.0	106.9	120.0	4.7	8.1	1020.9
1994	0.0	0.0	31.0	62.7	142.6	117.1	290.0	132.7	76.3	19.0	126.0	7.6	1005.0
1995	0.0	22.4	147.8	112.3	64.2	31.3	106.6	172.0	85.7	13.9	0.0	6.6	762.8
1996	66.5	3.4	81.8	141.0	143.4	121.1	107.9	214.3	22.5	137.6	8.8	0.0	1048.4
1997	27.5	7.3	71.5	106.0	15.4	70.6	243.7	140.2	99.5	234.4	110.0	0.2	1126.3
1998	108.8	32.4	130.3	38.4	71.1	51.7	108.6	175.8	193.8	86.6	1.7	0.0	999.2
1999	25.8	1.3	162.4	4.6	21.8	82.4	275.9	204.0	144.8	229.6	3.5	0.0	1156.1
2000	4.8	0.0	10.5	88.1	67.1	13.4	119.4	200.6	66.2	137.6	45.8	25.0	778.5
2001	8.3	24.5	170.2	36.3	121.7	56.2	210.3	280.9	81.9	17.8	2.9	20.9	1031.9
2002	37.8	0.0	102.9	37.2	18.0	48.8	65.6	125.2	52.3	0.0	47.7	59.9	595.5
2003	9.4	5.9	74.4	62.2	0.0	49.9	217.9	129.8	85.3	16.4	7.0	68.8	727.0
2004	34.8	0.5	122.5	151.2	1.8	63.2	133.5	157.4	125.5	59.6	14.1	32.1	896.2
2005	52.7	0.0	78.0	103.8	100.3	38.2	174.3	154.6	103.3	21.7	47.9	0.0	874.8
2006	0.0	38.8	165.8	47.4	22.4	51.8	220.9	175.6	95.5	93.0	1.4	50.1	962.7
2007	16.8	40.9	81.5	104.9	85.9	59.1	121.8	221.5	124.5	24.4	13.7	0.0	895.0
2008	5.4	2.4	1.1	74.6	85.5	42.1	193.9	176.4	102.0	143.1	48.6	0.0	875.1
2009	67.7	0.0	49.3	56.3	28.7	22.4	147.8	181.9	54.5	165.0	14.5	5.2	793.3
2010	19.9	148.2	44.1	76.2	152.0	73.0	152.3	167.8	130.3	0.0	65.0	1.7	1030.5
2011	0.0	18.2	61.2	27.3	130.1	106.6	56.7	176.6	218.7	3.8	108.7	0.0	907.9
2012	0.0	0.0	38.0	83.6	47.4	37.2	249.6	285.4	76.7	11.4	7.0	5.8	842.1
2013	496.0	2.1	33.6	123.2	72.5	57.3	208.5	135.8	97.3	34.0	45.1	0.0	1305.4
2014	0.0	0.0	48.6	79.5	82.7	9.6	94.4	107.2	153.0	121.2	13.9	0.0	710.2
Mean	48.7	41.0	73.7	83.7	69.1	59.0	153.4	159.4	101.0	70.5	34.3	23.7	917.6

Station name: Walanchiti

Element: Monthly total rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	40.8	0.0	31.6	36.3	7.5	57.6	293.4	301.8	26.0	0.0	0.0	0.0	795.0
1981	40.8	0.0	31.6	36.3	7.5	57.6	293.4	301.8	26.0	0.0	0.0	0.0	795.0
1982	0.0	27.5	14.0	18.0	128.4	13.0	81.4	313.3	83.0	66.0	49.2	54.8	848.6
1983	0.0	54.6	72.4	72.5	75.2	12.5	100.0	225.7	12.0	0.0	0.0	0.0	624.9
1984	0.0	0.0	0.0	0.0	101.1	91.5	146.1	93.0	19.4	0.0	0.0	25.7	476.8
1985	10.2	0.0	0.0	0.0	166.0	92.5	541.1	836.1	235.7	0.0	0.0	0.0	1881.6
1986	0.0	169.0	0.0	104.4	16.0	80.9	155.8	95.1	154.1	8.0	0.0	0.0	783.3
1987	0.0	37.7	225.4	132.3	272.6	1.0	100.7	165.6	24.7	9.7	0.0	0.0	969.7
1988	15.0	17.2	5.6	30.5	6.5	29.8	185.3	209.2	186.9	16.9	0.0	0.0	702.9
1989	0.0	189.6	149.5	286.0	0.0	83.4	150.4	244.2	119.2	1.4	0.0	14.0	1237.7
1990	0.0	320.2	91.7	95.3	0.0	0.0	243.5	190.6	140.9	9.3	0.0	0.0	1091.5
1991	2.7	90.0	137.0	16.9	7.1	23.8	223.1	184.3	44.4	0.0	0.0	0.0	729.3
1992	0.0	0.0	0.0	101.5	0.0	42.5	130.8	356.8	90.7	17.5	3.4	8.1	751.3
1993	47.1	50.7	0.0	114.3	31.0	42.2	210.9	139.6	140.8	19.6	0.0	0.0	796.2
1994	0.0	2.1	27.4	23.7	26.0	66.3	304.5	185.9	77.5	77.5	36.9	13.4	841.2
1995	0.0	57.4	163.4	94.7	12.9	46.1	156.1	310.2	135.5	12.1	0.0	3.5	991.9
1996	92.1	0.0	93.0	180.0	168.8	86.1	200.7	150.6	42.5	75.1	42.5	0.0	1131.4
1997	29.8	0.0	38.2	23.2	44.7	145.7	255.3	131.1	88.6	117.8	51.8	0.0	926.2
1998	41.6	40.6	337.0	33.5	47.0	48.1	154.4	336.4	197.2	179.0	0.0	0.0	1414.8
1999	11.1	0.0	104.1	0.0	0.0	39.1	246.5	232.9	52.0	167.4	3.6	0.0	856.7
2000	0.0	0.0	15.5	18.4	47.9	58.4	215.0	249.5	110.9	96.3	30.5	6.1	848.5
2001	0.0	13.6	128.0	20.0	65.9	76.5	160.1	145.6	95.3	41.7	10.0	0.0	756.8
2002	0.0	0.0	48.9	61.4	10.0	18.7	166.2	231.8	36.0	0.0	0.0	97.7	670.7
2003	32.5	32.1	119.6	152.6	0.0	61.2	396.2	321.7	7.5	0.0	0.0	28.3	1151.7
2004	47.3	81.4	146.9	235.0	0.0	91.8	287.0	295.0	94.0	52.0	0.0	18.2	1348.6
2005	30.0	24.0	93.0	72.1	138.4	97.5	69.4	123.1	50.6	0.4	2.3	0.0	700.8
2006	9.4	32.2	42.9	75.9	17.9	11.8	142.0	144.6	53.8	6.1	0.0	25.6	562.2
2007	30.2	28.7	49.7	86.8	29.5	116.0	210.4	273.1	244.9	0.0	0.0	0.0	1069.3
2008	18.3	0.0	5.2	59.6	53.1	20.6	376.3	271.9	59.3	59.8	49.2	0.0	973.3
2009	71.1	32.3	44.7	45.8	49.6	59.2	124.8	117.4	58.6	117.8	40.7	37.1	799.1
2010	38.0	96.6	78.1	58.8	91.9	87.7	160.6	162.2	125.2	34.3	52.1	34.8	1020.3
2011	34.3	34.6	50.6	45.4	87.8	76.8	129.3	129.8	149.6	35.0	65.3	34.3	872.9
2012	34.5	32.1	44.0	79.8	51.5	54.3	280.3	210.1	100.6	37.3	34.8	36.9	996.3
2013	496.0	31.5	68.7	38.6	46.5	44.6	437.9	100.9	118.5	60.6	43.9	34.3	1521.9
2014	0.0	2.6	3.7	101.4	34.5	7.2	169.9	207.4	93.6	153.9	26.6	0.0	800.8
Mean	33.5	42.8	70.3	72.9	52.7	55.5	214.3	228.2	94.2	42.1	15.5	13.5	935.4

Station name: Metehara

Element: Monthly total rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	25.2	20.6	27.8	27.6	24.5	30.7	79.5	72.9	34.6	24.4	18.7	18.9	405.5
1981	25.2	20.6	27.8	27.6	24.5	30.7	79.5	72.9	34.6	24.4	18.7	18.9	405.5
1982	20.4	27.1	26.3	25.9	46.5	25.8	56.0	98.3	35.1	43.1	30.9	27.0	462.5
1983	19.4	30.1	32.9	37.2	56.1	26.4	67.5	83.9	38.0	21.3	19.8	18.9	451.7
1984	18.9	17.7	20.7	18.4	58.6	42.5	70.6	54.3	32.1	6.7	0.0	2.0	342.6
1985	6.3	0.0	29.6	76.6	108.5	12.0	166.7	153.7	41.9	4.4	0.5	0.0	600.2
1986	0.0	41.6	43.2	27.8	14.0	55.0	64.3	67.1	51.1	4.0	0.0	7.0	375.1
1987	0.0	24.1	71.6	78.2	74.8	0.0	53.6	110.4	8.0	2.8	0.0	0.0	423.5
1988	13.6	29.6	11.9	23.7	7.8	12.1	156.5	136.1	104.3	18.0	0.0	11.9	525.5
1989	0.0	28.0	104.8	119.9	7.5	82.1	48.7	110.3	28.2	5.6	0.0	12.7	547.8
1990	0.5	220.8	58.1	62.9	1.8	0.9	146.4	76.9	82.4	2.1	0.0	0.0	652.8
1991	0.0	54.3	56.1	46.7	53.3	15.4	137.0	132.0	49.6	11.7	0.0	0.0	556.1
1992	25.8	50.3	0.0	75.8	16.8	62.4	90.0	157.6	62.2	49.6	5.7	2.3	598.5
1993	43.8	59.5	0.0	139.6	57.3	23.7	103.4	103.7	41.6	21.9	0.0	56.9	651.4
1994	0.0	0.0	6.5	21.4	55.4	38.6	248.4	131.6	39.6	0.1	12.7	1.9	556.2
1995	0.0	43.5	81.9	44.0	10.5	28.5	47.3	144.1	57.7	0.5	0.0	0.0	458.0
1996	27.6	0.0	35.9	97.3	80.5	26.5	205.1	100.5	1.6	53.4	7.9	1.1	637.3
1997	30.2	0.0	12.6	44.3	11.5	35.1	139.7	53.8	22.7	114.2	14.6	0.0	478.6
1998	0.8	18.1	76.6	34.2	14.9	4.7	78.2	135.6	54.0	78.0	0.0	0.0	495.1
1999	0.0	0.0	73.6	6.2	15.9	16.7	136.1	151.2	16.4	76.2	2.2	0.0	494.5
2000	0.0	0.0	1.8	20.7	36.9	29.6	135.9	152.7	47.0	47.3	11.9	9.4	493.2
2001	0.0	13.6	92.7	26.3	12.7	20.2	154.8	82.8	15.3	7.1	0.0	1.6	427.1
2002	2.6	0.0	73.3	19.3	9.3	10.2	43.0	80.8	16.8	0.0	0.0	21.2	276.5
2003	4.6	19.4	33.6	13.7	0.0	29.5	118.9	186.0	31.0	0.0	3.2	15.7	455.6
2004	35.1	3.2	84.0	142.4	0.0	21.2	90.3	123.9	39.3	15.9	4.5	0.0	559.8
2005	19.3	0.0	48.0	54.3	75.5	35.7	146.4	138.4	21.6	0.0	5.2	0.0	544.4
2006	0.9	29.3	33.9	33.4	10.0	26.8	142.1	65.0	22.8	37.5	0.8	65.1	467.6
2007	4.7	17.3	9.1	44.7	105.4	23.3	29.7	7.0	94.0	157.5	69.7	0.0	562.4
2008	0.4	0.0	0.0	26.2	62.2	12.4	197.0	95.9	15.3	49.1	58.3	0.0	516.8
2009	84.8	0.0	11.4	16.1	14.1	30.2	54.7	86.6	37.4	69.6	2.5	37.3	444.7
2010	0.0	31.5	48.8	38.6	123.6	16.8	146.4	100.5	68.9	0.0	13.0	0.0	588.1
2011	1.5	13.4	198.2	80.2	0.0	0.0	28.0	0.6	78.2	57.7	5.3	0.0	463.0
2012	0.0	0.0	32.6	27.6	47.0	6.90	161.7	98.6	31.4	0.0	0.0	0.0	405.8
2013	496.0	14.0	18.7	21.0	24.2	30.5	272.0	38.6	100.9	24.3	26.0	0.0	1066.2
2014	0.0	8.6	39.7	23.6	34.6	0.3	89.9	67.5	73.1	81.6	2.2	0.0	421.1
Mean	25.9	23.9	43.5	46.4	37.0	24.7	113.9	99.2	43.7	31.7	9.6	9.4	508.9

2.1 Graphs Plotted to Test Homogeneity of the Stations

Figure 4-4 Homogeneity test for Addis Ginchi, Holota, Addis Alemand Tulubolo meteorological stations

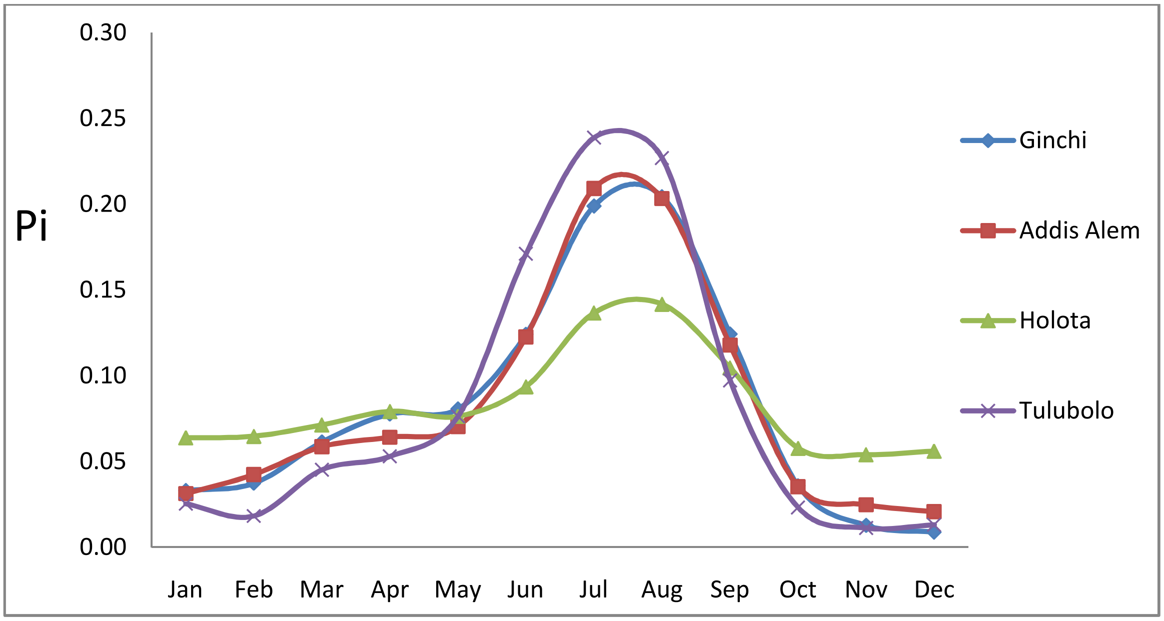
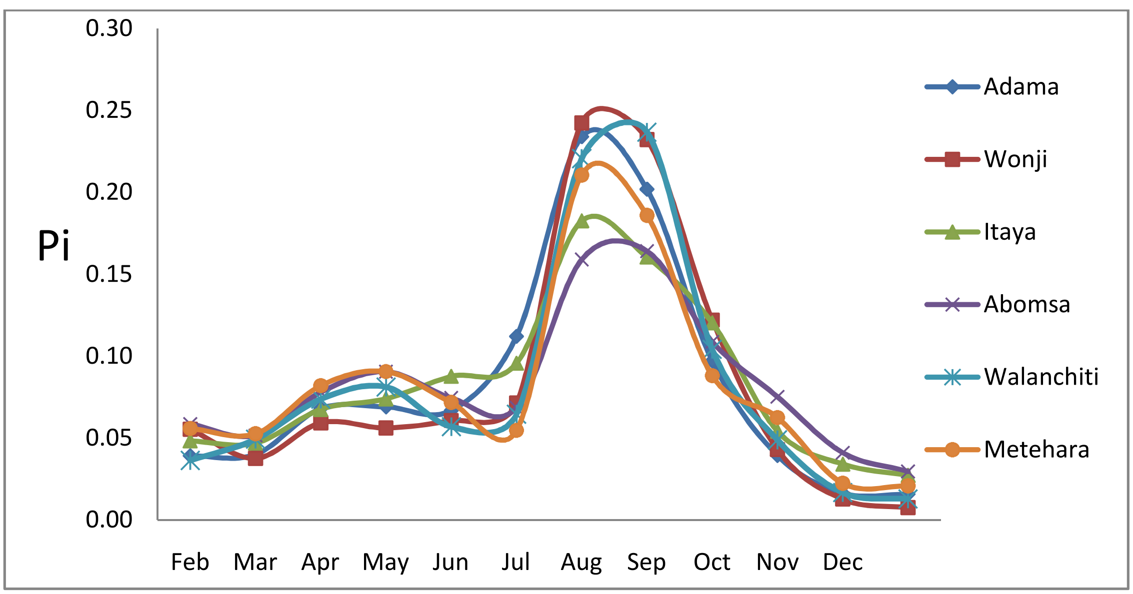


Figure 4-5 Homogeneity test for Adama, Wonji, Etaya, Abomsa, Walinchiti and Metehara meteorological stations



2.2 Graphs Plotted To Check Consistency of the Stations

Figure C-1 Consistency Test Bishoftu, Mojo, Hombolo and Koka Dam metrological stations

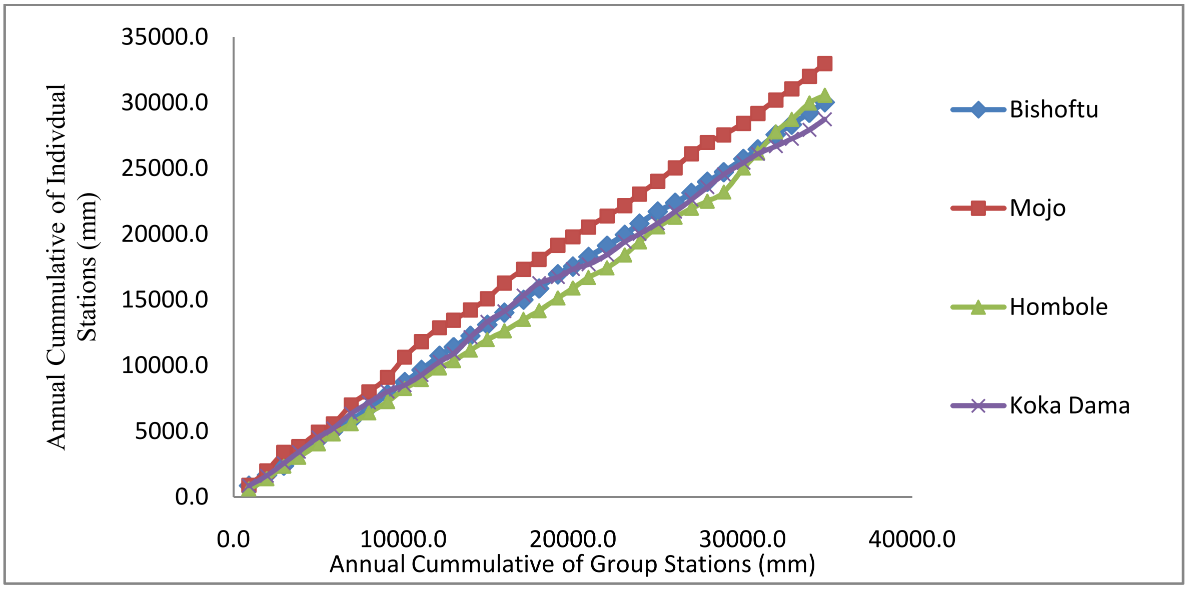
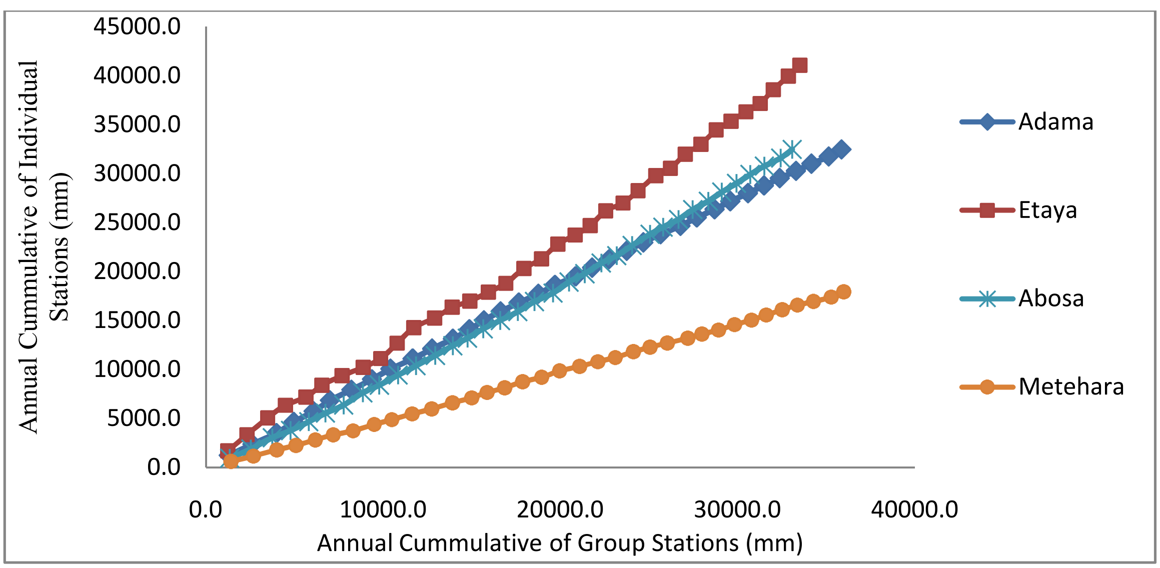
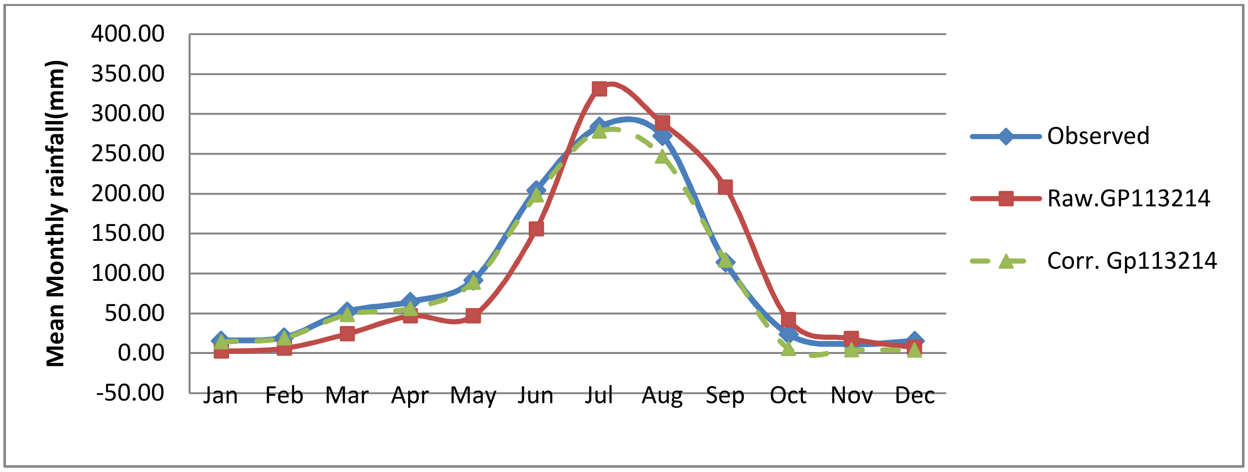
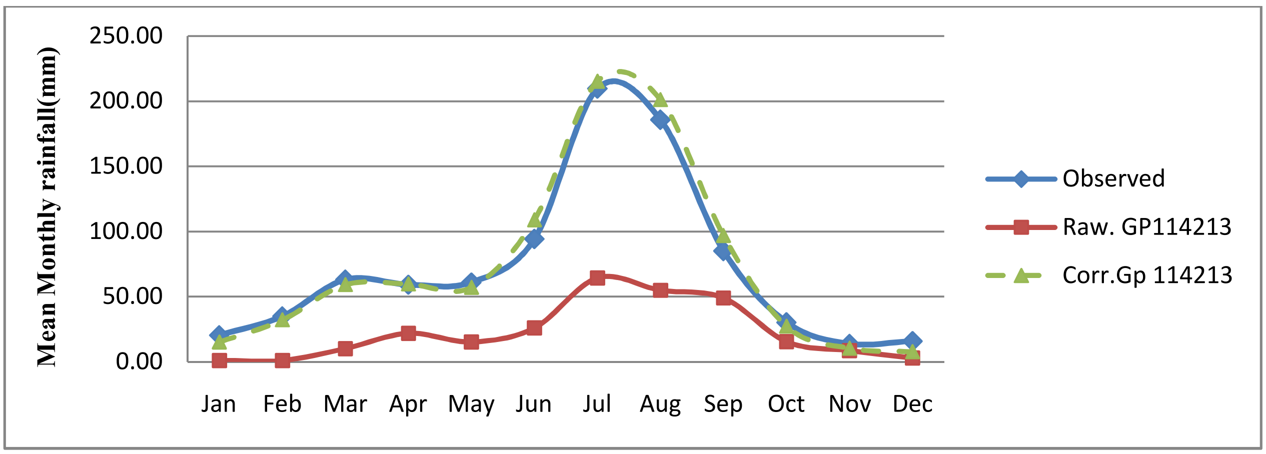


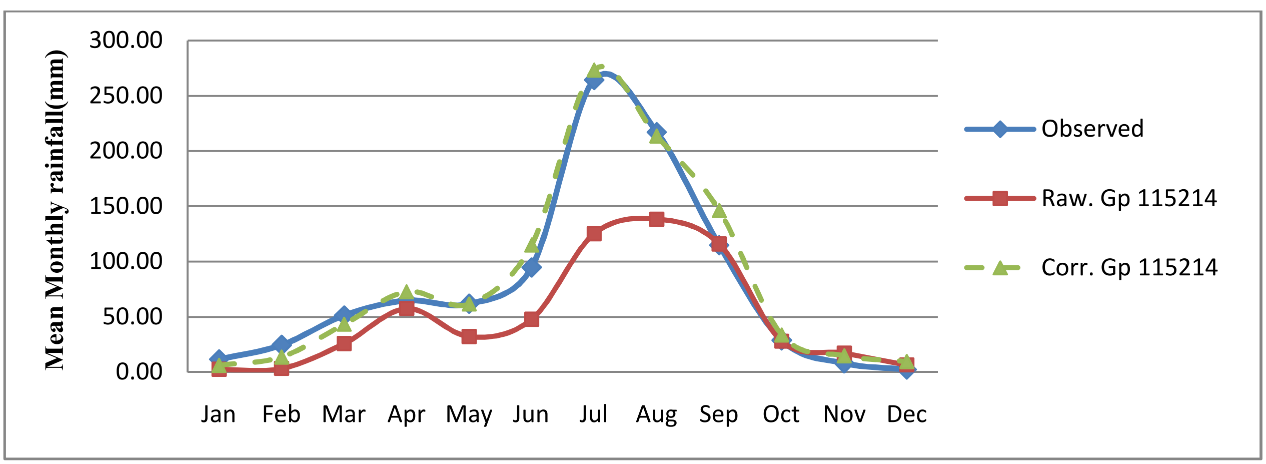
Figure C-2 Consistency Test for Adama, Wonji, Itaya, Abomsa, Walanchiti and Metehara metrological stations

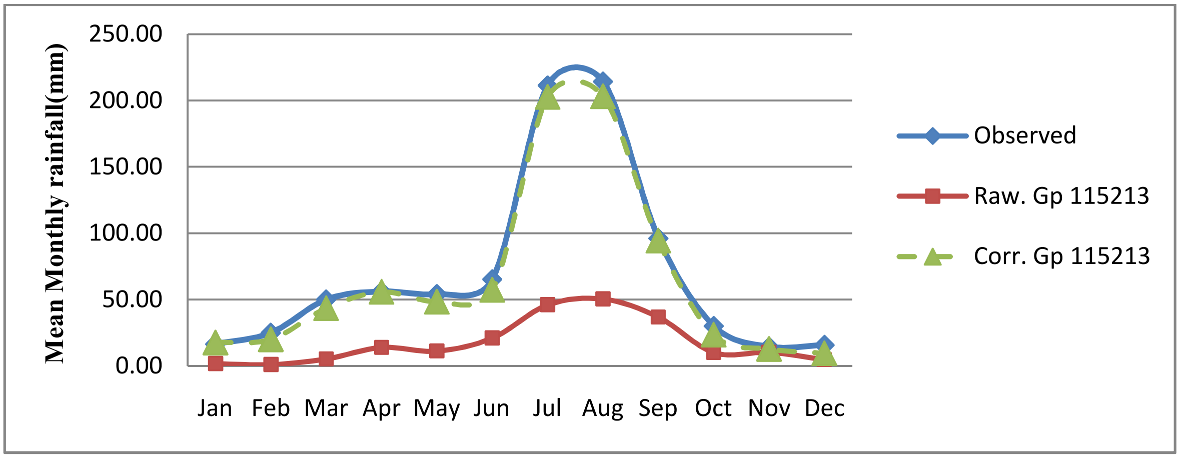


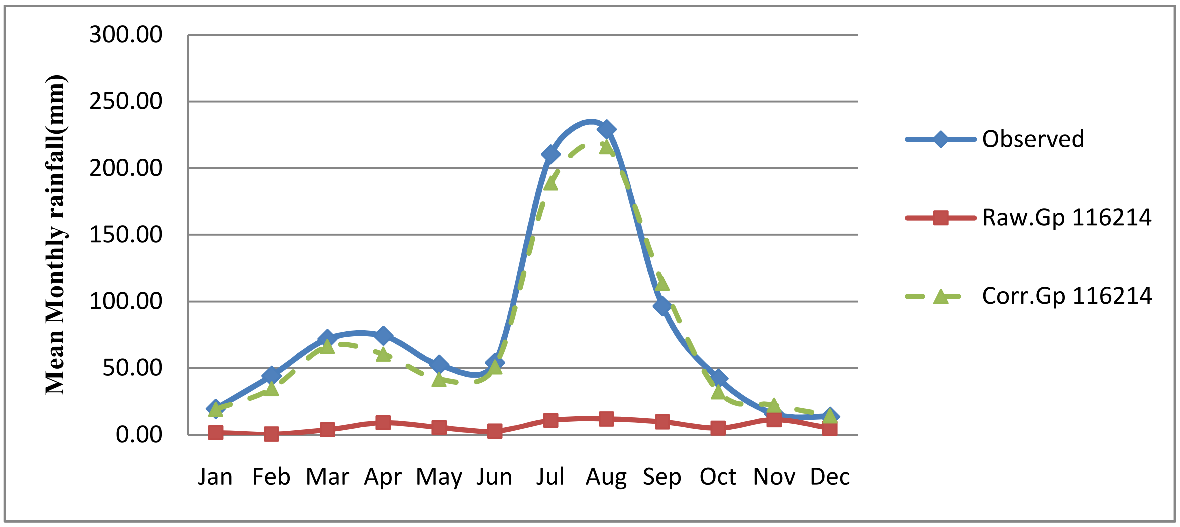
2.3 Stations and grid-based comparison of mean monthly

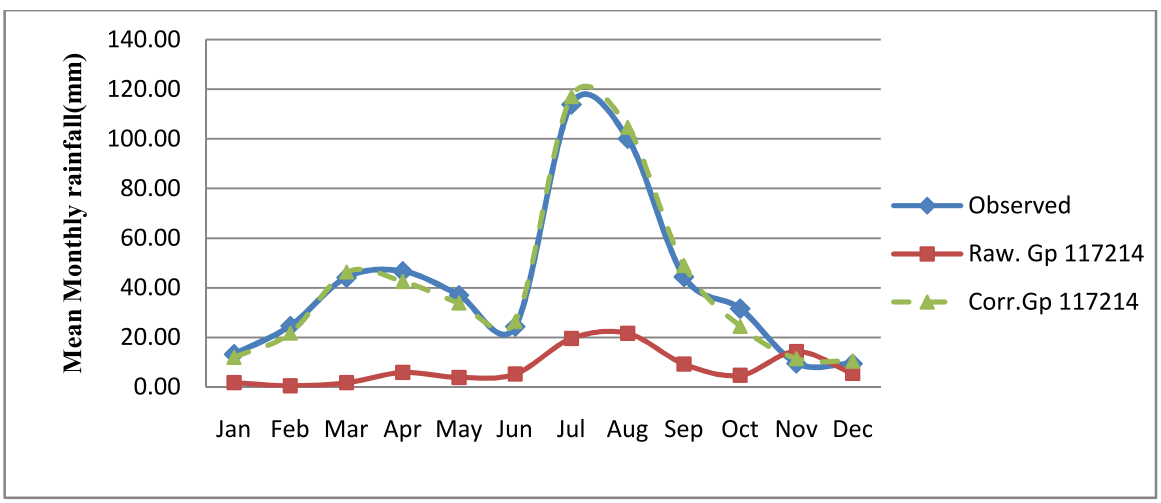


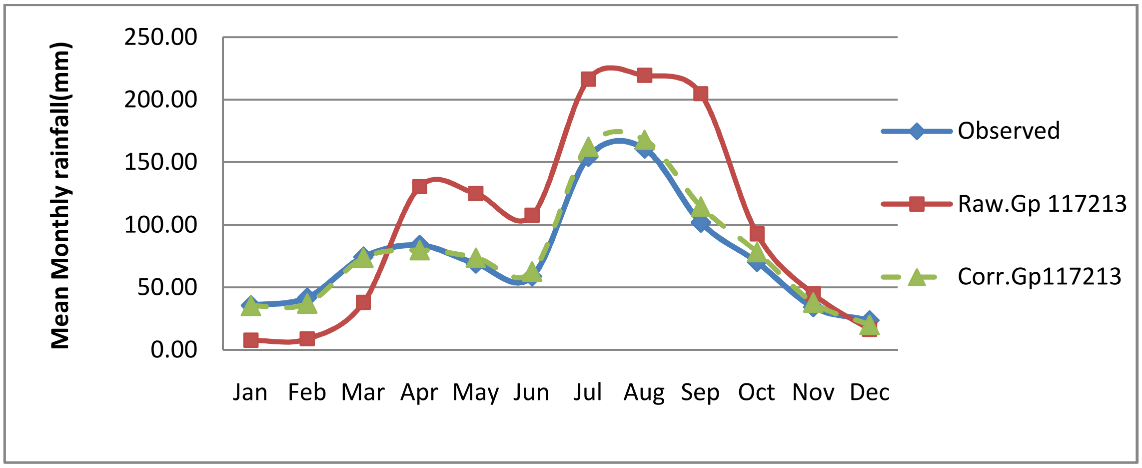





250.00
200.00
150.00
100.00
50.00
0.00
Mean Monthly rainfall(mm)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Observed
Raw. Gp 115213
Corr. Gp 115213


300.00
250.00
200.00
150.00
100.00
50.00
0.00
Mean Monthly rainfall(mm)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Observed
Raw.Gp 116214
Corr.Gp 116214


140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
Mean Monthly rainfall(mm)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Observed
Raw. Gp 117214
Corr.Gp 117214


Mean Monthly rainfall(mm)
250.00
200.00
150.00
100.00
50.00
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Observed
Raw.Gp 117213
Corr.Gp117213