# SURFACE WATER RESOURCES ALLOCATION UNDER EXPANSION OF IRRIGATION USING WEAP MODEL
# (THE KOKA RESERVOIR TO MIDDLE AWASH, ETHIOPIA)

**TIZAZU MOHAMMED**

**A Thesis Submitted to the Department of Water Resources Engineering, School of Civil Engineering and Architecture**

**Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Water Resource Engineering (Specialization in Irrigation Engineering)**

**Office of Graduate Studies**
**Adama Science and Technology University**

**May, 2024**
**Adama, Ethiopia**

# SURFACE WATER RESOURCES ALLOCATION UNDER EXPANSION OF IRRIGATION USING WEAP MODEL
# (THE KOKA RESERVOIR TO MIDDLE AWASH, ETHIOPIA)

**TIZAZU MOHAMMED (ID PGE/22031/13)**

**Advisor**
**Boja Mekonnen (Ph.D.)**

**A Thesis Submitted to the Department of Water Resources Engineering, School of Civil Engineering and Architecture**

**Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Water Resource Engineering (Specialization in Irrigation Engineering)**

**Office of Graduate Studies**
**Adama Science and Technology University**

**May, 2024**

**Adama, Ethiopia**

# DECLARATION

I, declare that this thesis entitled “Surface Water Resource Allocation under Expansion of Irrigation Using WEAP Model, The koka Reservoir to middle Awash, Ethiopia’’ is my own work. That is, it has not been submitted before for any degree or examination in any other university. It is being submitted for the partial fulfillment for the degree of Master of Science in Water Resource Engineering (Specialization in Irrigation Engineering) at Adama Science and Technology University School of Civil Engineering & Architecture.

| ____________________ | ________________ | _______________ |
|---|---|---|
| Name of student | Signature | Date |

I hereby certify that I have read and evaluated this thesis entitled “Surface Water Resource Allocation under Expansion of Irrigation Using WEAP Model, The koka Reservoir to middle Awash, Ethiopia’’ prepared under my guidance by **Tizazu Mohammed**. Therefore, I recommend that it can be accepted as fulfilling the thesis requirements.

| __________________________ | _______________________ | _______________ |
|---|---|---|
| Major Advisor/Supervisor | Signature | Date |

## APPROVAL SHEET FOR THESIS PROPOSAL

I hereby certify that all the correction and recommendation suggested by the board of examiners are incorporated into the final thesis entitled "Surface Water Resource Allocation under Expansion of Irrigation Using WEAP Model' The koka Reservoir to middle Awash, Ethiopia" by **Tizazu Mohammed**.

| | | |
|---|---|---|
| Major Advisor/Supervisor | Signature | Date |

We, the undersigned, members of the Board of Examiners of the thesis open defense by **Tizazu Mohammed** have read and evaluated his thesis entitled "Surface Water Resource Allocation under Expansion of Irrigation Using WEAP Model'', The koka Reservoir to middle Awash, Ethiopia" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the degree of Master of Science in Water Resource Engineering (Specialization in Irrigation Engineering).

| | | |
|---|---|---|
| Chairperson | Signature | Date |
| Examiner 1 | Signature | Date |
| Examiner 2 | Signature | Date |

Finally approved and acceptance of the thesis/dissertation proposal is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the candidate‘s Department Graduate Council (DGC) and School Graduate Committee (SGC).

| | | |
|---|---|---|
| Department Head | Signature | Date |
| School Dean | Signature | Date |
| Office of Postgraduate Studies, Dean | Signature | Date |

# Acknowledgement

First and foremost, I extend my heartfelt thanks to the Almighty 'GOD' for His unwavering mercy and grace that have guided me through all my endeavors and throughout my life journey.

My deepest gratitude goes to my advisor, Dr. Boja Mekonnen, for his exceptional guidance, unwavering support, meticulous supervision, and valuable editorial advice from the inception of the proposal development to the completion of the thesis.

Especial thanks to my beloved family for their boundless love, constant inspiration, and unwavering encouragement. Their unwavering support strengthen in that have been instrumental in navigating through my academic journey.

I also wish to express my appreciation to a special group of friends whose friendship and expert assistance have been a source of endurance. Among them, I must acknowledge Tegenu.Z, the first person who collaborated in this educational pursuit that I always remember. Additionally, I extend my sincere gratitude to Dr. Abdulkarim B. and Dr. Dereje for their encouragement and technical support during the proposal, seminar presentations, and our studying time in class.

# ACRONOMYS AND ABBREVIATIONS

| | |
|---|---|
| CROPWAT | Crop Water Requirements |
| DS | Demand Site |
| EEPU | Ethiopian Electric Power Utility |
| EIA | Environmental impact assessment |
| ESRI | Environmental Systems Research Institute |
| FAO | Food and Agricultural Organization |
| GIS | Geographical Information System |
| GPS | Geographical Positioning System |
| Ha | Hectare |
| ITCZ | Inter-Tropical Convergence Zone |
| Kc | Crop coefficient |
| Kms | Kilometers |
| LU | Livestock unit |
| M | Meter |
| $M^3$ /se | Meter Cube per Second |
| MCM | Million Cubic Meter |
| $Mm^3$ | Million meter cube |
| MoWIE | Ministry of Water, Irrigation and Energy |
| NSE | Nash-Sutcliffe Coefficient |
| $R^2$ | Coefficient of Determination |
| SRTM | Shuttle Radar Topography Mission |
| WEAP | Water Evaluation and Planning |
| UNCED | United Nations Conference on Environment and Development |
| WDM | Water demand management |
| SDG | Sustainable Development Goal |
| OECD | Organization for Economic Co-operation and Development |
| OWWDSE | Oromia Water Works Design and Supervision Enterprise |
| IWRM | Integrated Water Resource Management |
| SEI | Stockholm Environmental Institute |

**Table of Contents**

## List of Tables

## List Of figures

# ABSTRACT

The increasing need for water resources, driven by various factors such as water projects, population growth, urbanization, and industrialization, has strained existing water supplies. This has led to overexploitation of river systems and ecosystems due to the rise in irrigation areas. A crucial water allocation study was necessary to maintain ecosystem integrity and balance water supply and demand in the area. Data on hydrology, meteorology, and irrigation supply were analyzed statistically to feed into a model. Corrected meteorological and climatic data were correlated using multi-regression and distribution mapping methods. The study compared water demand and supply for both current and future development activities under irrigation expansion scenario. The thesis first examined model calibration, validation, and statistical measures, showing that the model performed well in simulating both current and future scenarios. The research aimed to establish a sustainable surface water allocation for the expanding irrigation activities around the Koka reservoir, using the Water Evaluation and Planning (WEAP) model as a decision-making tool to ensure social, economic, and environmental benefits. The WEAP model, known globally for its effectiveness in addressing water management challenges, was used to analyze current water supply-demand dynamics and develop future scenarios. The findings revealed unmet water demands in the reference scenario for the current year (1990), with an annual demand of 39.9 $Mm^3$. Under the expansion of irrigation scenario (2016–2035), the total irrigation water requirement surged to 788 $Mm^3$, with an unmet demand of 66 $Mm^3$. This study evaluated water scarcity in a basin undergoing irrigation expansion to ensure future water availability. It emphasized the importance of enhancing integrated water management to address water shortages during droughts. Additionally, the research aimed to create a water allocation model that distributes water resources to sectors based on economics for maximum benefits.

**Keywords:-**Irrigation expansion, water allocation and WEAP model.

# 1. INTRODUCTION

## 1.1. Background

Sustainable water resources management is a multi-stage, multi-disciplinary process that involves a diverse set of stakeholders with varying interests, technical expertise, and priorities. Sustainable water resources management necessitates the use of integrated water resource planning models capable of resolving the extremely complex problem. In addition to the complexity of the water allocation task, the increasing pressure caused by increasing demand and variability is a major challenge that must be addressed. As a result, understanding availability and reliability in the context of sustainability, equity, and deficiency is critical in the water allocation process (Hamlat et al. 2013). The complexity of the water allocation task, as well as the increasing pressure on water resources as a result of high water demand from population growth, river degradation and pollution of surface and groundwater sources, and the loss of potential sources of freshwater supply due to the use of old and unsustainable water management practices, has prompted many countries to revise water allocation aspirations (Roa-Garca 2014). As a result, effective water allocation and management necessitates an understanding of water availability and dependability, as well as equity, efficiency, and sustainability as key principles in water allocation (UNESCAP 2000).

The primary drivers of global water demand will be population and economic growth, rapid urbanization, and rising food and energy demand (GWP 2009). As a result, assessing the availability of water resources at relevant spatial and temporal scales is important (Yang and Zehnder 2007), and the ability to assess the availability of freshwater resources has been an issue of importance in most countries for many decades (WMO 2012). Many researchers around the world have conducted studies on the availability of surface water resources at various spatial and temporal scales ranging from watersheds to river basins (e.g., Tadesse 2006; Daniel et al. 2011; Flint et al. 2012; Sethi et al. 2015; Liu et al. 2017). According to these studies, many countries conducted water resource assessments at the watershed and basin scales to improve water resource planning and management.

The most important source of water is surface water. Knowing the potential, availability, and use of surface water will aid in increasing agricultural productivity, improving traditional water management systems, increasing drinking water supply, and hydroelectric power generation in future. Optimal surface water uses for the greatest benefit to people must take into account competing demands, such as domestic, industrial, and irrigation needs, as well as the needs of communities reliant on natural resources and the needs of ecosystems. The amount of water available to different users in a river basin can be optimally estimated (Mccartney and Arranz 2007).Water allocation in an optimal way has gotten a lot of attention across the world as population change and growth have pushed water resources to their natural limits (Yan et al. 2017). Despite this, the scope of the issue has become a research focus in many regions of the world (Babel et al. 2005; Yandamuri et al. 2006; )

The Government of Ethiopia is poised to make big investment in supporting the enabling environment for farmer-led irrigation, especially small-scale solar irrigation (Agricultural Transformation Agency, 2016; Amede, 2015; Chanyalew et al., 2010).

As rapid expansion of farmer-led irrigation is underway, questions loom large about who would truly benefit from such efforts. While most of the expansion efforts take care of biophysical aspects such as groundwater depth, land use pattern, solar irradiation (for solar irrigation) etc., socio-economics of potential beneficiaries is less understood. For example, in recent years, multiple studies have estimated the biophysical potential of farmer-led irrigation in Ethiopia (Addisu et al., 2019; Schmitter et al., 2018; Worqlul et al., 2017; You et al., 2011) as well as for the greater sub-Saharan African region (Altchenko and Villholth, 2014; MacDonald et al., 2012; Xie et al., 2014), but none of these considered socio-economic factors. Worqlul et al. (2017) assessed the land suitability for groundwater-based irrigation using biophysical indicators (e.g. land use pattern, groundwater storage, rainfall, road proximity etc.) and population density. Their model produced a map of land suitability for groundwater irrigation and showed that Ethiopia has more than 6 million hectares of land suitable for groundwater-based irrigation.

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).

Therefore, water allocation models are useful because, by simulating scenarios of situations encompassing complicated hydrological, environmental and socio-economic factors, they can provide insights into the likely impacts of different development options (McCartney, 2007).

## 1.2. Statement of the problem

The Awash Basin, known for its strategic location, accessibility, and abundant land and water resources, has become one of the most densely populated and intensively utilized river basins in Ethiopia (Zemede, 2011). The GTP report, however, without including Amhara region listed around 1.9 million ha (more than 1.0 million ha in Afar Region) potentially suitable for surface water irrigation only. A recent GIS based assessment study document put the potential as 1.2 million ha (MoWEI, 2018). GTP plan document clearly listed the locations where small, medium and large scale projects to be developed which is substantiated by the report of MoWEI (2018).

Regarding equipped irrigated areas, different sources have different figures but most recent reports agreed on 0.19 to 0.2 million ha (9 to 11% of rainfed cropland) (Yibeltal, 2013; AAiT and AwBA, 2018; AwBA, 2018). Estimate of AAiT and AwBA (2018) was 0.198 million ha from which around 12,000 ha is schemes with areas below 2.5 ha. Karimi et al. (2014) reported 0.217 million ha equipped area. FAO and IHE Delft (2020) increased it to 0.39 million ha but recommended further verification.

Upstream areas of the basin often perceive water abundance, and awareness of downstream water stress is low. This perception leads to inefficient water use and wastage in upstream regions. To address these challenges, various water resource simulation models have been employed, including MODSIM (Berhe et al., 2013), WAS (Yan et al., 2018), CWAM (Wang et al., 2008), WEAP (Adeba et al., 2015), and MOEA (Yan et al., 2017). Among these, the Water Evaluation and Planning (WEAP) model stands out for its ability to incorporate diverse hydrological components in data-scarce areas, as well as its adaptability, simplicity, inclusiveness, and potential for modeling the impact of climate change scenarios on reservoirs and evaluating water resources using a scenario-based approach (Gedefaw et al., 2019). Compared to previous allocation models, WEAP also simulates water usage for domestic, irrigation, and ecological purposes over time and space. The model provides a set of objects and methods applicable to reservoirs, river basins, and watersheds, enabling water resources managers and planners to address challenges using a scenario-based methodology (Davijani et al., 2016). Previous studies have modeled the hydrological parameters of the Awash River Basin using various distributed hydrological models. For instance, Berhe et al. (2013) employed the MODSIM-based allocation model to simulate the basin under three different scenarios, indicating its usefulness for water allocation. Adeba et al. (2015) attempted to use the SWAT model to evaluate the basin's water scarcity. Mesfin et al. (2018) modeled the upper Awash River Basin using the SWAT model to assess the suitability of the Climate Forecast System's reanalysis weather data for watershed modeling. Karimi et al. (2015) investigated the spatial evapotranspiration, rainfall, and land use data in water accounting, emphasizing how remote sensing measurement errors affected water accounting and the data provided to policymakers. Seasonal-based simulation of water allocation is crucial for irrigation planning (Singh, 2012). This study evaluated water scarcity in a basin undergoing irrigation expansion to ensure future water availability. It emphasized the importance of enhancing integrated water management to address water shortages during droughts. Additionally, the research aimed to create a water allocation model that distributes water resources to sectors based on economics for maximum benefits.

## 1.3. Objectives of the study

### 1.3.1. General objectives

The main aim of this thesis is to develop Surface water allocation for koka reservoir under expansion of irrigation using WEAP model as a decision support tool.

### 1.3.2. Specific objective

The specific objectives are:-

- Evaluate current water allocation, simulate impact of irrigation expansion and develop sustainable allocation.
- Evaluate and project water demands across various sectors.
- To evaluate the reservoir water evaporation losses.

### 1.4. Research Questions

- How can the management of water storage, inflows, and losses from the reservoir be optimized?
- What methodologies can enhance the allocation of downstream water requirements?
- What is the quantified water demand for different sectors?

## 1.5. The Significance of the study

The study serves as a valuable tool for decision and policy makers, administrators, planners, and water resources professionals engaged in the management of water resources. Its primary aim is to support these individuals in developing and executing efficient water allocation systems within the Awash River basin in the thematic area of Awash. By providing insights into the behavior of the water allocation system, the study equips stakeholders with the knowledge necessary to effectively balance water demand and supply dynamics both now and in the future.

Furthermore, the study extends its benefits to all relevant stakeholders at the grassroots level, empowering them to utilize water resources in a sustainable and efficient manner. By taking into account social, economic, and environmental considerations, the study ensures that water management practices contribute to overall well-being and long-term sustainability.

## 1.6. Scope and Limitation of study

The study aims to allocate reservoir surface water efficiently for downstream irrigation users, benefiting the socio-economic and environmental aspects in the basin. It focuses on fair distribution to support agriculture, domestic water needs, and livestock within the catchment area. While critical, the study does not cover flood and sediment challenges, which are vital for sustainable water management. It also does not address the impact of climate change on water quality, a factor that could affect long-term sustainability.

# 2. LITRETURE REVIEW

## 2.1. Water Allocation

Water allocation is the process of sharing a limited water resource among different regions and competing users. It is a process made necessary when the natural distribution and availability of water fails to meet the needs of all water users in terms of quantity, quality, timing of availability, or reliability. In related to the construction of Koka dam, water releasing system was developed to produce regulated power throughout the year. Although it is varied according to the power need, it had 40m3 /sec constant release rate for all months except July and August. This water releasing system didn't support with any allocation system simple the upstream users take the advantage to divert the water to their field and release their surplus water only.

A number of studies have already been conducted in the basin that could support the water allocation plan (Berhanu and Yilma 2008, MoWE and FAO, 2013, Berhe et al 2013, AWBA, 2016). The joint project of ministry of water and Energy (MoWE) and Food and Agriculture Organization (FAO) in 2012, have developed water audit model for the water demand and supply of the entire basin. In this study the spatial and temporal variation of surface water potential in the basin and the gaps to meet the water demand for various uses were evaluated. This study also inventoried the irrigation water use of all small, medium and large scale irrigation schemes. This study was the basis for changing the priority order of the water release of Koka Dam from Hydropower based release to irrigation based release. Berehe et al (2013) also conducted the water allocation modeling of Awash River Basin, using MODSIM, through scenario analysis. This study was conducted to analyze the water balance of the Awash Basin under different levels of irrigation development and also determine the water allocation in the Upper, Middle and Lower Valleys in the basin. The study also suggested unaccounted water diversions upstream of Koka and water losses in Gedebessa Swamp should be considered in the basin planning.

A recent study (AWBA, 2016) has developed an integrated water allocation system to be used as decision support tools with three interfaces: simulation, operation and monitoring. Current state of irrigation water demand in the basin has resulted in conflict among the stakeholders of the basin water thus the study has also included conflict identification and resolution study. The Water allocation Model developed for the entire basin in addition to existing water sources (surface and ground water sources) and demands (Agricultural, domestic and municipal, Industrial, and Environmental) identification and quantification conflict among users are well identified.

The study clearly indicate that with current and future water demand of the basin will satisfy if and only if additional water harvesting and ground water development undertake in different potential areas of the basin. The water allocation model has also developed scenarios for dry year, normal year and wet year water allocation and management. In support of the AWBA to view different options for strategic solutions (like, conjunctive use of ground and surface water sources, improvement of irrigation water use efficiencies of different users) on the basis of the available water options for analyzing climatic variations were also included. With its compressive nature it supports this strategic basin plan development

Allocation targets have evolved over time and different approaches have emerged calculation, definition and management of water resources. Ultimately, however, the water supply allocation the process of determining those entitled to available water continued. Essentially this consists of: Determining how much water is available for allocation. This could include assessing different locations, different sources (such as groundwater and surface waters), for different periods of the year or in different climatic conditions. Determine how to share that water among different regions and concurrent users: who should be entitled to what? The water allocation process can distinguish between different administrative or geographic regions, different sectors and (ultimately) individuals' water extractors and users (Zhanq et al., 2015)

## 2.2. Water Allocation Strategy Development

### 2.2.1. Strategic Priority setting

A number of issues were raised in the situation analyses that are relevant to the water allocation strategic plan development. All issues related to the strategic development are valid but their priority shall guarantee the success of the plan. This priority is set so that the execution of the prior will guarantee the success of later development (AWBA, 2016).

- Conflict management: institutional intent for cooperation, collaboration and stewardship
- Institutional coordination (Policy and regulation issue)
- Financing mechanisms

- Stakeholder engagement
- Monitoring and information (transparency)
- Resource development: State of water resources in providing goods and services to the community and the environment
  - Groundwater development o
  - Surface water resource development
- Water demand monitoring: social and economic outcomes related to water use
  - Water supply and sanitation
  - Environmental flow
  - Irrigation
  - Hydropower

## 2.3. Surface water demand and its allocation

Surface water allocation for human and environmental activities needs to be considered and it can be defined as a process which systematically divides the amount of available water in the system for different regions and competing users (OECD, 2015), such as agricultural, domestic, industrial, and environmental components. Precipitation minus evapotranspiration accumulates in a catchment and flows to streams and recharges to aquifers. Surface water allocation planning and management is typically undertaken, to achieve a series of overarching policy objectives. In many rules including (Speed, 2013)

- Equal distribution (allocation) of water among various user groups and regions.
- Allocating water recognizing fresh water-water dependant ecosystem and environmental water need.
- Water allocation should balance the water supply with the demand in order to manage variation of water availability.
- Development priorities such as supporting social and economic development.
- Allocating water by promoting efficient use of water available.

The water allocation of regional development and planning needs the incorporation of economic objectives with many factors, including historical, technological, and natural and resource constraints and potentials (Azazh, 2008).

Water allocation regarding with a priority helps to balance water requirement with supply. The approaches of water management recognize that, different users will be given various levels of priority and these are essential for development of watershed demands. Water demand allocation Priority represents the distribution of limited resources by giving rank among multiple demand sites. The priority for water demand should be fixed and resolved in allocation cycle of catchment before the remaining water is shared among the catchment water user. Water allocation priority is established by Government level.

## 2.4. Water Evaluation and Planning (WEAP) Model

WEAP model is a microcomputer tool of integrated water resource software created in 1988 by the Stockholm Environmental Institute (SEI) with user-friendly, flexible and transparent planning for assessment of current water demand and supply patterns and also, for designing and evaluation of alternative scenarios. The demand sides are; domestic water need for urban and rural site, livestock water need, irrigation water requirement and environmental flow water requirement with the equation of equipment efficiencies, water use rate, re-use and allocation whereas, supply side includes stream flow, catchment, reservoir and ground water. WEAP model is very important software for planning, management and allocation of constrained water resource and environmental quality. WEAP is also graphically oriented with programing language software library that utilize Map Objects from the Environmental Systems Research Institute (ESRI) which allows spatial referencing of watershed attributes (e.g. river and groundwater systems, demand sites, wastewater treatment plants, watershed, and river reach lengths). Several scenarios construct WEAP model simulations, where simulation time steps can be as short as one day, to weekly, to monthly, or even seasonally with a time horizon from as short as a single year to more than 100 years (Sieber J. Y., 2015).

## 2.5. Hydrology and water resources

Awash River has more than 14 tributaries and the basin is known for experiencing extreme floods and droughts. In between Koka and Awash station, tributaries such as Keleta, Wererso and Arba which drain the eastern catchment join Awash River. Beyond Awash station, the basin expands into the eastern plain as the Rift valley widens. Although the eastern plain accounts some 40% of the basin, the drainage channels terminate before reaching the Awash and receive rainfall less than 600 mm per year (WWDSE, 2016 citing Halcrow, 1989). From flow gauge station to the Gedebassa swamp, major tributaries such as Kesem and Kebena, which originate from the western highlands, join the river. Herdini also joins from eastern side. From the Hertale to Tendaho gauge station, the regime is complicated by Gedebassa swamp with estimated losses of 400 to 1,200 million $m^3$ per year. Ataye, Borkena, Chelela and Mille tributaries that originate from Wollo highlands are contributing about 900 million $m^3$ of water annually (Halcrow, 1989).

Different reports put different figures on surface water potential of the basin. According to master plan study developed by Halcrow (1989), mean annual runoff measured at Koka dam entrance has been estimated about 1,520 million $m^3$ . At Awash gauge station, the flow will be 1,546 million $m^3$. At Hertale gauge station, i.e. before the Gedebassa swamp, it will be around 2,692 million m3 while at Tendaho it is 2,424 million $m^3$ . Majority of previous and some recent studies, for instances AwBA (2017); EPCC (2015); Tadesse et al. (2003); Karimi et al. (2014); FAO (1997); AAiT and AwBA (2016); Seifu and Alexandros (2011); WWDSE (2013) and others reported 4.0 to 4.9 billion m3 as surface water potentials of Awash basin or annual flow of Awash river at its outlet. The major water users in the basin are 18.6 million human populations, 34.4 million livestock population, 199,234 ha irrigated land and different commercial and industrial activities. They demanded annual water of 3.4 billion $m^3$, 0.298 billion m3, 0.12 billion $m^3$ and 0.28 billion $m^3$ for irrigation, domestic, livestock and industrial uses respectively. If we aggregated the total water use demand in the basin it accounted as 4.11 BCM (AAiT and AwBA, 2016). If we compare differ water users the irrigation water use accounts 83% of the total water use of the basin (AAiT and AwBA, 2016; AwBA, 2018). However, AwBA (2018) further reported 8.2 billion $m^3$ as surface water potential which is close to FAO and IHE Delft (2020) report as 8.6 $km^3$ /year of which 2.1 $km^3$ /year (24% of available amount) is managed for irrigation. Moreover, annual precipitation of the basin is 72.0 $km^3$ /year (2.5% falls in irrigated areas) while actual evapotranspiration is 64.6 $km^3$ /year, 5.6% or 3.6 $km^3$ /year of this is from irrigated land with the assumption that mean irrigated land covers 3,126.8 $km^2$ . Awash being an internal drainage basin, there is no surface water outflow; the difference between rainfall and evaporation is due to changes in storage or groundwater outflow. Long term (2009 to 2018) mean imbalance between rainfall and actual evapotranspiration is 57 mm/year or 6.0 $km^3$ /year and in short, 10 year average available basin water is 8.7 $km^3$ /year (5.9 $km^3$ /year is exploitable and 2.8 $km^3$ /year is increase in storage). Historical Tendaho dam release data revealed that around 2.5 billion $m^3$ dam water is released to Awash River annually and when added with estimated 3.26 billion $m^3$ gross applied on existing schemes, the figure reported by FAO and IHE Delft (2020) which is 5.9 billion $m^3$ is acceptable.

Another contentious data is about potentials, distributions, quality and possibilities of using groundwater for irrigation. In Ethiopia including awash basin, groundwater is not properly studied and utilized. Frequently reported groundwater potential of the country is 36 billion $m^3$ (MoWIE, 2018) but much higher figures were also reported. Citing MacDonald et al (2012), Abeyou et al. (2017) stated that although there is no detailed study for Ethiopia, Africa has groundwater storage estimated to be 100 times more than annual renewable freshwater resources. Report of OIDA (2018), AgWater Solutions (2012), Seifu and Alexandros (2011), AAiT and AwBA (2016) and others substantiated this idea. For example, within the awash river basin estimated groundwater recharge of Middle Awash Basin alone which covers around 29,290.0 km2 (25% of the Awash basin) is around 1.988 billion $m^3$ and is equivalent to 7.4%–9.0% of annual rainfall (MoWIE and JICA, 2015). Betelhem (2017) reported that total groundwater potential of the basin at a depth of 200 m from the surface that can be used sustainably estimated to be within the range of 0.76 to 12.5 billion $m^3$. OIDA (2018) carried out detailed groundwater potential of Awash basin situated in Oromiya region covering around 25,627.7 km2 or 23% of basin area. According to the report, Average Groundwater Resources Potential (AGRP) of Awash basin of Oromiya region is about 63.43 billion $m^3$ /year of which 20.72 billion $m^3$ /year is for high potential zone; 34.54 billion $m^3$ /year is for moderate; and 8.17 billion $m^3$ /year is for low potential zones. Average Groundwater Exploitable Potential (AGEP) or exploitable groundwater resources is about 18.7 billion $m^3$ /year of which 7.34 billion $m^3$ /year is for high potential zone (borehole yield greater than 15 lit/sec); 10.99 billion $m^3$ /year for moderate (5-15 lit/sec) and 0.38 billion $m^3$ /year for low potential zones (below 5 lit/sec). Generally, yields of boreholes in the basin vary from 5 to 35.5 lit/sec (mean 23.1 lit/sec) in high potential zones and from 2 to 15 lit/sec (7.5 lit/sec) in moderate potential zones as compared with 0.042 to 5 lit/sec (1.7 lit/sec) in low potential zones. Each zone has almost equal area coverage. Groundwater areas which are suitable for irrigation accounts 10,055.7 km2 or 36.4% of total area whereas unsuitable ground waters for irrigation constitutes 5.7% (1,576.5 $km^2$) of the total area. Western parts around Becho plain, more than 68% of the Afdem, and all areas of Erer-Hurso, Mile and Gololcha generally have very good groundwater quality for irrigation. However, groundwater particularly around

Adulala town, south and east of Bishoftu town, around Bole town (south of Lake Beseka), and around Bordede town have very poor quality not suitable for irrigation. Well depth up to 80 m is considered as shallow wells and has average static water level of 13.8 m whereas deep well have 35 m (OIDA, 2018).

Abeyou et al. (2017) reported the average groundwater storage, aquifer productivity and groundwater depth of Awash basin as 11,847 mm (1,308 billion $m^3$ for 110,439 km2 basin area), 5.6 lit/sec and 38.8 m, respectively. Suitable groundwater irrigation potential of Awash basin is 0.73 million ha (6.6% of basin area). Seifu and Alexandros (2011) suggested that around 10% of the groundwater is exploitable whereas AwBA (2018) puts groundwater potential of the basin to be around 10.3 billion $m^3$. Hence, it is reasonable to consider 5.9 and 1.0 billion $m^3$ (10% of 10 billion $m^{3)}$ respectively as exploitable surface and groundwater potentials for irrigation.

## 2.6. Optimal Surface Water allocation

The aim of optimal water resources allocation is to reallocate the limited water resources scientifically among different water use sectors based on a fair, effective and sustainable principle in a given region through measures such as restraining water demand reasonably, increasing water supply effectively, and protecting the ecological environment positively (Xiang et al., 2015).

Water allocation is essentially an exercise in allocating available water to demanding users. In order to make wise operational decisions regarding solutions to sharing water in a river basin or watershed, a fundamental scientific understanding of how the limited available water resources can be shared efficiency is required. Historically, access to water has been regulated to meet a wide range of social objectives, including agricultural production, economic development, public health and more recently environmental protection. The allocation should be done efficiently, practically and economically, technically and socially fair. Economical efficient allocation means distribution of water to maximize profit. Socially fair allocation tends toward distribution for preserving interests and fair allocation of water to weaker economical groups. Hence it is necessary to have a proper water allocation system, in which water is considered as a socially and economically merchandise (Bahram et al., 2015).

Allocation objectives have evolved over time, and different approaches have emerged to calculating, defining and managing water resources. Ultimately, though, water resource allocation has persisted the process of deciding who is entitled to the available water. Fundamentally, this consists of: Determining how much water is available for allocation. This can include assessing different locations, different sources (such as groundwater and surface water), for different times of the year, or under different climatic conditions. Determining how that water should be shared between different regions and competing users: who should be entitled to what? The water allocation process may distinguish between different administrative or geographic regions, different sectors, and (ultimately) individual water abstractors and users (Zhanq et al., 2015)

## 2.7. Irrigation Developments in Ethiopia

Irrigation development is vital to the sustainable and reliable agricultural developments in Ethiopia. Subsistence dominated smallholder farmers' economy can be improved through the use of irrigation in the Ethiopian agriculture (MoA, 2011b). Similarly, make use of irrigation agriculture is going to be a means for increased agricultural production to meet the growing food demands of rapid population growth. Irrigation development in Ethiopia can be considered as a cornerstone of food security and poverty reduction tool as it has a power to stimulate economic growth and rural developments (Hagos et al., 2009). As a result, irrigation infrastructures are increasing year after year, which show country wide positive development implications and experiences in small and large scale irrigation schemes. In Ethiopia, farm size per household is 0.5ha and the irrigated land per households' ranges from 0.25 ha - 0.5 ha in the Ethiopian context. As a result, individual land holdings per households are too small to feed the household. With this limited landholdings, increasing food demands of the population depends on either one or a combination of increasing agricultural yield, increasing the area of arable land, and increasing cropping intensity by growing two or three crops per year using irrigation. On the other way, Irrigation development in Ethiopia is in its infancy stage (MoA, 2011a). The Ethiopian government is therefore pursuing plans and programs to develop irrigation in an effort to substantially reduce poverty and create an atmosphere for social change.

As a result, the Ethiopian average rate of irrigation development for the last 12 years was about 1,090 - 1,150 ha/year (Nata et al., 2008; Bekele et al., 2012). In Ethiopia, only 10% of the estimated potential irrigable land is actually irrigated (Gebremedhin and Pedon, 2002) and 2% of cultivated lands are irrigated (MoWR, 2001). Similarly, irrigated agriculture comprises only 3% of the total national food production (Bacha et al., 2011). That is why; irrigated agriculture is far from satisfactory despite of considerable investment, public interest, and strategic support of the government. Belay and Bewket, (2013) explained that irrigation water is critical to poverty alleviation through increased production in rural areas so as to improve food security and rural livelihoods.

Smallholder irrigation has recently received significant focus from local governments to enable farmers to cultivate crops twice or more per year. Bacha et al. (2011) in the study of the impact of small-scale irrigation on household poverty in central Ethiopia, reported that land productivity, asset ownership, credit utilization, extension support, resilience to poverty, mean off-farm income, and mean food consumption and expenditure on food and non-food assets were significantly higher for irrigators than non-irrigators. Irrigation development is taking place through the use of government budgets, donor programs and NGOs. However, As compared to its potential and rain-fed farming, contribution of irrigation to the national economy is quite limited which contributes about 2.5% of the overall GDP (Hagos et al., 2009; MoA, 2011a). Moreover, the existing irrigation development in Ethiopia, as compared to the irrigation potential the country has, is not significant (MoA, 2011b). Thus, irrigation has to play significant contribution in mitigating food insecurity and hence poverty reduction

## 2.8. Water allocation criteria

To achieve optimal resource allocation requires appropriate means of resource allocation source. Different criteria are used to compare forms of water allocation (Weragala, 2010) such as: Flexibility in the allocation of stocks; Rent protection for established users; For real the opportunity cost of providing the resource is paid by the users; Predictability of the result of the allocation process; Parity of the assignment process and political and public acceptability.

## 2.9. Objectives and Principles of water allocation

Basin water allocation planning is typically undertaken to achieve a series of overarching objectives including equity, environmental protection, and development priorities, balancing supply and demand and promoting the efficient use of water. The basic principles for the allocation of water resources are efficiency, equity, and sustainability, with the aims of pursuing the maximum benefit for society, the environment and the economy, whilst maintaining fair allocation among various areas and people (Jin et.al. 2007).

Water allocation in general aims to maximize the benefits to the society from the resource. However, the general objective has implication to the more specific objectives such as social, economic and environmental with the corresponding principles of equity, efficiency and sustainability, respectively (UNESCAP, 2000). Equity indicates a fair sharing of water resources in river basin at all level (local, national and international) and among all users. Efficiency guides to a financially sustainable use of water resources; however, it also implies the fair compensation for water reallocation between users. Sustainability on the other hand advocates the environmentally sound use of the resource. Water allocation follows either of the principles of water right such as riparian right, prior appropriation rule, public ownership along with a number of mechanisms such as administrative, user-based, marginal cost pricing and water market (Savenije and Van der Zaag, 2000).

## 2.10. Water Demand

Water demand is defined as the amount of water users need to meet their needs. Water demand forecasting is a process accomplished through various techniques and is most commonly used to forecast future water demand for various applications including hydroelectric power and water needs for households and agriculture. The demand for water is increasing with agricultural practices leading to industrialization. The need to use water is determined according to social, economic and environmental needs (number of households, irrigated hectares of cultivated areas and plant species, minimum running water and other needs) and the respective effectiveness of water use. When resources are limited compared to needs, as in some cases for irrigated regions, conflicts can arise between competing users.

According to Williams, in2010, accelerated human population growth, rapid advances in industry and agriculture led to a rapid increase in human water use along with water availability and excess water management, a critical factor in the development of all regions of the world. While Ethiopia's water resources are vast, very little has been developed for agriculture, hydroelectricity, industry, water supply, and other purposes. National coverage of potable water supplies was 26% in 1992, while sewerage was only 7%; which is low even by sub-Saharan standards. There is also a large divergence in water coverage between urban (76%) and rural (18.8%) areas (Seleshi, 2010).

Meeting the needs of diverse users requires increased efficiency efforts by using all water resources (surface water, groundwater, and rainfall) and water allocation plans that maximize the resulting economic returns for limited water resources, while protecting the fragile ecosystem. Water demand management (WDM) is an integral part of the challenge of maintaining water demand and supply. We know that the fundamental principle of water demand management is: "Efficient use of water to maintain environmental flow for life and reduce reliance on infrastructure projects expensive. For example, you can flush the toilet or do your laundry with one-third the amount of water normally used, with equal or greater efficiency (Wong et al., 2009).

### 2.10.1. Domestic Water Demand

Domestic Water Demand is the amount of water needed for drinking, preparing food, washing, cleaning, bathing and other various household purposes. The amount of water used for domestic purposes strongly depends on lifestyle, living standards and climate, way of service and convenience of users. The per capita demand for sanitary water different categories of questions vary according to the size of the city and the level of development, the type of water supply plan, the socio-economic condition of the city and the climatic conditions of the area.

### 2.10.2. Agricultural Water Demand

Rain fed agriculture remains the bulk producer of our food and fiber. Since there is little scope of policy-makers influencing rainfall, at this level there is little to plan and forecast. We can safely leave this task to our rain fed farmers. In this section we rather concentrate on irrigation water demand. One remark however: there is still a lot of scope to improve the productivity of rain fed farming, and the water utilization efficiency, for instance through:

- Alternative tillage techniques best suited for the local climatic and soil conditions, which conserve soil and water;
- Appropriate fertilization; as water is not the only constraint in crop production, improved fertilization will result in higher production per mm of rain water
- The best possible choice of crops and crop varieties given local conditions; this includes the option of e.g. intercropping.

Such measures may translate into higher production, offsetting the need to create new irrigation schemes, and thus freeing water and monetary resources. Irrigation is in many river systems the main water user. Often water use for irrigation accounts for at least 80% of total water use in a water resources system. For the proper planning and management of such a system it is therefore important to have adequate tools to reliably estimate the demand for irrigation water, the possible yield reductions due to water shortages, and the economic benefits of irrigation water.

The present subject belongs to the working area of specialists such as agriculturalists and irrigation engineers. However, it is important that water resources managers have a basic understanding of the subject matter, such that they can weigh the water demand from the agricultural sector vise-a-visa the demands for water from other sectors. (Pieter vanderZaag, 2003)

Land irrigation has been practiced for millennia through the necessity to maximize food supply for humanity but the dramatic expansion in irrigated land has mainly taken place during the 20th century, with irrigation becoming the principal water use in many countries. Indeed, agriculture is now reckoned the largest consumer of water, accounting for some 80% of total water use. Before the late 197Os, intensive irrigation development could be found in all the continents, forcing the growth in irrigated areas and guaranteeing an increase in crop production. In the 198Os, however, the rate of global increase in irrigated areas dropped considerably in both developed and developing countries. (UNESCO, 1998).

Assessment and evaluation of surface water potential and demands in Baro -Akobo river basin, Ethiopia 11 Ethiopia has a significant irrigation potential identified from both available land and water resources. Irrigation would provide farmers with sustained livelihoods and improve their general well-being (Belay et.al 2013). However, the country's irrigable land has been underutilized, and only 4 to 5% of the potential area has been developed for irrigation (Awulachew et al., 2007). Consequently, the agricultural economy of the country is largely based.

### 2.10.3. Water use in industry and energy production

Industrial water use is typically dependent on sustained quantity and quality of water, whereby sudden reductions in water availability can potentially lead to higher costs and/or production losses. Water quality requirements vary significantly depending on the type of industry, food and beverages and pharmaceuticals exemplifying the highest standards. Besides its growing prioritization for economic reasons, industrial water use may limit water availability for other uses due to point-source pollution. Water use efficiency (SDG 6.4) in industries and energy generation can generally be improved with optimized processes, more efficient technologies and recycling, reuse, reduction or even, where appropriate, replacement of water use with waterless alternatives. Curbing water pollution from industries (SDG 6.3) goes hand in hand with efficiency improvements and provides cost savings and lower water-related risks to business.

Availability of water in the energy sector is critical for society and gaining increasing international attention as demand for resources mounts and governments continue to struggle to ensure reliable supply to meet sectorial needs. Water shortages may lead to power outages or significant generation losses, with typically widespread impacts on all other sectors and their water use systems. In trans-boundary water management and allocation contexts, an especially important aspect to consider is flow regulation. The production of hydropower is mainly associated with reservoirs, which, in many cases, have a continuous multipurpose function, such as flood protection, navigation, as a source for consumptive use of water, or recreational water use activities. Since hydropower is commonly generated to meet peak demands, however, hydro peaking may occur and, if not adjusted upon high flows, flooding may be aggravated downstream(London, CDP Worldwide, 2020).

Dams, particularly large-scale hydropower dams, may cause a range of direct or indirect impacts, including: environmental impacts, such as altered fish spawning, biodiversity loss and reduced sediment loads; social impacts, such as loss of livelihood and involuntary resettlement of local communities; and potentially exacerbating climate change impacts **(**Berlin-Heidelberg, Springer, 2012.)**.** Any such impacts that could cause significant trans-boundary harm should be addressed in both the planning and operationalization phases, if not already at a stage of strategies and policies (e.g. designation of no-go zones). Measures to address impacts include the placement, size (capacity) and design of individual dams, which need to be subject to environmental impact assessment (EIA), including for trans-boundary impacts, along with prior notification and consultation. Depending on the outcomes, this may require further negotiation, redesign or searching for alternative solutions. Additionally, it is beneficial for States to seek to agree on an operational regime that reconciles different needs and cascades of dams with different operation regimes. This requires cooperation and potentially joint infrastructure development, which can further facilitate broader benefit-sharing.

### 2.10.4. Environmental needs

#### *2.10.4.1. Ecosystem well-being as a foundation for sustainable water allocation*

The health of freshwater ecosystems is the foundation for the sustainability of water resources and the services and benefits derived from water. In modern water allocation arrangements environmental needs are assessed and an environmental reserve is recommended to be set aside before allocating water to other uses (Speed and others (2013) .While deciding on environmental requirements in water resources management is ultimately a political process and decision, such decisions should be based on verifiable scientific data. The latest science, as well as the SDGs (notably 6.6, 14, 15), emphasizes that the environment should not be seen as a water-using sector among others, the needs of which may be negotiated, but, rather, that ecosystem well-being must be given high value as it affects all other water uses. The 1992 Convention on Biological Diversity can be used as a general guide for water allocation in this regard insofar as it defines an ecosystem approach relevant to IWRM and distinctly promotes "the restoration and maintenance of biologically diverse ecosystems as a way of improving access to clean drinking water and as a means to eradicate poverty" (Montreal, 2010).

#### *2.10.4.2. Environmental and ecological flows*

Environmental needs within water allocation are best described with the concept of environmental flows, often used interchangeably with ecological flows, with both commonly abbreviated to "e-flows". While multiple definitions of the term exist, the most comprehensive recent definition, from The Brisbane Declaration and Global Action Agenda on Environmental Flows (2018), describes environmental flows as "the quantity, timing, and quality of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, sustainable livelihoods, and well-being". The concept of ecological flows focuses on ecosystem needs as a part of the overall environmental flow. When properly implemented, environmental flows can achieve multiple benefits, including: helping sustain and generate ecosystem services and livelihoods dependent on them; creating economic and recreational value; preserving rivers; sharing benefits of basin development more equitably; and in general contributing to the sustainable management of rivers (Berkeley, California, International Rivers, 2017).

#### *2.10.4.3. Environmental flows in trans-boundary water allocation*

Environmental flows have emerged as one of the key frameworks for informed, participatory decision-making in water resources planning to arrive at a balance among extraction, use and conservation of watersheds and their waters. One of the key challenges of environmental flow management is to maintain a sufficient minimum flow of water in rivers and prevent over abstraction during low-flow periods. Periodic high flows are required for maintaining water quality, triggering fish spawning and migration, sediment transport, groundwater recharge and wetland inundation (Montreal, 2020). River ecosystems may also be negatively affected if too much water is released from storage during periods when rivers would naturally experience low flows. As all aspects of the environmental flow regime are potentially important to the environment, ideally, water allocation arrangements should account for natural variability, predictability, seasonal timing and flood magnitude of the given aquatic system and its connections to other systems (e.g. surface and groundwater) (Hripad Dharmadhikary , et al.,2017)

## 2.11. Stakeholder Engagement

Traditional engineering and economic solutions are insufficient to resolve most complex water issues. Management of water as a resource is becoming increasingly critical in urban, peri-urban and rural areas. Watershed boundaries transcending political boundaries increase the complexity of issues. The major drive for this critical situation stems from two aspects; the experienced and predicted scarcity of water spatially and temporally all over the world (Faust et al. 2013) and the increasing demand for available water, both in quantity and quality, among multiple stakeholders (Pinto and Maheshwari 2010). Additionally, the anthropogenic activities degrading water quality has ironically impacted the very existence of humans (Erdogan 2013; Grover and Krantzberg 2015, 185-86). The sustainability in all aspects of water from source to user has thus drawn important and urgent attention from various use sectors across the world with the significant environmental and political issues created (Erdogan 2013; Gudowsky and Bechtold 2013; Webb et al. 2009). Sustainable water systems are defined as 'water systems that are managed to satisfy changing demands placed on them (both human and environmental) now and into the future, whilst maintaining ecological and environmental integrity of water systems.

Stakeholder engagement and participatory approaches for decision making are increasingly considered in various sectors, including water, to overcome alienation, foster communication and stimulate reform process (Larson and Williams 2009). As such, striking a balance between the traditional top-down and emerging bottom-up approaches is a part of water diplomacy process so important to address future water challenges and improve water security in a longer term. Among the many attempts to address the numerous issues related to water resources, there is sufficient evidence that 'participatory' or 'bottom-up approaches' have gained growing recognition in decision making, strategic policy formulation and operational management as opposed to conventional top-down planning, which was mostly inefficient, unsuccessful in implementation, and unsustainable (Erdogan 2013; Faust et al. 2013; Gutrich et al. 2005; Zorrilla et al. 2010). The most important feature in a participatory approach to decision making is the conscious effort that is made to include and engage stakeholders in an attempt to find a holistic solution to the issue and validate the solution with stakeholders.

## 2.12. Energy sources and potentials

Existing energy sources of the basin include hydropower, fossil fuel (diesel), thermal (simple and cogeneration) and wind powers while thermal, solar and geothermal sources are at project levels (AwBA, 2018). Hydropower potential of the basin is not like that of others in the whole Ethiopia, because topographical fall of the basin is concentrated on the upstream where river flow is smaller while the downstream is flatter. A recent study (Zhao et al., 2015) revealed that the basin"s theoretical hydropower potential is 18,666 GWh while technical exploitable potential is 689 MW (2,388 GWh) from 41 plants. From these, 127 MW (420 GWh) is economic exploitable from 4 plants.

The first hydropower and wind energy sources developed in the country are found in Awash Basin. Currently, there are four hydropower plants (Koka, Awash II, Awash III and Aba Samuel) with total installed capacity of around 113.8 MW or 350 GWh (AwBA, 2018) i.e. Aba Samuel (1.5 GWh) commissioned in 1939; Koka (43.2 MW and 80 GWh) commissioned in 1960; Awash II (32 MW and 135 GWh) commissioned in 1966; and Awash III (32 MW and 135 GWh) commissioned in 1971 (Tadesse et al., 2003; Zhao et al., 2015).

Regarding wind power, Adama I and Adama II power plants have total capacity of 204 MW. Dire Dawa with installed capacity of 43.6 MW; Awash 7 Kilo with installed capacity of 35

MW and Kality with installed capacity of 14 MW diesel power station can also be mentioned as standby electricity sources of the basin (Jemal, 2013; MoWE, 2013).

Biofuel is clearly an option given the countries extensive farmland and current water landscape (Tan et al., 2015). There are also two types of thermal energy sources in the basin; simple thermal and cogeneration. Simple thermals are biomass power plants in which all electricity generated is exported to the power grid. The Reppi (Qoshie) project of Addis Abeba city with installed capacity of 25 MW is the only one existed in the country for its type. Cogeneration means that electricity is generated by a power plant attached to a factory (typically sugar factories) to be consumed mainly by the factory with surplus power being supplied to national 25 grid. Metehara, Wonji, Kessem and Tendaho sugar factories are expected to produce a total of 88,000 m3 of ethanol to mix with fuel that might substitute the import (Wasihun et al., 2019).

Wonji-Shoa Sugar factory using bagasse generates a maximum of 30 MW. From which 9 MW is used by the factory for its own use while the rest 21 MW is exported to the national grid. Metehara sugar factory produces 9 MW and consumed all. Kessem Sugar factory bagasse is expected to produce 26 MW from which 10 MW is for its own use and the rest to be exported. The terminated Tendaho sugar factory was expected to produce around 100 MW for its own consumption and 65-70 MW to the national grid. However, bagasse is only available during and after sugarcane harvesting which limited operations of the plants and their cogeneration facilities. Hence, the capacity factor of the plants has low chances to be above 0.5 (AwBA, 2018; Jemal, 2013; MoWE, 2013; Wasihun et al., 2019).

# 3. MATERIALS AND METHODOLGY

## 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 115,560 $km^2$ and total length of 1200 km (FAO and MoWIE, 2013). The Awash River originates from Becho, West of Addis Ababa in the central Ethiopian Highland with an elevation up to 3000 masl. 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. Rainfall patterns within the Awash Basin vary significantly, with locations like Ankober receiving around 1600 mm annually, in stark contrast to Asayita'160 mm. Notably Addis Ababa experiences a major portion of its annual rainfall between March and September, while Dubti sees a more balanced distribution across two rainy periods. Temperature variations are also pronounced, with mean annual temperatures ranging from 20.8 0C at Koka to 29 0C at Dubti, peaking in June.It crosses three administrative regions, Oromiya, Afar and Amhara, and two administrative cities, Addis Ababa and Dire Dawa (zemede, 2011).

The land use and cover in the Upper Awash Basin primarily consist of cultivated agricultural land, grassland, and shrub land, collectively occupying 93.2% of the total area. Savanna covers about 3.6%, with the remaining 3.2% encompassing diverse land cover types. This intricate landscape not only supports various ecosystems but also presents challenges and opportunities for sustainable water resource management in the region. (Mussa, 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 (8o 26’N and 39o 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.

The increasing demands for water resources driven by water resource projects, population growth, urbanization, and industrialization have significantly strained existing water supplies. The surge in irrigation areas has aggravated water resource depletion, leading to the overexploitation of river systems and the natural environment's ecosystem. Consequently, a critical water allocation study was imperative to preserve the ecosystem's integrity and harmonize water supply with demand within the catchment area.

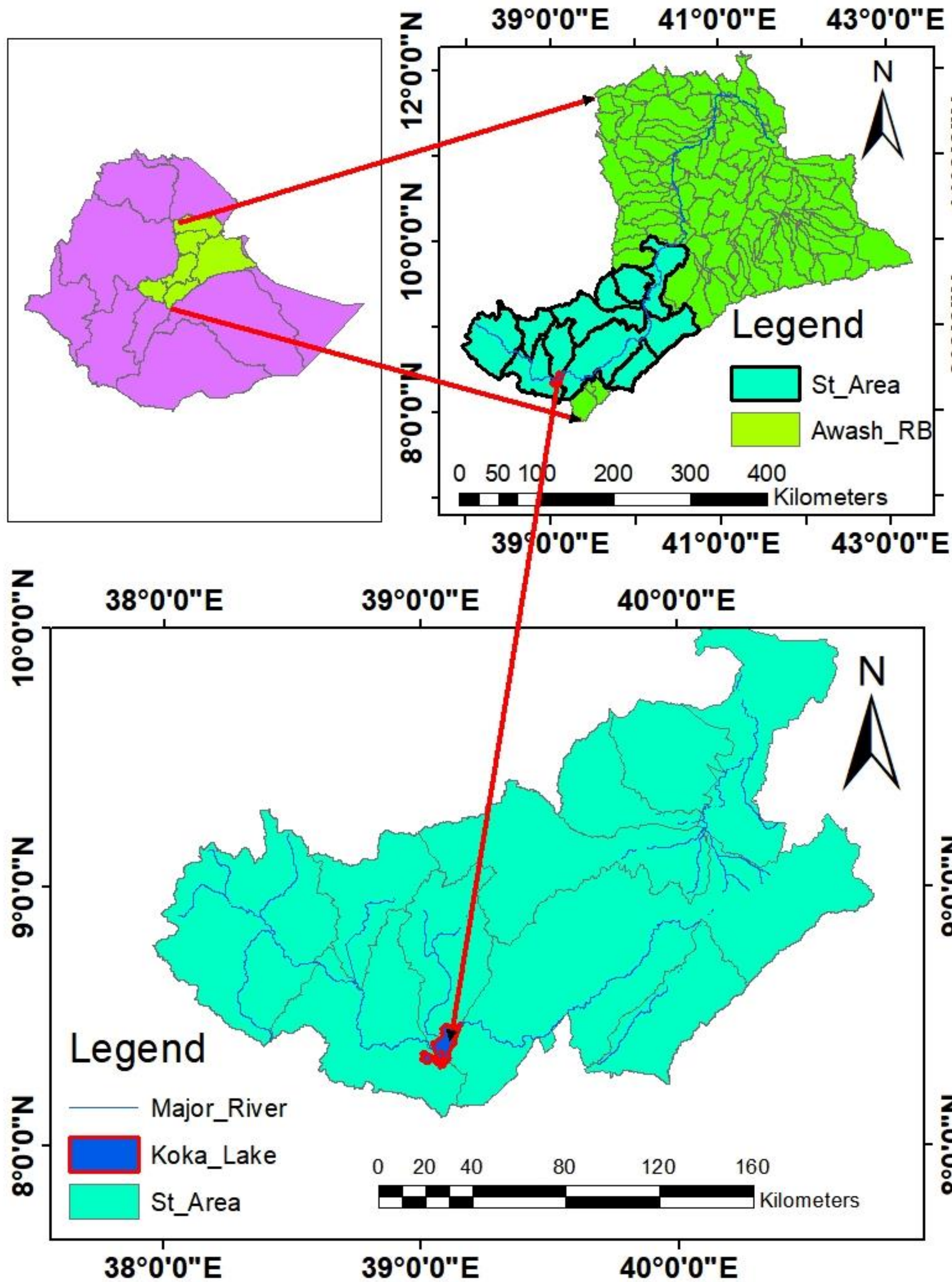


Figure 3.1.Location map of the Study Area

### 3.1.1. Physical Characteristics of the Basin

The Awash River Basin divided into two fundamental physiographic sections the Ethiopian plateau and the Rift Valley (FAO and MoWIE, 2013). The Ethiopian plateau topography is typically 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 elements, the basin is divided into four zones referencing imply above sea level (masl). As a result, upper Valley (above 1,500m), Middle Valley (between 1,500m to 1,000m), and Lowest Valley (beneath 1,000m) in addition to the Eastern Catchment between 2,500m to at least one,000m) that joins Awash River simply before it ends at lake Abe.

The valleys are part of the Great Rift Valley system which the Rift Valley a part of the Awash Basin being seismically active. The lower Awash Valley incorporates the deltaic alluvial plains in the Tendaho, Asaita, and Dit Behri place. This basin includes crucial financial activities for the country inclusive of electricity technology, mining, agriculture and tourism.

Although the alluvial plains in the Rift Valley are rather huge, there are deeply carved river valleys and volcanic loads rising to 3,850m. The physical geography of the Awash Basin is ruled by the underlying geology and lithology. The plateau is separated from Rift Valley by means of a chain of principal 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 ITCZ 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.

**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.

The rain fall distribution the study area it shows upstream of koka dam is relatively better than downstream of koka dam. Spatially, Average annual rainfall per year varies from 577.23mm at Metehara, towards the east of the basin to 1044.47 mm of upstream said Koka dam of Akaki , referring to downstream of the study area.

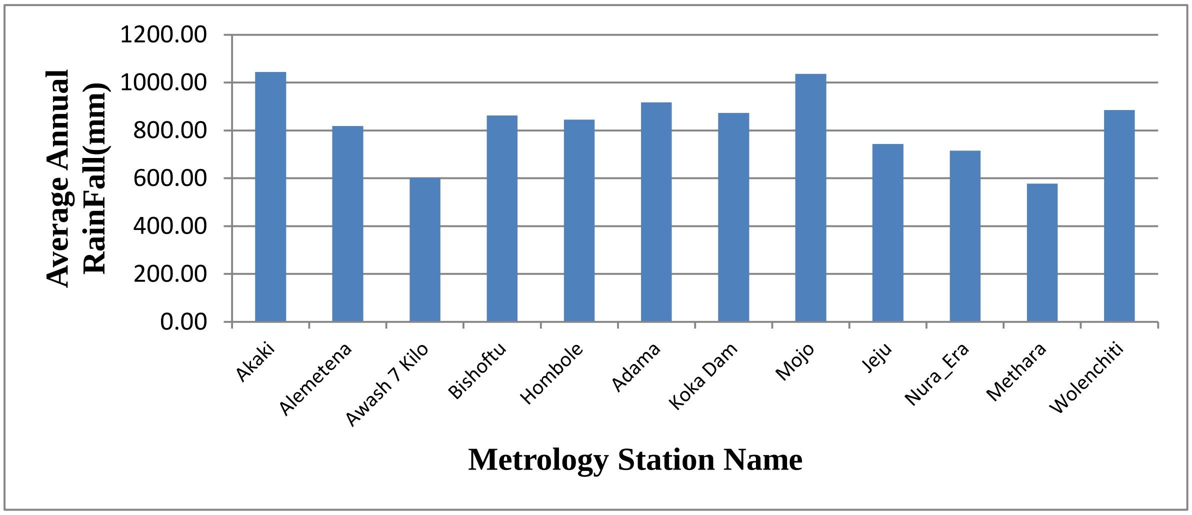


Figure 3.2.Average Annual rainfall of the study Area.

**Temperature**

The temperature varies considerably in the basin within altitude. The Average annual maximum temperature of the study area varies from 26.77$^{O}$C to 34.84$^{O}$C; while the Average Annual minimum temperature varies from 12.55$^{O}$C to 20.57$^{O}$C.

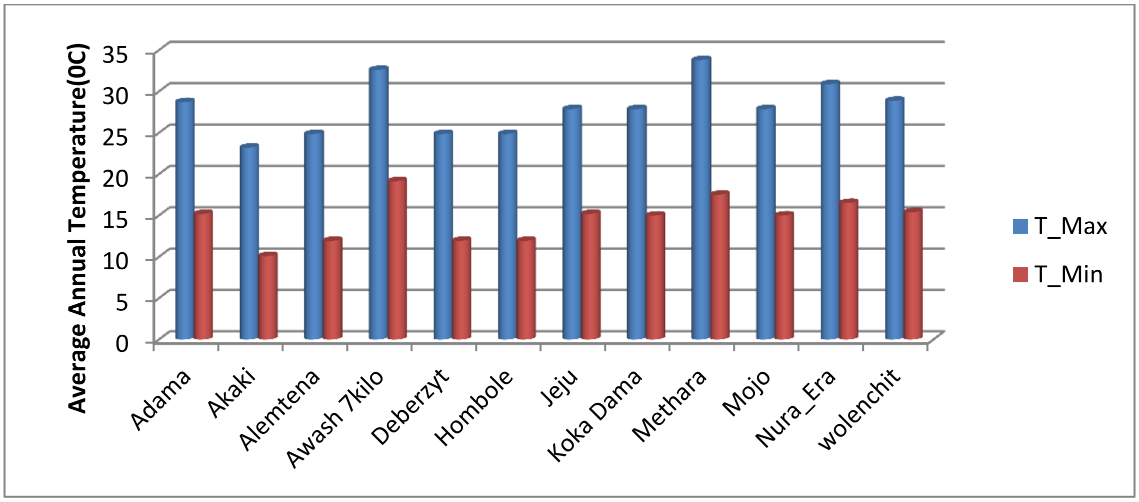


Figure 3.3.Average Annual Temperature T_max and T_min of the study Area.

**Relative humidity**

The relative humidity has been gauged at diverse stations within or neighboring the study area. The study area shows minimal fluctuations, with the mean annual relative humidity ranging from 69.67% in Akaki to 79.85% in awash 7kilo. The areas with lower rainfall are anticipated to have higher seasonal fluctuations.

### 3.1.3. The land use/cover (LULC)

The actual meaning of land use is the method in which individuals in a particular region utilize land to generate necessary resources through the application of labor, resources, and available technology. On the other hand, land cover refers to the physical appearance of the earth's surface. Essentially, land cover pertains to the natural or man-made entities that are visibly present on the ground. The primary types of land cover in the study area include built-up areas (such as settlements and infrastructure), cultivated land( crops), Flooded vegetation, forest, water bodies, bare ground( bare land), Trees and Rangeland. I created the land use and land cover map of the research region utilizing the Sentinel 2-10m Land use/Land cover 2022/01/01-2023/01/01 G.C satellite image. It is estimated that built-up areas (such as settlements and infrastructure) 5.7 %, cultivated land ( crops) 45.8% ,Flooded vegetation 0.1%, ,water bodies 0.9% ,bare ground( bare land) 0.3 %, Trees 4.00 % and Rangeland 43.2%.

Table3.1. Land Use Groups Used in the Arc GIS

| FID | GRIDCODE | LULC | Shape Area Km Sq | Percentage% |
|---|---|---|---|---|
| 0 | 1 | Water | 287.5 | 0.9 |
| 1 | 2 | Trees | 1255.5 | 4.0 |
| 2 | 4 | Flooded vegetation | 26.0 | 0.1 |
| 3 | 5 | Crops | 14491.6 | 45.8 |
| 4 | 7 | Built Area | 1815.0 | 5.7 |
| 5 | 8 | Bare ground | 104.2 | 0.3 |
| 6 | 10 | Clouds | 0.1 | 0.0 |
| 7 | 11 | Rangeland | 13670.2 | 43.2 |

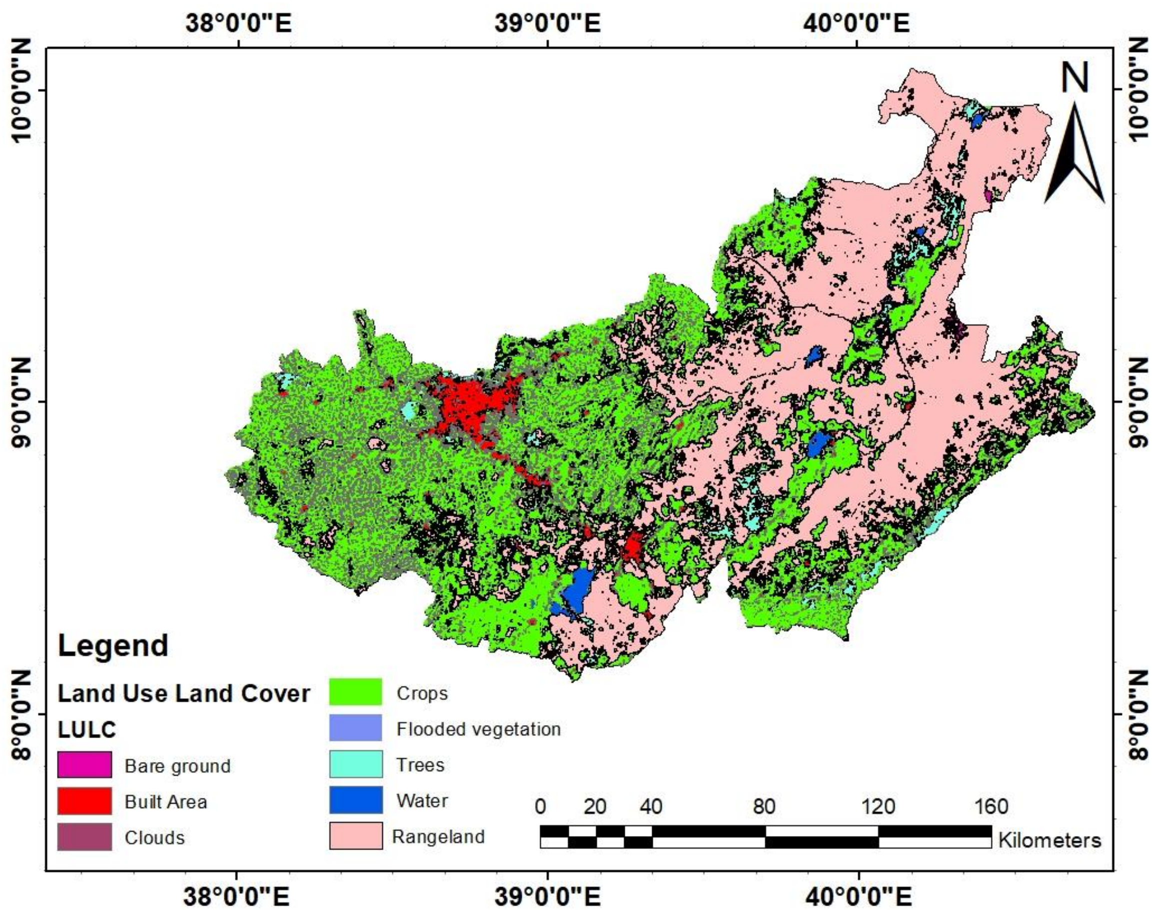


Figure 3.4.Land use and Land cover of Study Area.

### 3.1.4. Soil Type

The types of soil vary according to climate and parent rock. The more dominated soil types in the study area are pellic vertisols, vertic cambisols and eutric cambisols. According to both the FAO and USDA soil taxonomy, a vertisol is a soil in which there is a high content of expansive clay known as montmorillonite. This soil forms deep cracks in drier seasons or years. When irrigation is available, crops such as cotton, sorghum and rice can be grown. Vertisols are especially suitable for rice because they are almost impermeable when saturated. Vertisols (pellic and chromic):-Soils with 30% or more clay. Clays usually active, cracking when dry and swelling when wet. Extremely difficult to manage hence easily degraded but very high natural chemical fertility if physical problems overcome.

Cambisols (eutric, dystric, humic, calcic, chromic, vertic, and erralic):-Tropical ‘brown earth’ with a higher base status than Luvisols, but otherwise similar limitations. They have relatively good structure and chemical properties, and are not therefore greatly affected by degradation processes until these become large. Because of increasing clay with depth, they tend not to be greatly impacted by degradation. Cambisols have high resilience to degradation, and moderate sensitivity to yield decline.

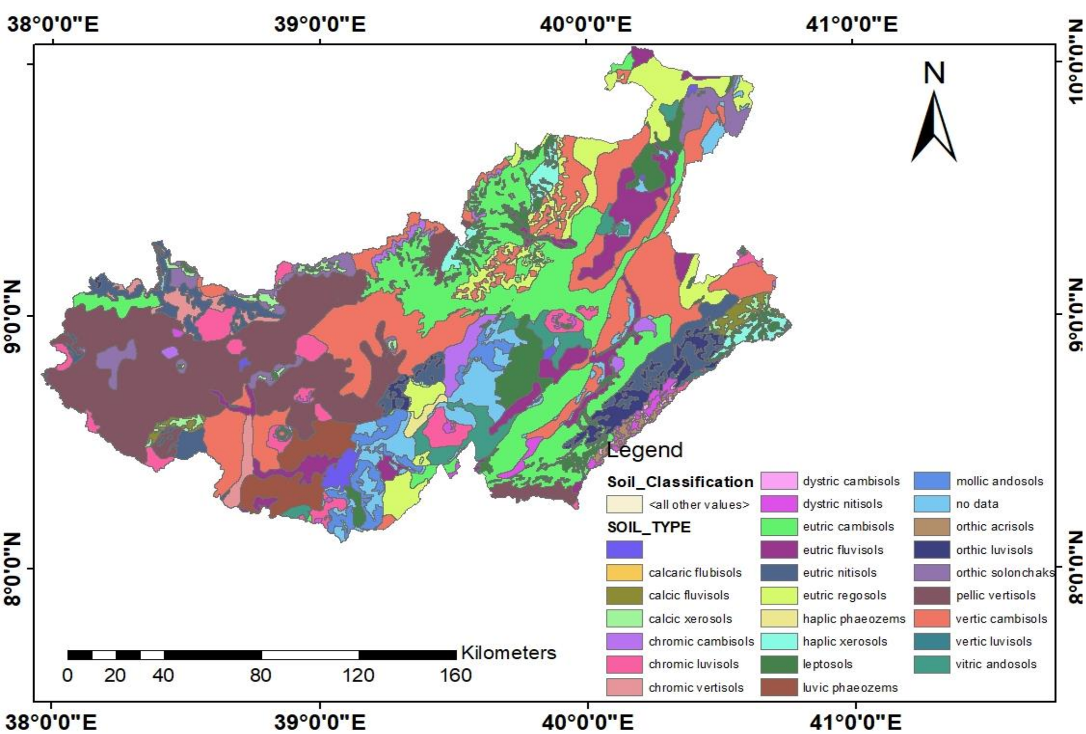


Figure 3.5.Soil Type of Study Area

## 3.2. Methodology

### 3.2.1. Digital Elevation Model (DEM)

Topography is characterized by a digital elevation model (DEM) that depicts the elevation of any point in a given area at a specific spatial resolution. The DEM used to delineate the watershed and to examine the drainage patterns of the land surface terrain. Basin parameters such as slope gradient, slope length of the terrain and the stream network characteristics such as channel slope, length, and width will be derived from the DEM. DEM with 30 m spatial resolution will be used that will be obtained from the Shuttle Radar Topography Mission (SRTM)

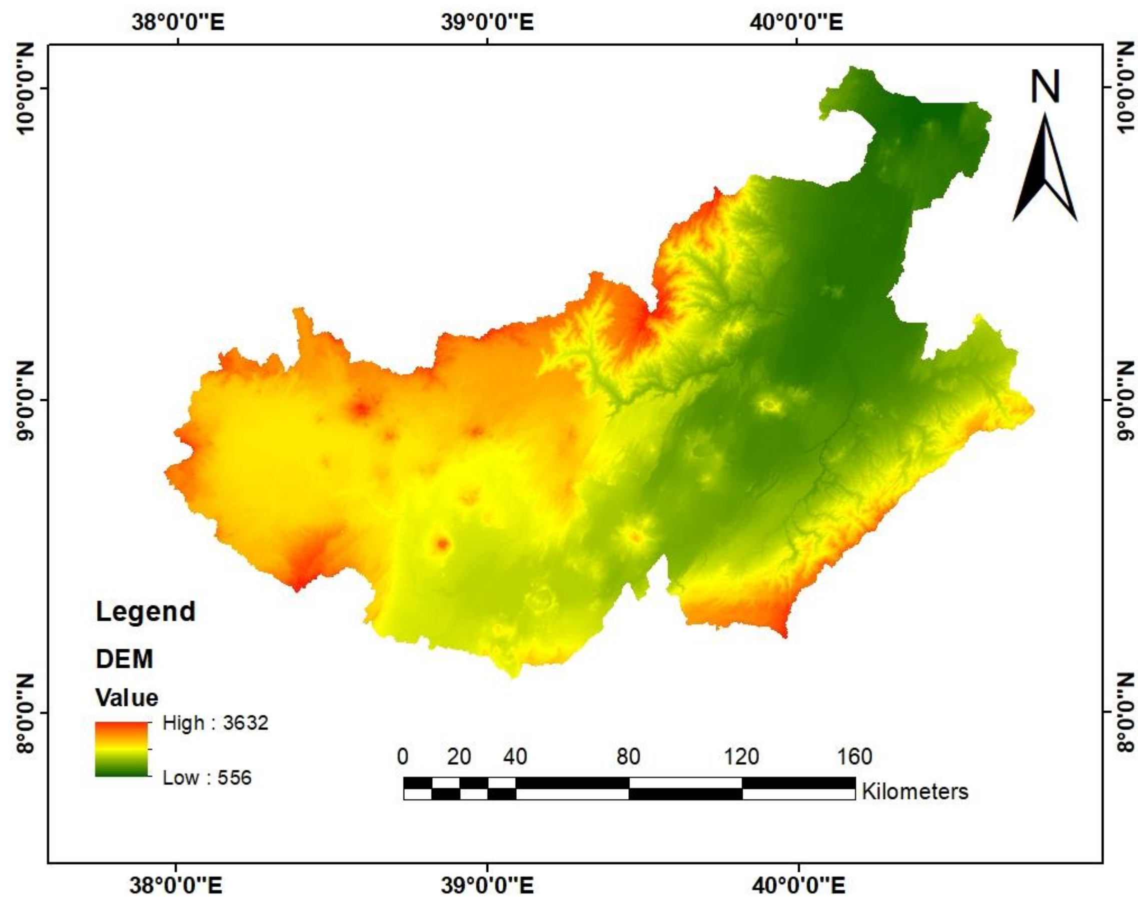


Figure 3.6.Digital Elevation Model map of the study area Watershed

### 3.2.1. Watershed delineation

Prior to data gathering, the limits of the examination of the study area were defined. The DEM (Digital elevation Model), which adheres to the drainage boundaries and encompasses the study area, is presented below.

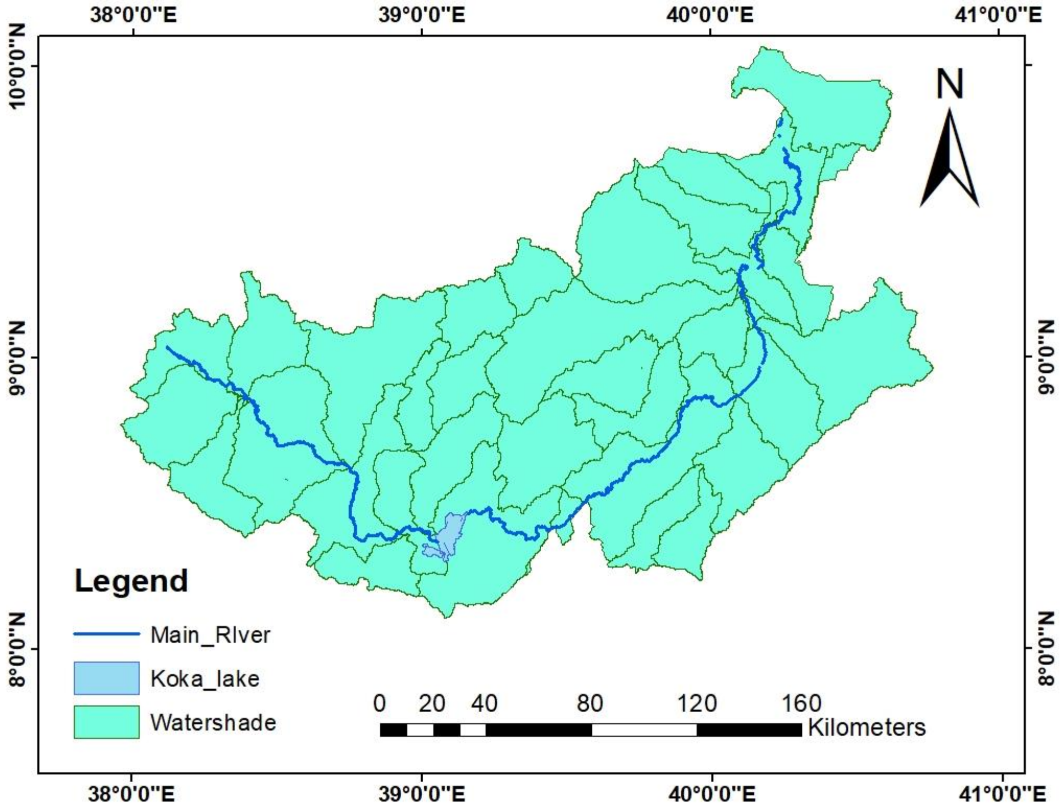


Figure 3.7.Watershed Delineation

### 3.2.2 Methods of data collection

The Ministry of Water and Energy, the National Meteorological Agency, the Awash Basin Administration office, and the Koka Dam Administration served as the data sources. The following primary and secondary data sets were required for the modeling tasks in the study. The primary data collection methods involve watching the study area and using GPS to collect UTM locations. The design documents of Irrigation Scheme and water supply projects, metrological data (rainfall, temperature, relative humidity and wind speed), hydrological data (stream flow data), DEM data, land use/land cover satellite image, water supply data (population number, growth rate, per capita water consumption), and irrigation data (agricultural land area, agricultural monthly variation demands, and water requirements per hectare of crops) are all examples of secondary data collection techniques.

**Materials and Tools Used**

Materials for this study included DEM data used as an input for ARC-GIS software for catchment delineation and estimation of catchment characteristics, Hydrological and meteorological data, WEAP model for basin simulation, and Microsoft EXCEL to analyze WEAP outputs. The materials used for this study varied depending on the objectives.

### 3.2. 3 Hydrological data

Hydrology information is crucial for modeling the behavior of the water resources system under various hydrologic conditions. WEAP is a very adaptable model that accepts daily, monthly, and annual data. Every hydrological and water resource model has its own method and format for data acceptance. The model was, however, run using monthly average data. The daily river discharge used in this study was gathered from the Ethiopian Ministry of Water and Energy and Awash Basin Administration office

There are 21 hydrological gauging stations in the Upstream Koka sub basin that record the flow. Awash at Hombole and Mojo River gauging stations are the major ones that flow to Koka reservoir because the other streams are the tributes to the main Awash River. Fig 3.8 below shows the basic spatial distribution of stream flow gauging stations in the upstream koka Sub basin.

Table3.2. Major hydrological stations i in upstream Koka Sub basin.

| Station_NO | River | Station Name | Latitude(x) | Longitude(y) | Drainage Area(Km^2) | River Basin | Period |
|---|---|---|---|---|---|---|---|
| 1 | Mojo | Mojo | 8.607258 | 39.112578 | 2075.62 | Awash | 1990-2015 |
| 2 | Awash | Awash Hombole | 8.371524 | 38.789223 | 3180.95 | Awash | 1990-2015 |

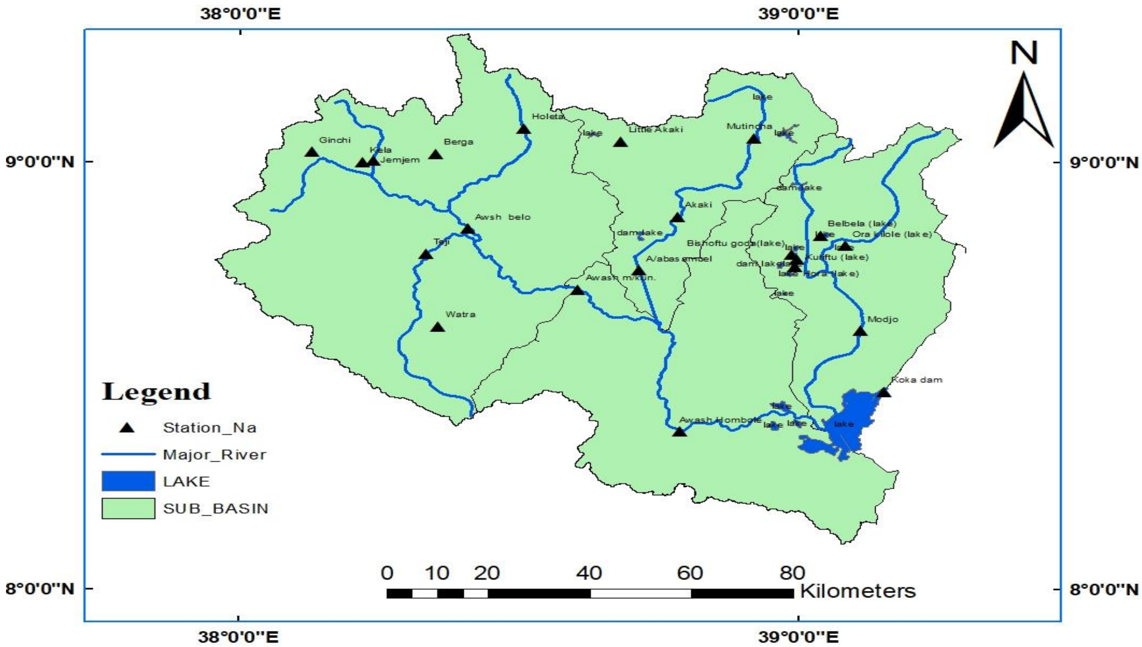


Figure 3.8.Stream flow gauging station

### 3.2.4. Meteorology data

The National Meteorological Agency (NMA) of Ethiopia installed a number of meteorological stations that are currently operational. Despite the fact that a sufficient number of meteorological stations have been set up throughout the project area, there is very little information available regarding the specific climatic conditions of the region due to malfunctioning gauging stations, recorders that are not timely measuring the data, etc.

The quality of the necessary components and the volume or long-term records of data affect the studies' level of quality. The most frequent issues were those caused by inadequate and incomplete basic data. There was a lack of sufficient, complete meteorological data for high and low land areas in this study. 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 3.3 below.

Table3.3. Summary of selected rainfall stations within the study area

| S/no | Station Name | Latitude | Longitude | Elevation | Years of data used | Missed data (%) | Sub basin |
|---|---|---|---|---|---|---|---|
| 1 | Adama | 8.56 | 39.28 | 1648 | 1990-2015 | 4.26 | Awash |
| 2 | Akaki | 8.87 | 38.79 | 2057 | 1990-2015 | 0.367 | Awash |
| 3 | Alemetena | 8.29 | 38.91 | 1656 | 1990-2015 | 15.675 | Awash |
| 4 | Awash 7 Kilo | 8.99 | 40.17 | 934 | 1990-2015 | 21.34 | Awash |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5 | Bishoftu | 8.73 | 38.95 | 1900 | 1990-2015 | 13.818 | Awash |
| 6 | Hombole | 8.37 | 38.78 | 1743 | 1990-2015 | 20.23 | Awash |
| 7 | Jeju | 8.39 | 39.69 | 2101 | 1990-2015 | 11.23 | Awash |
| 8 | Koka Dam | 8.47 | 39.16 | 1625 | 1990-2015 | 24.26 | Awash |
| 9 | Mojo | 8.61 | 39.11 | 1771 | 1990-2015 | 11.23 | Awash |
| 10 | Methara | 8.87 | 39.92 | 952 | 1990-2015 | 23.95 | Awash |
| 11 | Nura_Era | 8.67 | 39.78 | 1141 | 1990-2015 | 10.81 | Awash |
| 12 | Wolenchiti | 8.67 | 39.43 | 1458 | 1990-2015 | 9.83 | Awash |

### Filling missing rainfall data

In hydrologic analysis and design, missing measured precipitation data may present a number of challenges. It can be very challenging to have complete records of data at every station clearly due to the expense associated with data collection and certain natural and man-made conditions.

The aforementioned factors can sometimes make it difficult to collect both quantitative and qualitative data relevant to the study area. Missing data may occur for gauges that call for periodic observation if the observer neglects to visit the gauge when required, destroys recording gauges, or the instrument fails due to a mechanical or electrical malfunction. The length and amount of information in the precipitation record are both decreased by any such causes of instrument failure. Therefore, the missed data for the analysis of the rainfall data from the study area were computed using the multi-regression filling method.

The equation into which the given value should be calculated to obtain the estimated records of the missing data for the corresponding time period is provided by performing multi-regression between the stations after choosing which station's records best match the records of the station in the query using the less percentage of missing data method.

In most cases, missing data should be filled using multiple stations because they might not be found entirely in a single one. In such cases, either the remaining gaps will be filled using monthly means of already available data (if they cover a short time period) or another regression will be performed using a different station that has data for those months and years.

### Homogeneity test

A change in the statistical characteristics of the time was separated using homogeneity analysis series information. The causes can be either man-made or natural. These include changes to land use along with moving the observation gauging station. Consequently, to choose the representative meteorological station for checking the homogeneity of rainfall estimates and analysis. The homogeneity of the chosen gauging stations' daily rainfall records is crucial were carried out using non-dimensional equation.

$$P_i = \frac{\bar{p}_i}{\bar{p}} ---------------------------------3.1$$

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

$\bar{p}_i =$ Over years averaged monthly precipitation for the station i

$\bar{p} =$ Over year's average yearly precipitation of the station

### Consistency test

Consistency of time series data was analyzed with the theory that a plot of two cumulative quantities measured over the same time period should be linear and maintain their proportionality, which is symbolized by slop. As a result, the double-mass curve technique was used to create inconsistency in the record. Based on the idea that recorded data are consistent when they originate from the parent population, this method was developed. The double mass curve technique was used to correct precipitation records to account for non-representative factors like change in location or exposure of rain gauge. A comparison is made between the gauge in question's cumulative totals and the equivalent totals for a sample of nearby gauges. It should be corrected by if a sizable change in the curve's system is seen.

$$\mathbf{P'_x} = P_x * \frac{M'}{M} ---------------------------- 3.2$$

Where:- $\boldsymbol{P'_x} =$ Corrected precipitation at station x

$P_x =$ 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 river basin, rain measurement stations are evenly distributed throughout the sub-basin. The amount of rain at one station in a basin may differ from that at another station in the same catchment area. Based on this concept, the average precipitation value for the entire basin is calculated in order to accurately define the limits of the catchment area. Therefore, rainfall over a specific area of interest must be estimated using these individual measurements.

There are typically three methods for determining the areal precipitation over a catchment area using rain gauge measurements. These methods include the Arithmetic means, the Thiessen polygon, and the Isohyet method. However, for this study, the Thiessen polygon method was utilized due to its strong theoretical foundation and the availability of computational tools. It is important to note that this method relies on having a well-established 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

$$P_{avg} = \frac{P_1A_1 + P_2A_2 + P_3A_3 \ldots\ldots + P_nA_n}{A} ---------------------- 3.3$$

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 ($km^2$);

A = total watershed area of sub-basin ($km^2$).

To derive an accurate estimation of the average precipitation for the entire basin, it becomes essential to ascertain the average rain catchment by carefully defining the boundaries of the catchment. Consequently, rainfall over a specific area of interest needs to be estimated by leveraging these point measurements obtained from the rain gauge stations.

By considering the diverse data points collected from these stations, it is possible to calculate the average rainfall over the basin and extrapolate it to estimate the rainfall across the entire area of interest. This approach enables a more comprehensive understanding of the spatial distribution of rainfall within the given drainage basin

Table3.4. Areal rainfall interpolated using Thiessen polygon method for the study areas

| No | Station name | Area ($Km^2$) | Area Ratio | Annual rain fall (mm) | Weighted rainfall |
|---|---|---|---|---|---|
| 1 | Mojo | 755.81 | 0.02 | 1010.7 | 24.14 |
| 2 | NuraEar | 1707.35 | 0.05 | 723.68 | 39.04 |
| 3 | Awash_7kilo | 8512.54 | 0.27 | 631.34 | 169.80 |
| 4 | Methara | 3909.35 | 0.12 | 631.34 | 77.98 |
| 5 | Akaki | 6173.9 | 0.20 | 950.16 | 185.34 |
| 6 | Koka Dam | 1062.65 | 0.03 | 854.2 | 28.68 |
| 7 | Hombole | 2152.12 | 0.07 | 749.8 | 50.98 |
| 8 | Bishoftu | 1584.86 | 0.05 | 877.98 | 43.96 |
| 9 | Alemetena | 828.26 | 0.03 | 758.36 | 19.85 |
| 10 | Adama | 711.95 | 0.02 | 897.5 | 20.19 |
| 11 | Wolenchit | 3036.86 | 0.10 | 877.98 | 84.24 |
| 12 | Jeju | 1214.67 | 0.04 | 627.09 | 24.07 |
| | Total | 31650.3 | 1 | 799.18 | 768.27 |

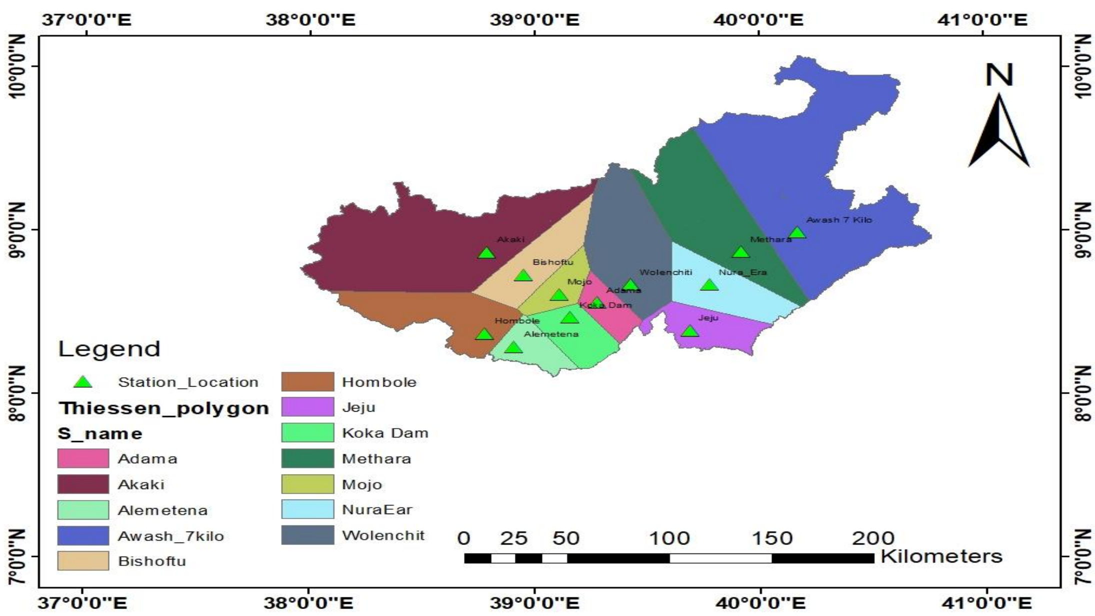


Figure 3.9.Thiessen polygons for the selected rainfall stations.

## 3.3 Model Calibration

Calibration is an iterative process used in modeling studies to determine the most appropriate parameter. Its significance lies in the fact that certain parameters can only be assigned reliable values through calibration (Reuben, 2007). During calibration, the primary focus is on identifying the key model parameters and adjusting the parameter set accordingly. These parameters are divided into two categories: physical parameters, which represent measurable properties of the watershed, and process parameters, which are not directly measurable. Calibration methods can be manual, automatic, or a combination of both (Tigist, 2009). Manual calibration involves the modeler making adjustments to parameters through multiple simulation runs using trial and error techniques. This method is subjective and time-consuming, as it relies on the modeler's assessment. On the other hand, computer-based automatic calibration employs numerical algorithms to optimize a given numerical objective function. Model performance is evaluated statistically by comparing the model's output with observed flow values. Commonly used statistical measures for assessment include 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 crucial step of demonstrating that a site-specific model has the ability to make precise predictions. To accomplish this, the calibrated model is put to the test using a separate dataset that falls outside the range of the calibration data, without altering the parameter values. The validation process aims to establish the model's accuracy and predictive capability within acceptable boundaries (Reuben, 2007). Similar to the calibration procedure, observed and simulated hydrograph values are once again compared. If the resulting fit is deemed satisfactory, the model's predictions are considered valid.

The model performance was evaluated using standard statistics as described by Sieber and Purkey (2011); Mean error (ME), mean square error (MSE) and model coefficient of efficiency (EF)

$$E_Q = Q_m - Q_0(\text{Model residual}) ---------------------------3.4$$

$$ME = E_Q = \sum_{i=1}^{n} \frac{Q_m(i) - Q_o(i)}{n} = \sum_{i=1}^{n} \frac{E_Q(i)}{n} -------------------3.5$$

$$MSE = \sum_{i=1}^{n} \frac{Q_m(i) - Q_o(i))^2}{n} = \sum_{i=1}^{n} \frac{(E_Q(i))^2}{n} -----------------------3.6$$

$$EF = \left[1 - \frac{\sum_{i=1}^{n} Q_m(i) - Q_o(i))^2}{\sum_{i=1}^{n}(Q_o\,(i) - Q_o)}\right] = \left[1 - \frac{MSE}{S^2 Q_o}\right] -------------------3.7$$

Where; Qo = Observed flow, Qm= Simulated flow, ME = Mean Error, MSE = Mean Squared Error, EF = Model Efficiency Coefficient, n = The number of data points, S = Variance (squared standard deviation)

The objective assessment relies on creating measures of errors using statistical parameters for evaluations of the model. These error methods include mean error (ME), mean square error (MSE) and the model coefficient of efficiency. (EF) Ahmed et al. 2007; The MSE measures the mean square of the errors, which is the difference between the simulated and observed flow values. The EF is used in assessing the predictive power of hydrological models. Krause et al. 2005;. It is the non-dimensional parameter and scaled version of MSE ranging between 0 and 1, most of the time it gives clearer evaluation of the model results and performances. The efficiency value 1 indicates a perfect match between the observed and simulated discharge whereas, the efficiency value 0 indicates that the model prediction is accurate as the mean of the observed data (Tesfaye, E. 2014).

## 3.5. Water Demand Calculations

The calculation process, as outlined in the WEAP User Guide, is centered on maintaining a mass balance of water for each node and link, taking into account demand priorities and supply preferences. The calculations commence from the first month of the current account year and continue until the last month of the final scenario. For non-storage nodes, such as points along a river, the calculation for the current month is independent of the previous month's calculation. However, for storage nodes like reservoirs, soil moisture, or aquifer storage, the current month's storage is influenced by the previous month's value. Water entering the system during a month is stored in reservoirs, aquifers, or catchment soils, or it exits the system due to demand site consumption or evapotranspiration.

Individual demands were incorporated into the model as separate demands rather than group demands in the schematic configuration. Although this approach may reduce flexibility in modeling the specific water demands of each irrigation site based on its distinct cropping pattern. Using the demand priorities and supply preferences, WEAP determines the order in which water demand should be allocated. The WEAP Allocation Algorithm processes demand sites with higher priorities first. These priorities are valuable in representing a water rights system and are especially significant during water shortages (SEI, 2005). Supply Preferences indicate the preferred source of supply when multiple sources are available for a demand site. The allocation order reflects the actual calculation order employed by WEAP for water allocation. Table 3.5 provides an overview of how priorities were assigned to each demand category compartment.

Table3.5. Assigned priority levels for different demand

| **Demand type** | **Priority level** |
|---|---|
| Domestic water supply with Industrial water demand and Environmental flow requirement | 1 |
| Irrigation and Livestock water demand | 2 |

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:

$$\text{Annual Demand}_{\text{DS}} = \sum \text{Br}\ (\text{Total Activity level Br} * \text{Water use Rate}) ------3.8$$

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:

$$\text{Total Activity level} = \text{Activity level}_{\text{Br}} * \text{Activity level}_{\text{Br'}} * \text{Activity level}_{\text{Br''}} * \dots \text{equ3.9}$$

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:

$$\text{Monthly Demand}_{\text{DS,m}} = \text{Monthly Variation Fraction}_{\text{DS,m}} * \text{Adjusted Annual Demand}_{\text{Ds}} --3.10$$

**1. Domestic Water Demand**

The quantity of water needed for domestic use is primarily determined by assessing the number of people living in an area and how much water each person requires within a specific region. However, accurately determining the amount of water used by individuals is challenging due to the unpredictable nature of people's needs. To establish a baseline, standard guidelines have been developed in various literatures, measured in liters per second per person per day (Lpcd).

World Health Organization (WHO) recommends a minimum of 100 liters of water per person per day to meet basic needs. In Ethiopia, the GTP-1 set targets of 20 liters per capita per day for urban areas and 15 liters per capita per day for rural areas. However, these targets did not achieve full coverage. Consequently, a new standard was developed in GTP-2, with a supply of 25 liters per capita per day (Lpcd), for rural areas and 40-100 liters per capita per day for urban areas.

In this particular study, the rural area's water demand was based on the GTP-2 standard of 25 liters per capita per day (Lpcd), which aligns with the overall water demand goal of 60 liters per capita per day (Lpcd), for urban areas. To determine domestic water demand, the predicted population is multiplied by the appropriate per capita demand. Domestic water consumption includes activities such as bathing, cooking, washing, drinking, laundry, dishwashing, gardening, car washing, and other less water-intensive or infrequent purposes.

Per capita water demand determined for town/cities with their categories that is given based on population range table 3.6.

Table3.6. Per-capita water demand for each category of towns/cities

| **Town/cities** | **population Estimated** | **Per-capita** |
|---|---|---|
| Category 1 | >1 Million | 80 l/c/day |
| Category 2 | 100,000-1million | 60 l/c/day |
| Category 3 | 50,000-100,000 | 50 l/c/day |
| Category 4 | 20,000 - 50,000 | 40 l/c/day |

**2. Livestock Water Demand (LWD)**

Livestock water demand estimated based on FAO livestock standard water demand for East Africa countries mainly Ethiopia is applied 25 liters, 5litres 125 liters, 15 liters and per head of cattle, sheep/goat, camel and donkey/horse per day respectively.

Table 3.7.Estimated Livestock Population and their water demand

| Woreda | Awash Fental | Adama | Boset | Merti | Jeju | Total No | Average water demand (lpd) | Water Consumption $m^3$/year |
|---|---|---|---|---|---|---|---|---|
| Cattle | 186,301 | 105,092 | 240,622 | 108,627 | 164,888 | 805,530 | 25 | 7,350,461.25 |
| Sheep | 109,405 | 51,346 | 67,515 | 85,019 | 135,366 | 448,651 | 5 | 818,788.08 |
| Goat | 256,441 | 42,511 | 197,172 | 102,918 | 69,606 | 668,648 | 5 | 1,220,282.60 |
| Camel | 107,998 | 474 | 15,567 | 1,088 | 1,344 | 126,471 | 125 | 5,770,239.38 |
| Donkey | 38,362 | 40,292 | 41,410 | 18,546 | 23,085 | 161,695 | 15 | 885,280.13 |
| Horse & Mule | 0 | 1,114 | 1,871 | 9143 | 10,090 | 22218 | 15 | 121,643.55 |
| **Total Water Consumption $m^3$/year** | | | | | | | | **16,166,694.98** |

(Source: -Awash basin Administration office Water Audit data collected by Addis Abeba university water and land resource center)

**3. Industrial Water Demand (IWD)**

In the realm of industrial water consumption, a direct correlation between the water demand of industries and the population they serve is not typically observed. Instead, a planning approach is adopted where it is conventionally assumed that the water demand of industries within a basin is equivalent to 10% of the domestic water demand across all towns encompassed within said basin.

**4. Agricultural water demand**

In the context of Agricultural water demand; the WEAP model necessitates input data concerning the potential of irrigated land, specific crop types, and the respective cultivation seasons. Consequently, the data pertaining to irrigation was sourced from both the Awash Basin development office and the respected district of Agricultural bureau. The sub basin under investigation in this study includes a compilation of selected irrigation demands, along with their corresponding areas and crop types, as outlined in table 3.8.

Table3.8. Selected irrigation demands with their corresponding areas and crop types.

| S/no | User | Area (ha) | Crop Type |
|---|---|---|---|
| 1 | Wonji Shoa Sugar Factory | 8,200 | |
| 1.1 | State Intake | 5,800 | sugarcane |
| 1.2 | Dodota Intake | 2,400 | sugarcane |
| **2** | Adama Woreda direct pumped at different place+Waketiyo Intake +Wonji out growers+ Batu Degaga IWUA | 3,984 | vegetables and Cereal |
| 3 | Wlenchiti project(Intake) | 4,000 | vegetables and Cereal |
| **4** | Doni Intake | 676.56 | vegetables |
| **5** | Tibila Scheme | 4,266 | Vegetable and cereal |
| **6** | Africa Juice Share Company | 461 | |
| 6.1 | Membere Hiwot pump | 265 | vegetables & fruits |
| 6.2 | Degaga Pump | 196 | vegetables & fruits |
| **7** | UAAIE Abadiska Pump | 2016.79 | |
| 7.1 | UAAIE Abadiska Pump | 685 | Fruits |
| 7.2 | Jeju Woreda | 1,331.79 | Vegetable and cereal |
| **8** | Merti Jeju Main Canal | 4,453.00 | |
| 8.1 | UAAIE | 647 | Fruits |
| 8.2 | Awash Wine | 517 | Fruits & maize |
| 8.3 | Farmers | 3,289 | Vegetable and cereal |
| **9** | Nura Era Main Canal | 6,032 | |
| 9.1 | UAAIE | 3,069 | vegetables & fruits |
| 9.2 | Farmers boset and fental woreda | 3,233 | Vegetable and cereal |
| **10** | Qawa Fentale project @ 3rd Camp diversion | 6509 | vegetable and Cereal |
| **11** | Bole Gologota main canal | 1,980 | Vegetable and cereal |

| | | | |
|---|---|---|---|
| **12** | Abadir Main Canal | 4,492 | |
| 12.1 | Metehara Sugar Factory | 3,600 | sugarcane |
| 12.2 | Farmers | 892 | vegetables |
| **13** | Merti Main Canal | 7,502 | |
| 13.1 | Metehara Sugar Factory | 6,646 | sugarcane |
| 13.2 | Farmers | 856 | vegetables |
| 14 | Middle Awash @Melkasedi Weir | 11,000 | |
| 14.1 | Middle Awash @Melkasedi Weir | 8,500 | cotton |
| 14.2 | Middle Awash @Melkasedi Weir | 1,500 | vegetable |
| 14.3 | middle Awash @Melkasedi Weir | 1,000 | cereal |
| Total | | 66,033 | |

(Source; Awash Basin Administration office yearly Water allocation plan and the respected district of Agricultural office)

### 3.6. 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 study 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 3.8). 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,

$$Rd_j \frac{d_{z_1,j}}{d_t} = P_e(t) - PET(t)k_{c,}j(t)\left(\frac{5_{z_1,}j - 2_{z_1,}j^2}{3}\right) - P_e(t)z_{1,}j^{RRF_{j1}} - (1-f_i)k_{s,}j^{z_1,}j^2 - f_j k_s, j^2 - 3.11$$

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,

$$RT(t) = \sum_{j=1}^{N} A_j \, (t)_{z_1}, j^{RRF_j} + f_j k_s, j^{z_1} j^2 \text{ ------------------------ } 3.12$$

Base flow emanating from the second bucket is computed as:

$$S_{max}\left(\frac{dz_2}{dt}\right) = \sum_{j=0}^{N} (1 - f_j A_j) k_{s,} \, j^{z_1} \, j^2) \; - k_2 {z_2}^2 \text{ ------------------------ } 3.13$$

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.

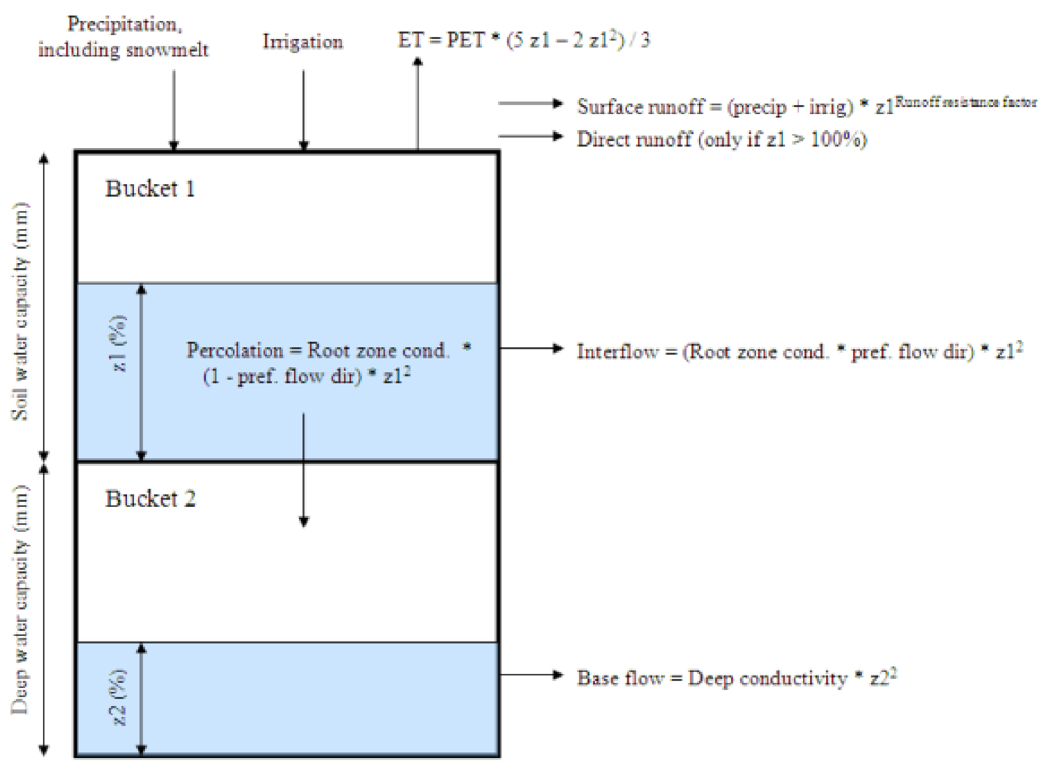


Figure 3.10.Concept of soil moisture and equations (source: WEAP User Manual)

### 3.7. WEAP Model Structure and Modeling Process

The WEAP model is a powerful tool used to simulate various development and management scenarios for the future. It allows users to define time frames, spatial boundaries, and system components to accurately assess the allocation of water in a river basin. With its Geo-spatial capabilities, WEAP is capable of modeling water planning and allocation at different scales, from a community to a watershed to a basin (Yates, 2005; Sieber et al., 2005). By characterizing the water demand-supply system and its spatial relationships, users can simulate water allocation by considering different water sources (such as surface water, groundwater, desalination, and water reuse), withdrawal methods, transmission systems, reservoirs, wastewater treatment facilities, and water demands from various sectors. The flexibility of the data structure and level of detail allows for customization based on the specific analysis requirements and data limitations. Additionally, the graphical interface provided by WEAP enables users to easily visualize the physical features and layout of the system within the catchment area.

WEAP21 offers users a comprehensive and organized interface through five distinct "views" of the working area: Schematic, Data, Results, Overview, and Notes. These views are conveniently accessible as graphical icons on the View Bar, located on the left side of the screen. The Current Accounts, which define the existing water system, serve as the fundamental basis for all scenario analyses. Scenarios, on the other hand, present internally consistent narratives of how the future system may evolve within a specific socio-economic context and under particular policy and technological conditions. The main screen of WEAP21 comprises the View Bar on the left and a top menu, granting users easy access to the program's most crucial functionalities. Operating on a monthly time step, WEAP21 diligently calculates water quantity and pollution mass balances for each node and link in the system. The dispatch of water is guided by considerations such as meeting in-stream and consumptive requirements, prioritizing demands, supply preferences, maintaining mass balance, and adhering to various constraints.

The Current and future water demands to domestic and agriculture were analyzed using WEAP model. The steps below were followed for current situation water demands and scenario analysis:

- Creation of geographic representation of the area Setting of general parameters

- Entering elements into the schematics
- Entering of data for demand sites/nodes
- Connecting demand with supply of Creating return flow links
- Running of the model and getting the results

### 3.7.1. WEAP Schematic

Within the schematic component of WEAP, the delineation of watershed boundaries, specification of rivers, demand sites, and reservoirs takes place. To accurately determine the precise locations of streams within WEAP, GIS maps of rivers and reservoirs are utilized. This approach includes the schematization of the Koka reservoir, where the total inflows, namely the Awash Hombole and Mojo Rivers, are considered as headwaters. The outflow from the Koka reservoir, represented by the Awash River, is configured as a minimum flow requirement with the highest priority, ensuring a consistent flow into the river Awash.

To establish the WEAP model, the demand areas reliant on surface water within the study area were consolidated into sixteen distinct groups. Specifically, the irrigation areas were combined based on their sources of water abstraction, as indicated in Table 3.8.

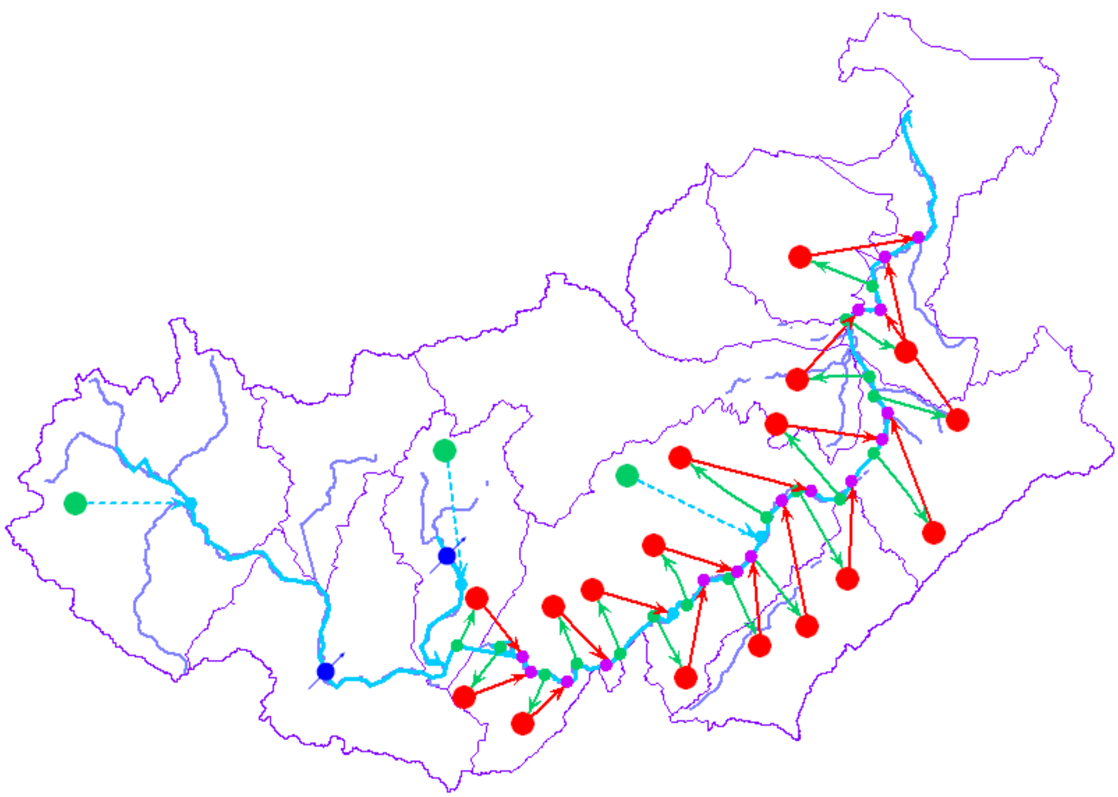

**Figure 3.11.Schematic part of the WEAP model for Abstraction sources.**

To properly establish the satisfaction of demand within the WEAP model, the water supply source (rivers) needed to be connected to each demand site. This was achieved within the schematic view by adding transmission links. Initially, the link was positioned on the supply source and then directed towards each demand node. In order to effectively utilize the return flow for other demands, the return flow links were connected back to the rivers, with a return flow routing set at 100%. The return flow routing represents the percentage of total outflow from a demand node, and for the given link, it must be set at 100%. Downstream of the sources, return flows from irrigation sites were appropriately configured. However, the return flow from domestic water supply was not included in the model, as its quantity is deemed insignificant and thus preferable to overlook.

## 3.8. Scenario Creation

Scenarios in WEAP are coherent narratives depicting the potential evolution of a future system within a specific socioeconomic context while considering particular policy and technology conditions. These scenarios can be constructed using WEAP and then compared to evaluate their water requirements, costs, and environmental impacts. They can address a wide range of hypothetical questions. In WEAP, a key concept is the differentiation between a "business-as-usual" scenario and alternative policy scenarios. The "business-as-usual" scenario reflects existing trends in economic and demographic development, water supply availability, and water-use efficiency, without incorporating new conservation measures or supply projects. This serves as a reference point against which the impacts of alternative policy scenarios can be assessed. The current water accounts and the "business-as-usual" scenario are established based on the continuation of present patterns, with population growth as a driving factor. From there, "what-if" scenarios are introduced, derived from the reference scenario, considering current conditions and projected future water demands for irrigation Expansion.

### 3.8.1. Reference scenario

The Reference scenario is the scenario in which the current situation, the current account year as 1990 and is extended to the future (2016-2035).

### 3.8.2. Scenario in irrigation Expansion

The Awash River basin is renowned for its suitability for irrigation and agriculture, and it is experiencing rapid growth in terms of cultivated area. The Ethiopian government's initiation of the wheat campaign is further contributing to the expansion of irrigation in the region. This scenario specifically focuses on the impact of expanding irrigated lands on irrigation water demand, which in turn affects the volume of water required downstream. To analyze this scenario accurately, the area of potential irrigable land for each irrigation demand at the abstraction node was properly considered.

# 4. RESULT AND DISCUSSION

## 4.1. Results of WEAP Model

Prior to starting the calibration and validation process, it is commanding to understand the impact potential of calibration and validation parameters on model efficiency. Consequently, the parameters were adjusted within various feasible ranges to align the average monthly observed stream flow with the model's simulated data, and the model's performance was assessed. Table4.1, defines a reasonable parameter range for the catchment's calibration.

Table4.1. Calibration parameters in reasonable ranges

| **Calibration parameters** | **Range** | **Unit** |
|---|---|---|
| Soil water capacity | >0 | mm |
| Deep water capacity | > 0 | mm |
| Runoff Resistance Factor | 0 – 1000 | ---- |
| Root zone Conductivity | 20 | mm/month |
| Deep Conductivity | 20 | mm/month |
| Preferred flow direction | 0 – 1 | ---- |
| Initial Z1 | 0- 100 | % |
| Initial Z2 | 0-100 | % |

### 4.1.1. Calibration and validation results

It is crucial to thoroughly analyze the potential impact of calibration and validation parameters on the performance of the model before initiating the calibration and validation procedures. In this phase, the simulated model outcomes were compared with the observed flows at each monitoring station. These comparisons consider the statistical metrics discussed in earlier sections. In this study, the observed stream flows from two monitoring stations situated within the river basin were contrasted with the model's simulated outputs. The alignment between these two sets of data on a monthly basis signifies the model's ability to accurately simulate the outputs based on the land use and land cover characteristics of the catchment area, reflecting the recorded stream flow data. Overall, the findings suggest that the model effectively captures the hydrological dynamics of the basin in correlation with the measured data, as evidenced by the results of the calibration and validation processes. This demonstrates the model's reliability in replicating real-world conditions and enhances confidence in utilizing the model for water resource management decisions.

#### 4.1.1.1. Calibration

Calibration is a crucial iterative process in which the most sensitive parameters of the watershed model are adjusted to closely align with the realities of the catchment area, thus ensuring that the WEAP model accurately reflects the conditions of the study area. This necessary step validates that the WEAP model effectively represents the characteristics and behavior of the watershed.

The calibration of the WEAP model involved utilizing observed stream flow data from the Hombole gauging stations located upstream of the Koka reservoir. In the calibration process, the performance of downstream gauge stations is dependent on the accuracy of the upstream gauges. Therefore, it is essential to calibrate the head flow gauge or the upstream station first to establish a stable upper boundary condition for the downstream gauges.

Before developing scenarios, the calibration and validation of the WEAP model were conducted. Monthly simulations of stream flow were compared with observed data over a 25year period (from 1990 to 2015), with the results displayed in Figures 4.1 and 4.2 representing the stream flow gauging station Hombole.

The calibration outcomes of the WEAP model, comparing observed stream flows with simulated results in the study area, indicate the model's proficiency in reproducing historical stream flow patterns. The model demonstrated a high level of performance with ($R^2$) value for Hombole 0.88 during the calibration period. These metrics signify the model's capability to accurately simulate stream flow dynamics and validate its effectiveness in representing the hydrological processes of the watershed.

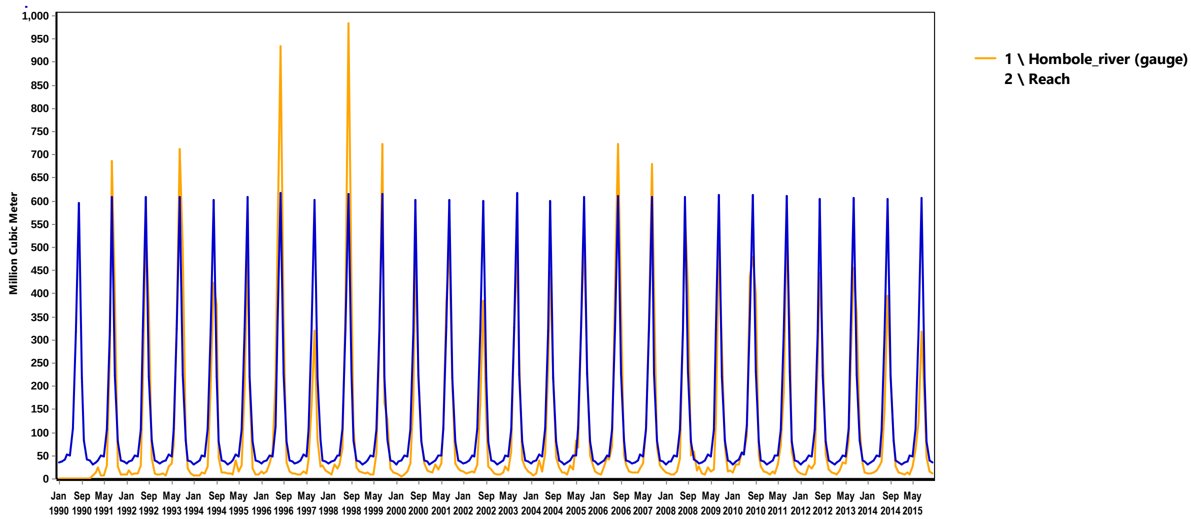


Figure4.1. Hombole Stream-gauging Station

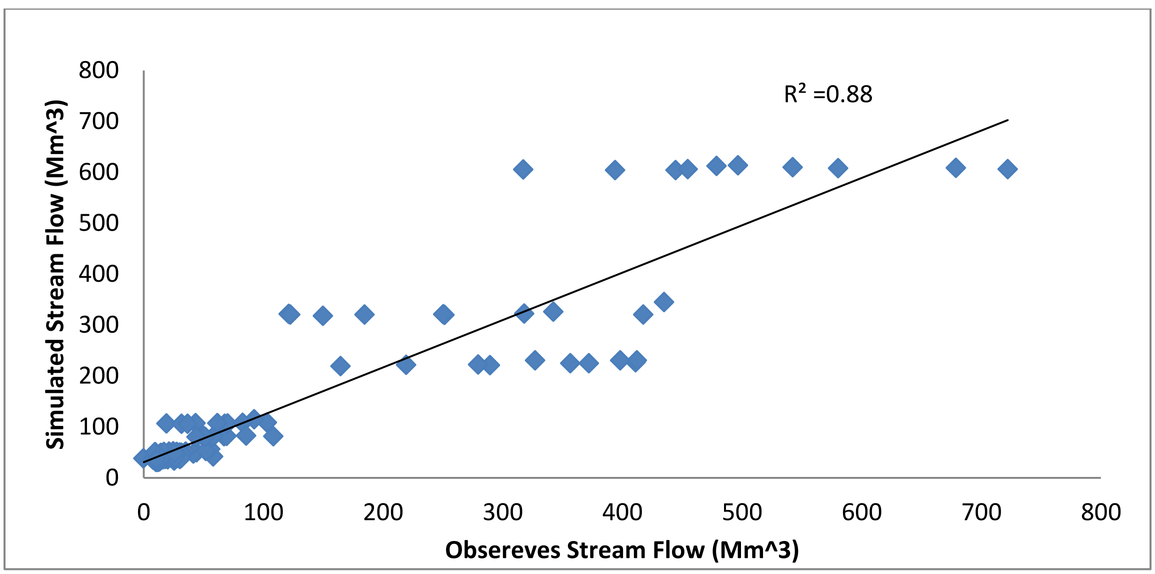


Figure4.2. Hombole Stream-gauge

#### 4.1.1.2. Validation

The validation process utilized the data range from each stream flow gauging station to assess the flow accuracy during the period from 2005 to 2015 for Hombole station. The outcomes of the model validation were represented in Figures 4.3 and4.4. The simulated monthly flows closely resembled the naturalized or observed flows for the selected stations. Furthermore, the relationship between these flow datasets demonstrated a strong correlation for the selected stations.

Overall, the model exhibited commendable performance in simulating stream flow data, as evidenced by correlation coefficient ($R^2$) values of 0.841 for Hombole. These results indicate the model's ability to accurately replicate stream flow patterns and dynamics at the specified gauging stations during the validation period.

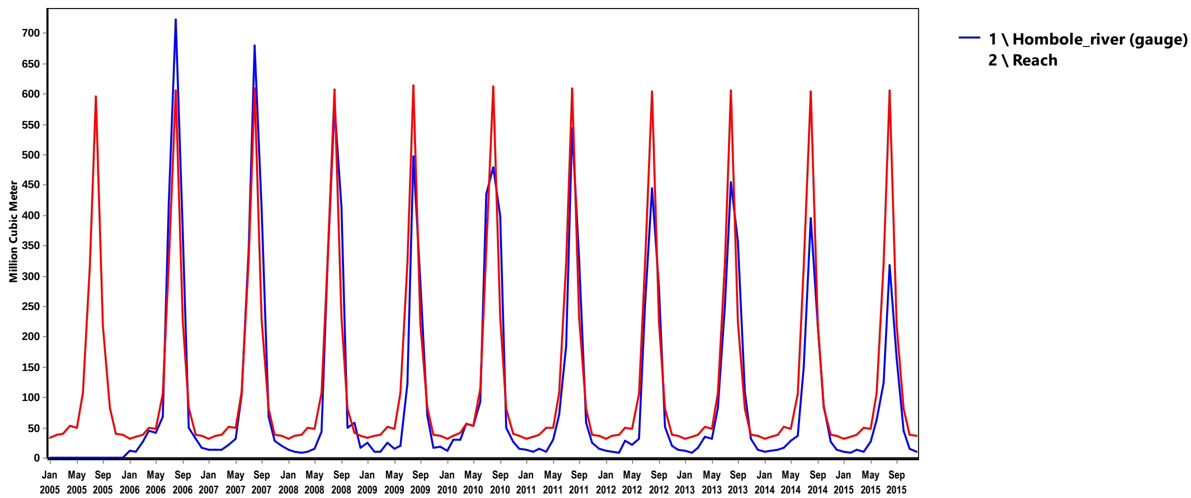


Figure4.3. Hombole Stream-gauging Station

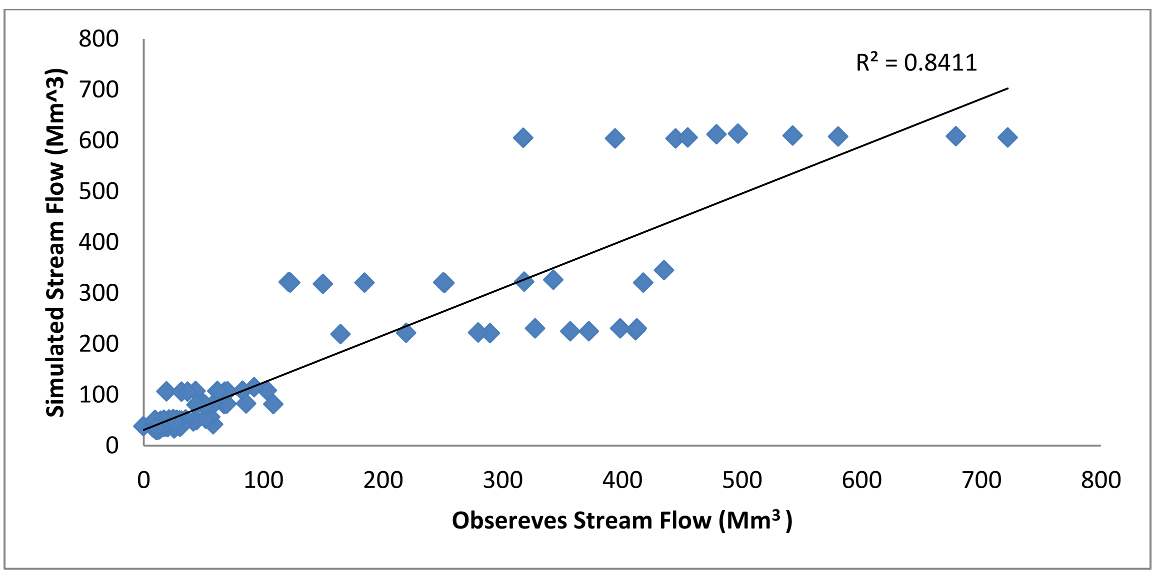


Figure4.4. Hombole Stream-gauge

#### 4.1.1.3 Statistical analysis

The statistical measures play a crucial role in evaluating the effectiveness of the model calibration process and ensure that the model accurately captures the hydrological characteristics of the study area. This statistical evaluation of the correlation coefficient ($R^2$) and Nash-Sutcliffe Coefficient (NSE) involves comparing modeled and observed stream flow values during the calibration period. These metrics are essential for assessing the alignment between the model outputs and the actual flow observations. The $R^2$ value indicates a strong fit at the Hombol stations, demonstrating the model's accuracy in replicating the observed stream flow dynamics. Similarly, the NSE highlights a high level of agreement between the simulated and observed stream flow data at Hombole gauging stations. The table4.2 below provides a detailed summary of these statistical performance measures.

Table4.2. Comparison of observed and simulated mean monthly stream flows for calibration period

| Gauge station | Correlation Coefficient ( $R^2$) | Nash-Sutcliffe Coefficient (NSE) |
|---|---|---|
| Hombole | 0.88 | 0.81 |

The statistical analysis of the correlation coefficient ($R^2$) and Nash-Sutcliffe Efficiency (NSE) involves comparing the modeled stream flow values with observed data during the validation period. These metrics play a critical role in assessing the consistency between the model outputs and actual stream flow observations. The $R^2$ value shows a strong fit at the Hombole station and a lower fit at the Mojo station, indicating the model's accuracy in reproducing the observed stream flow patterns. Similarly, the NSE metric demonstrates a high level of agreement between the simulated and observed stream flow data at the Hombole station. The summary table 4.3 below offers a comprehensive overview of these statistical performance indicators.

Table4.3.Comparison of observed and simulated mean monthly stream flows for validation period

| Gauge station | Correlation Coefficient ( $R^2$) | Nash-Sutcliffe Coefficient (NSE) |
|---|---|---|
| Hombole | 0.841 | 0.73 |

When comparing the findings of the central Rift Valley of the Awash River Basin in Ethiopia, Gedefaw et al. (2019) conducted a calibration and validation of the WEAP model. They achieved values of $R^2$ (0.73–0.89) and NSE (0.65–0.83) for one set of comparisons and $R^2$ (0.63–0.91) and NSE (0.50–0.84) for another set, reflecting the agreement between measured and simulated average monthly stream flows from four gauging stations. Through graphical analysis (examining stream flow hydrographs and scatter plots comparing simulated and observed values) and evaluation of statistical model performance, it was determined that the WEAP model demonstrates a high level of accuracy in representing historical stream flow patterns.

## 4.2. Reservoir inflows and outflows

The Awash@Hombole and Mojo Rivers serve as primary sources of inflow for the Koka Reservoir due to their significant contributions, with other rivers feeding into these main channels. The downstream users dependent on the Koka Reservoir are highly reliant on the controlled discharge of water from the reservoir. The inflow dynamics of the reservoir exhibit a fluctuating pattern, reaching peak levels in August and dropping to a minimum in January. The total annual inflow from upstream sources and the outflow to downstream areas of the reservoir were 1509.62Mm$^3$ and 1294.79 Mm$^3$, respectively. In months such as January, February, March, April, May, October, November, and December, the absence of rainfall was considered, with inflow reductions falling short of the outflow, resulting in a decline in the reservoir volume. On the other hand, during June, July, August, and September, the inflow exceeded the outflow, leading to an increase in the reservoir volume. This fluctuation underscored the complex interplay of factors that affected water balance and management in the Koka Reservoir system. The table 4.4 below displays the monthly inflows and outflows of the Koka reservoir in the baseline year.

Table 4.4.Monthly inflows and outflows of Koka reservoir (Mm$^3$)

| Flow | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Inflow | 25.33 | 25.18 | 28.63 | 36.46 | 42.68 | 106.95 | 301.77 | 570.50 | 218.44 | 87.69 | 34.65 | 31.34 | 1509.62 |
| Outflow | 74.27 | 83.20 | 85.38 | 82.06 | 86.43 | 78.34 | 117.80 | 225.60 | 181.83 | 96.37 | 94.33 | 89.18 | 1294.79 |

The inflow and outflow patterns of the Koka Reservoir display distinct characteristics; with the maximum inflow were occurring in August and the peak outflow was observed in August and September. This difference in timing can be attributed to the concept of concentration time, which represents the duration required for runoff from distant areas of the catchment to reach the outlet of the watershed. Consequently, the peak outflow from the reservoir occurs during August and September, highlighting the importance of understanding hydrological processes and timing in water resource management strategies for the Koka Reservoir. The belowFigure4.5 shows the monthly inflows and out flows of the Koka reservoir in the baseline year.

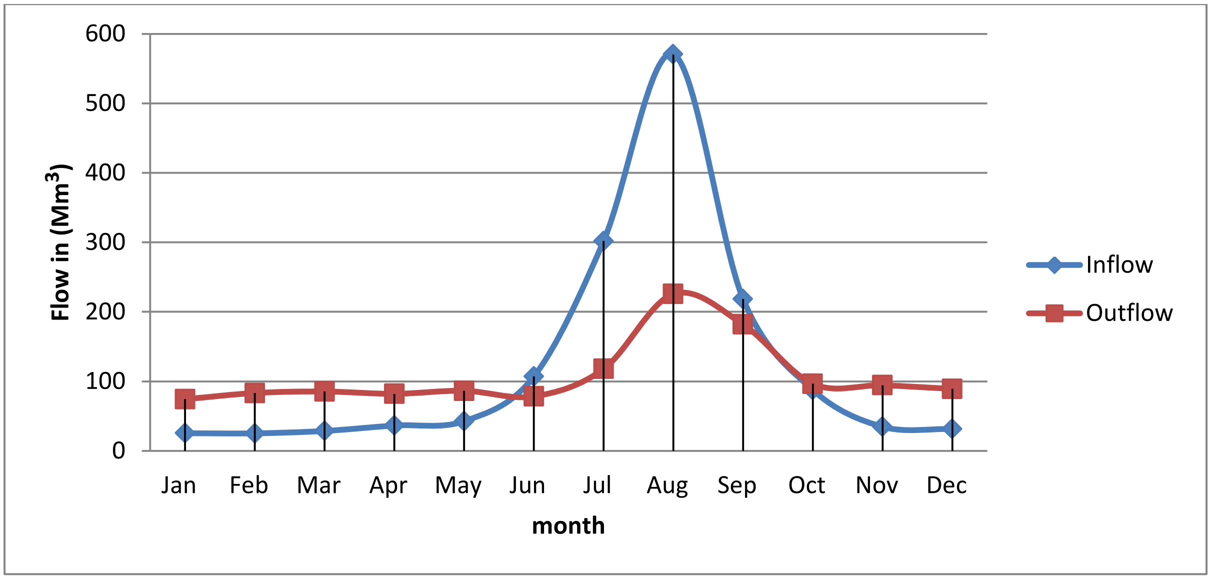


Figure 4.5.Monthly Inflow and outflow of Koka reservoir ($Mm^3$)

### 4.3. Evaporation from the reservoir

The results of the modeled reservoir evaporation in the current context reveal a variable trend within the reservoir. As shown in table 4.6, the water level displays both an upward and downward pattern across different months. The highest and lowest net evaporation rates were observed in January, March, April, and February, with values of 204.6 Mm3, 210.8 $Mm^3$, 198 $Mm^3$, and 134 $Mm^3$ during the simulation period. The total annual evaporation amounted to 2131.6 $Mm^3$ for the current time frame, and this trend is projected to remain consistent in the future period from 1990 to 2015.

Table 4.5. Monthly average evaporation of koka reservoir ($Mm^3$) in current account year

| Monthly | Jan | Feb | Mar | Apr | May | jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Koka reservoir | 204.6 | 134.0 | 210.8 | 198.0 | 189.1 | 171.0 | 161.2 | 151.9 | 141.0 | 192.0 | 192.0 | 186.0 | 2131.6 |

## 4.5. Water Demand in the Current Account Year (1990-2015)

### 4.5.1 Domestic and Irrigation Water demand

The current account served as the foundational representation of the existing water system, establishing the baseline year for all scenarios. It was crucial to understand the demand dynamics in the current account year, as it served as the fundamental reference point for all future projections and assessments. Prior to the development of any scenarios, a thorough analysis of the current state of water demand and supply was undertaken to characterize the water resource system within the basin and assess the demands from various sectors including domestic, agriculture, and livestock.

This comprehensive assessment involved modeling the current water demand and supply situation to determine the monthly average of available water relative to the existing demands. By conducting this analysis, the aim was to gain insights into the current water resource utilization patterns and to evaluate the balance between water availability and demand. The outcome of this assessment provided a detailed overview of the water demands at specific sites within the catchment area, offering valuable information for informed decision-making and sustainable water resource management practices.

The model output provides the average monthly water demand and annual total demand for the downstream of each irrigation water demand site and domestic water demand. The cumulative water needed to fulfill the irrigation needs of all sites in Current Account Year was 719 $Mm^3$, with October, November and December showing the highest demand levels and to fill domestic needs 18 $Mm^3$. Conversely, July, August and September exhibited lower demand compared to other months due to the rainy season.

Table4.6.Monthly Average Domestic water Demand without including loss ($Mm^3$) in current account year 1990-2015.

| Branch | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Adama_city | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.25 | 1.26 | 15.000 |
| Methara_City | 0.26 | 0.23 | 0.26 | 0.25 | 0.26 | 0.25 | 0.26 | 0.26 | 0.25 | 0.26 | 0.25 | 0.26 | 3.00 |
| Sum | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.51 | 18.0 |

Table4.7.Monthly average irrigation water demand for each site ($Mm^3$) in current account year.

| Branch | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Abadir_canal | 7.1 | 7.1 | 6.3 | 6.3 | 7.1 | 6 | 3 | 2.8 | 4.7 | 10 | 9 | 9 | 78.6 |
| Adama_Woreda | 2 | 1.8 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 23.9 |
| Africa_Juice | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0 | 0 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 4 |
| Dodota_intake | 3.8 | 3.8 | 3.4 | 3.4 | 3.8 | 3 | 2 | 1.5 | 2.5 | 5.5 | 4.8 | 4.8 | 42 |
| Doni_intake | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0 | 0 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 4.1 |
| Fental_Qawa Scheme | 3.1 | 2.8 | 3.1 | 3 | 3.1 | 3 | 3 | 3.1 | 3 | 3.1 | 3 | 3.1 | 36.4 |
| Gologota_canal | 1 | 0.9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 11.9 |
| Melkaside_Weir | 6.6 | 8.8 | 13.2 | 14 | 11 | 9 | 10 | 6.6 | 3.3 | 8.8 | 8.8 | 9.9 | 109.9 |
| Merti jeju_Canal | 3.3 | 3 | 3.3 | 3.2 | 3.3 | 3 | 3 | 3.3 | 3.2 | 3.3 | 3.2 | 3.3 | 38.6 |
| Merti_methara | 11.8 | 11.8 | 10.5 | 11 | 12 | 11 | 5 | 4.6 | 7.9 | 17 | 15.1 | 15.1 | 131.3 |
| Nura_Era main canal | 4.4 | 4 | 4.4 | 4.3 | 4.4 | 4 | 4 | 4.4 | 4.3 | 4.4 | 4.3 | 4.4 | 51.9 |
| Tibila_Scheme | 2.2 | 2 | 2.2 | 2.1 | 2.2 | 2 | 2 | 2.2 | 2.1 | 2.2 | 2.1 | 2.2 | 25.6 |
| UAAIE_Abadiska | 1.5 | 1.4 | 1.5 | 1.4 | 1.5 | 1 | 2 | 1.5 | 1.4 | 1.5 | 1.4 | 1.5 | 17.5 |
| Wolenchit_intake | 2 | 1.9 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 24 |
| Wonji_Main SF | 9.1 | 9.1 | 8.1 | 8.1 | 9.1 | 8 | 4 | 3.6 | 6.1 | 13 | 11.7 | 11.7 | 101.5 |
| Sum | 60.1 | 60.5 | 63.1 | 64 | 65 | 58 | 44 | 41 | 46 | 76 | 70.5 | 72.2 | 719.1 |

According to the Current Account Year the total monthly average water demand for the downstream Koka Irrigation results comparison shown on Figure 4.13 blow for current water demand schemes.

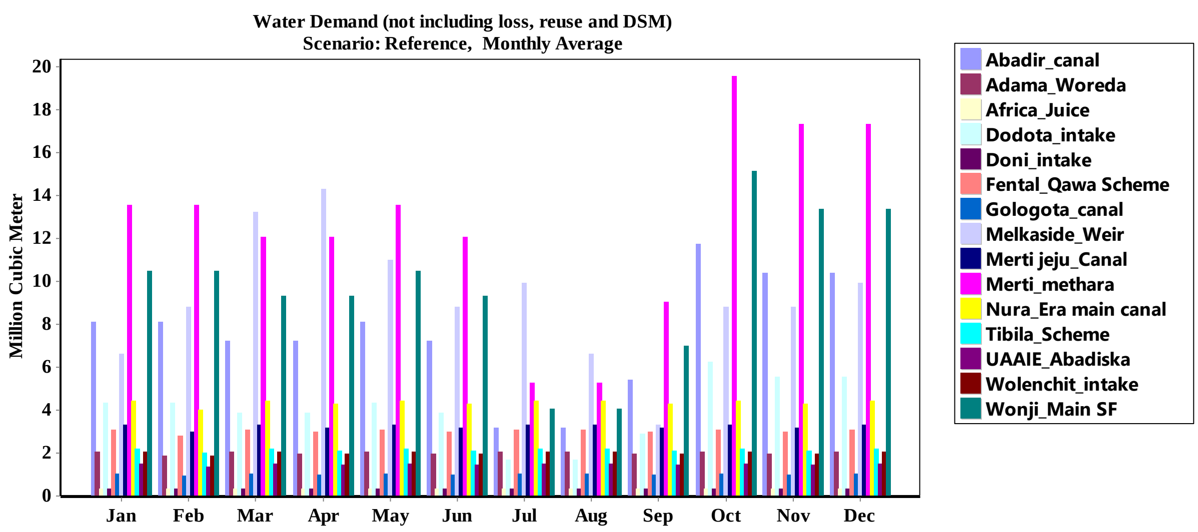


Figure 4.6.Monthly average Current irrigation water demands (without including losses)

### 4.5.2. Supply delivered

The total net amount of water delivered to the irrigation site from the water required to meet the irrigation demands of all sites and domestic demand in current account year 1990 was 678.1 $Mm^3$. During this time period, it was observed that the months of April, May, October, and December relatively exhibited the highest demand for water delivery, while July and August experienced lower demand compared to other months. This disparity between the amount of water demanded and the actual amount delivered highlights the presence of unmet demand in the irrigation system.

The imbalance between water demand and supply, especially during the peak demand months of April, May, October, and December, suggests potential challenges in water management and allocation. Factors such as seasonal variations in crop water requirements, climate conditions, and irrigation scheduling may contribute to the fluctuations in water demand throughout the year.

Table4.8.Monthly average supplies delivered for all demand sites in current scenario ($Mm^3$)

| Demand Site | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Abadir_canal | 5.8 | 6.7 | 5.9 | 6.3 | 7.1 | 6.3 | 2.8 | 2.8 | 4.7 | 10.2 | 7.7 | 7.1 | 73.2 |
| Adama_city | 1 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.1 | 1 | 14.2 |
| Adama_Woreda | 1.7 | 1.7 | 1.9 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1.7 | 1.6 | 22.6 |
| Africa_Juice | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 3.8 |
| Dodota_intake | 3.1 | 3.6 | 3.1 | 3.4 | 3.8 | 3.4 | 1.5 | 1.5 | 2.5 | 5.5 | 4.1 | 3.8 | 39.1 |
| Doni_intake | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 3.8 |
| Fental_Qawa Sch | 2.5 | 2.7 | 2.9 | 3 | 3.1 | 3 | 3.1 | 3.1 | 3 | 3.1 | 2.5 | 2.4 | 34.3 |
| Gologota_canal | 0.8 | 0.9 | 0.9 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0.8 | 0.8 | 11.2 |
| Melkaside_Weir | 6.6 | 8.3 | 12.3 | 14.3 | 11 | 8.8 | 9.9 | 6.6 | 3.3 | 8.8 | 8.8 | 8.6 | 107.2 |
| Merti jeju_Canal | 2.7 | 2.8 | 3.1 | 3.2 | 3.3 | 3.2 | 3.3 | 3.3 | 3.2 | 3.3 | 2.7 | 2.6 | 36.5 |
| Merti_methara | 9.7 | 11.2 | 9.8 | 10.5 | 11.8 | 10.5 | 4.6 | 4.6 | 7.9 | 17.1 | 12.8 | 11.9 | 122.3 |
| Methara_City | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.2 | 0.3 | 0.3 | 0.2 | 0.3 | 0.2 | 0.2 | 2.8 |
| Nura_Era main canal | 3.6 | 3.8 | 4.1 | 4.3 | 4.4 | 4.3 | 4.4 | 4.4 | 4.3 | 4.4 | 3.6 | 3.5 | 49 |
| Tibila_Scheme | 1.8 | 1.9 | 2 | 2.1 | 2.2 | 2.1 | 2.2 | 2.2 | 2.1 | 2.2 | 1.8 | 1.7 | 24.2 |
| UAAIE_Abadiska | 1.2 | 1.3 | 1.4 | 1.4 | 1.5 | 1.4 | 1.5 | 1.5 | 1.4 | 1.5 | 1.2 | 1.2 | 16.5 |
| Wolenchit_intake | 1.7 | 1.8 | 1.9 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1.7 | 1.6 | 22.7 |
| Wonji_Main SF | 7.5 | 8.6 | 7.6 | 8.1 | 9.1 | 8.1 | 3.6 | 3.6 | 6.1 | 13.2 | 9.9 | 9.2 | 94.6 |
| Sum | 50.3 | 57.2 | 59.1 | 63.6 | 64.5 | 58.1 | 43.9 | 40.7 | 45.5 | 76.4 | 61.1 | 57.7 | 678.1 |

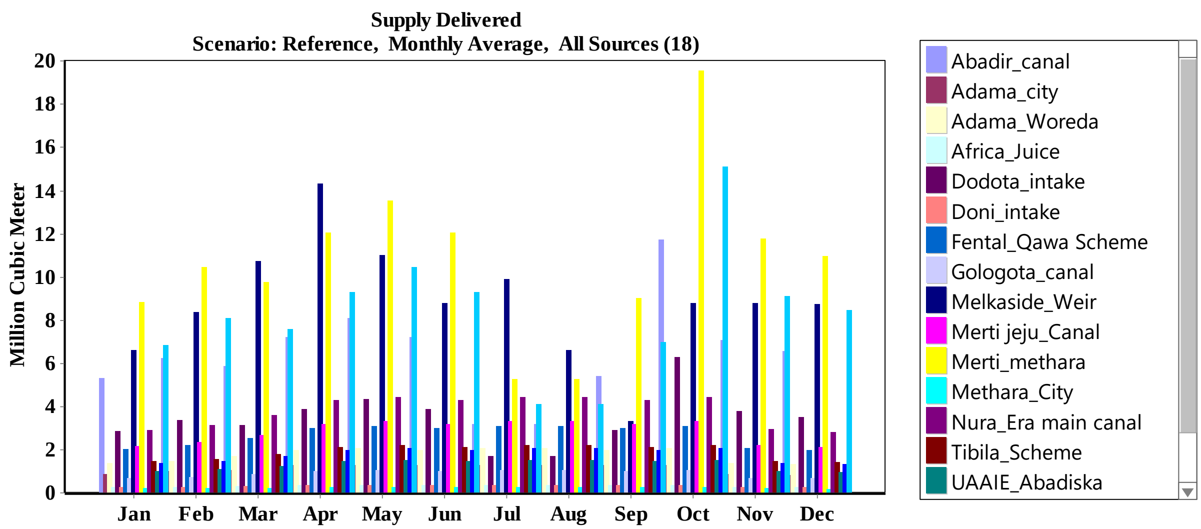


Figure 4.7.Monthly average supplies delivered for all demand sites in current scenario

### 4.5.3. Unmet Water Demand in the Current Account Year (1990-2015)

Unmet demand is difference between the supply requirements and the actual supply delivered at a specific demand site within a defined time frame. It represents the unfulfilled portion of the water demand that was expected to be met. In the context of irrigation water supplies, unmet demand reflects the insufficient supply capacity to meet the total water demand at certain demand sites over a specified period. Out of a total water demand of 719 $Mm^3$, irrigation water needs of all sites, 39.967 $Mm^3$ (equivalent to 5.7 % of the total demand) was not met during the current accounting years for all cumulative demands.

Table 4.9.Monthly average unmet demands all Irrigation site in current scenario ($Mm^3$)

| Demand Site | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Abadir_canal | 1,296 | 385 | 408 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,369 | 1,911 | 5,369 |
| Adama_Woreda | 371 | 100 | 131 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 296 | 428 | 1,326 |
| Africa_Juice | 62 | 16 | 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 49 | 71 | 219 |
| Dodota_intake | 691 | 204 | 216 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 731 | 1,021 | 2,863 |
| Doni_intake | 62 | 16 | 21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 50 | 72 | 221 |
| Fental_Qawa Scheme | 564 | 151 | 199 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 451 | 651 | 2,016 |
| Gologota_canal | 183 | 49 | 64 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 146 | 212 | 654 |
| Melkaside_Weir | 0 | 479 | 856 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,326 | 2,661 |
| Merti jeju_Canal | 599 | 161 | 211 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 479 | 692 | 2,142 |
| Merti_methara | 2,165 | 644 | 681 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2,286 | 3,192 | 8,968 |
| Nura_Era main canal | 807 | 218 | 286 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 643 | 929 | 2,883 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tibila_Scheme | 397 | 107 | 140 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 317 | 458 | 1,419 |
| UAAIE_Abadiska | 270 | 71 | 94 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 215 | 312 | 962 |
| Wolenchit_intake | 372 | 100 | 131 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 298 | 430 | 1,331 |
| Wonji_Main SF | 1,674 | 498 | 527 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,767 | 2,467 | 6,933 |
| Sum | 9,513 | 3,199 | 3,986 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9,097 | 14,172 | 39,967 |

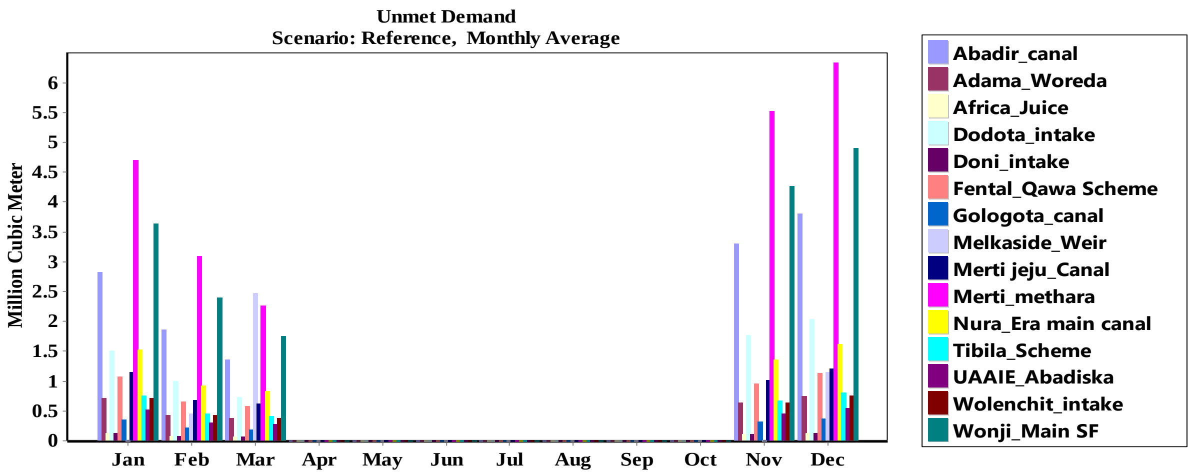


Figure 4.8.Monthly average Unmet Demand for all irrigation demand sites in current scenario

## 4.6 Scenario Analysis

In the context of scenario analysis, three distinct scenarios were developed to evaluate future water demand, considering both the impacts of the expansion of irrigation and water demand during the dry season. The first scenario, referred to as the reference scenario, focuses on forecasting future water demands without factoring in the influence of technological changes on water requirements. The two additional scenarios account for the potential effects of technological advancements alongside the expansion of irrigation and water demand during the dry season.

The outcomes of these scenarios are elaborated upon in the subsequent section, shedding light on the implications of expansion of irrigation and dry season on future water demands offering insights into the varying trajectories based on different assumptions and forecasting models.

### 4.6.1. Irrigation expansion scenarios

Key scenarios outlining potential future irrigation conditions in the lower Koka Basin have been established. These scenarios are based on the premise that, in accordance with the new Water Resources Management Strategy, the primary goal is to maximize the development of irrigation areas. Building upon this premise, the Koka reservoir dam within the basin has been chosen to model the supply of irrigation water to downstream Irrigation Schemes.

Currently, as per this study, 66,033 hectares of land are under cultivation, as indicated in Table 3.8 with the collected data. However, based on the design document of the Kawa Fentale and Tibila irrigation schemes, it is noted that the full capacity has not yet been realized. It is projected that by 2035, both schemes could potentially cultivate the remaining 11,490 hectares and 1,750 hectares respectively.

The model output provided the monthly average water demand in the Irrigation Expansion scenario and the annual total demand for the downstream Irrigation Scheme. The cumulative water volume required to meet the irrigation needs of all sites from 2016 to 2035 totaled 788 $Mm^3$. Among the months, January, February, March, April, May, October, November, and December had notably higher demand levels, reflecting peak requirements. In contrast, June, July, August, and September experienced lower demand, attributed to the rainy season compared to other months.

Table 4.10.Monthly Average Water Demand in Irrigation Expansion with respect to future Scenario ($Mm^3$)

| Scenario | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Irrigation Expansion | 65.9 | 65.8 | 69 | 69.2 | 70.3 | 63.8 | 49.8 | 46.5 | 51.2 | 82.3 | 76.1 | 78.1 | 788 |
| Reference | 60.1 | 60.5 | 63.1 | 63.6 | 64.5 | 58.1 | 43.9 | 40.7 | 45.5 | 76.4 | 70.5 | 72.2 | 719.1 |

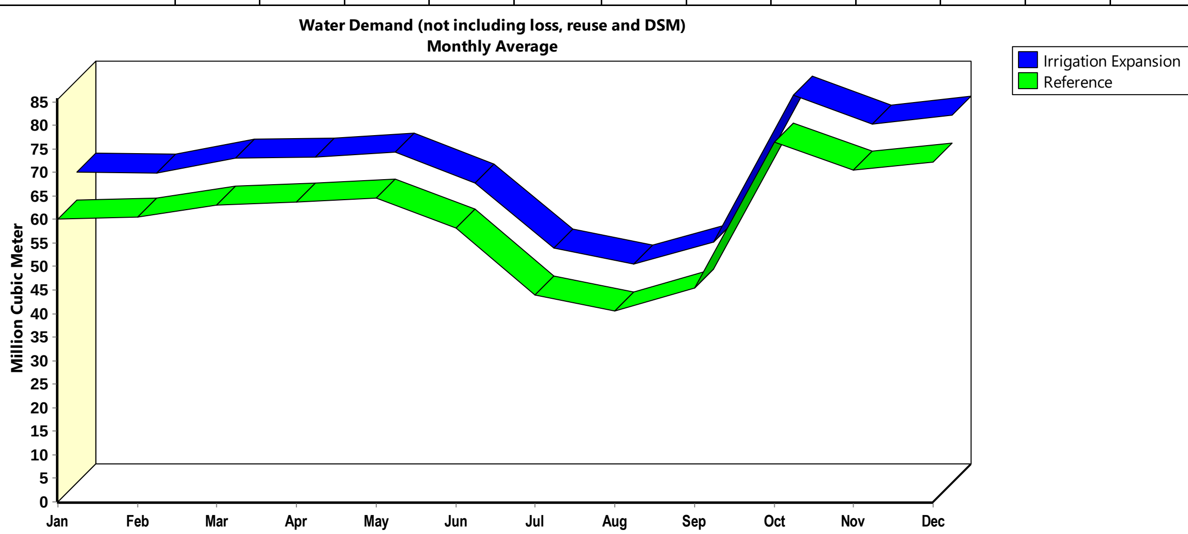


Figure 4.9.Monthly Average water demand in Irrigation expansion ($Mm^3$) with respect to future scenario (2016-2035)

#### 4.6.2.1 Unmet water demand in Irrigation Expansion Scenario

In this study, my focus was on the actual demand for irrigation water at each demand site. The model's findings in reference scenario indicated that the demand for irrigation water amounted to 719 $Mm^3$. Furthermore, the model revealed that there had been 39.9 $Mm^3$ of unmet demand at that time. Under different circumstances, additional irrigation expansion in two irrigation schemes was taken into account to accommodate the potential demand for irrigation water. The model's results demonstrated a total water demand of 788 $Mm^3$, with 66$Mm^3$ (equivalent to 9.18 % of the total demand) representing unmet demand in this revised scenario. These results indicate a notable shift in both water demand and unmet demand between the reference scenarios and the irrigation expansion scenarios.

The occurrence of unmet demand in both the current and irrigation expansion scenarios is not attributed to a deficiency in supply but is primarily a consequence of the utilization of an inadequate irrigation system. The absence of a properly engineered drainage system has resulted in significant water wastage, leading to decreased irrigation efficiency and subsequently capping in a notable level of unmet demand.

Hence, to alleviate the issue of unmet demand, enhancing the efficiency of irrigation water utilization can be achieved through the adoption of modern irrigation systems and the establishment of a well-designed drainage system. This approach aims to optimize water distribution, reduce wastage, and ultimately improve the overall effectiveness of irrigation practices.

The unmet demand identified in both the current and irrigation expansion scenarios during the months of November, December, January, February, and March is primarily a result of peak water demand periods that align with the operational activities of the large sugar plantations in Wonji and Methara Sugar Factory. These sugar plantations exhibit high water consumption requirements during these months, particularly due to the cultivation of sugarcane crops that have a significant demand for water. This elevated water demand intensifies during the specified months, contributing to a situation where the available water resources may not adequately meet the needs of both the agricultural sector and other users; thereby underscoring the challenges associated with water management and allocation strategies.

Table 4.11.Monthly average unmet water demand in Irrigation expansion ($Mm^3$) with respect to future scenario (2016-2035)

| Scenario | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Irrigation Expansion | 15 | 8 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 20 | 66 |
| Reference | 9.7 | 3.4 | 3.7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.1 | 14 | 39.9 |

# 5.0 CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

The primary objective of this research was to establish surface water allocation for the Koka reservoir during irrigation expansion, utilizing the WEAP model as a decision support tool in a sustainable manner to ensure social, economic, and environmental benefits. The study examined the impact of irrigation expansion on the reservoir and downstream irrigation development, emphasizing the importance of water release from the Koka reservoir for optimal water allocation across current and future development phases.

Addressing missing meteorological data through the multi-regression method and calibrating the WEAP model against observed stream flow data for the Hombole gauging station upstream proved essential for accurate analysis. The WEAP model exhibited strong statistical performance, accurately predicting current irrigation water demand and future impacts of irrigation expansion on flow requirements in the study area.

The estimation of water requirements considered various factors for 16 demand sites, revealing a cumulative water demand of 719 $Mm^3$ in the current accounting year, with noticeable fluctuations throughout the months. Under the Irrigation Expansion scenario, a total water volume of 788 $Mm^3$ was projected for irrigation needs from 2016 to 2035, with a corresponding unmet demand of 66 $Mm^3$.

The analysis underscored significant shifts in water demand and unmet demand between reference and expansion scenarios, highlighting the role of poor irrigation systems and water losses in diminishing irrigation efficiency and resulting in unmet water demand. Overall, the Water Evaluation and Planning System (WEAP) Model emerged as a valuable tool for Integrated Water Resources Management, aiding in the harmonization of water supply and demand across different priority levels for both current and future scenarios.

## 5.2 Recommendations

Several key recommendations emerge from the results and analysis of this study:

Firstly, the examination of 14 irrigation abstraction nodes revealed a common issue of ineffective irrigation practices leading to high levels of water wastage. It is essential to enhance awareness and provide training to improve irrigation water usage efficiency across all sectors.

Secondly, understanding and managing water allocation among different user categories is crucial to safeguarding finite water resources. Registering irrigation water users is vital, especially for small-scale farmers who may lack knowledge of water allocation principles.

Furthermore, with the Koka reservoir aging and showing a decline in water holding capacity, conducting a biometric survey to assess its current capacity accurately is recommended. Measures should be implemented to capture winter rainwater effectively, address water scarcity in summer, and manage potential winter floods, including the construction of additional mini dams.

Moreover, focusing on surface water analysis in the Koka Reservoir basin is a limitation of this study. Given the area's development potential and challenges related to water demand, quality, and flood risks, exploring alternative water supply opportunities like groundwater utilization and rainwater harvesting is essential.

Lastly, revisiting irrigation methods to minimize water losses and selecting crops with lower water requirements can help mitigate future water demands in agricultural practices.

# REFERENCES

AAiT and AwBA (2016). Awash River Basin Water Allocation Modeling and Conflict Resolution Study Project. Draft Final Report: WP3 Water Demand. Addis Ababa Institute of Technology (AAiT) and Awash Basin Authority (AwBA). Federal Democratic Republic of Ethiopia. Addis Ababa, Ethiopia.

AAiT and AwBA (2018). Awash River Basin Water Allocation Modeling and Conflict Resolution Study Project. Draft Final Report: WP3 Water Demand. Addis Ababa Institute of Technology (AAiT) and Awash Basin Authority (AwBA). Federal Democratic Republic of Ethiopia. Addis Ababa, Ethiopia.

Abeyou W. Worqlula, Jaehak Jeong, Yihun T. Dile, Javier Osorio, Petra Schmitter, Thomas Gerik, R. Srinivasan and Neville Clark (2017). Assessing potential land suitable for surface irrigation using groundwater in Ethiopia. Applied Geography 85 (2017) 1-13. http://dx.doi.org/10.1016/j.apgeog.2017.05.010

Addis Ababa Institute of Technology, 2016: Awash Basin water allocation modeling and Conflict Resolution Study. Draft final Report, Work Packages Surface water study, Ground water study and Water allocation modeling

Adeba, D. Assessment of water scarcity and its impacts on sustainable development in Awash basin, Ethiopia. Sustain. Water Resour. Manag. **2015**, 1, 71–87.

AgWater Solutions (2012). Groundwater Management in Ethiopia. Agricultural Water Management Learning and Discussion Brief. February 2012

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.

Allen, R., L. S. Pereira, D. Raes, and M. Smith, 1998. Crop evapotranspiration Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper No 56.

Andrea Rossi, Ricardo Biancalani and Lucie Chocholata, (Rome, FAO, 2019 "Change in water-use efficiency over time (SDG indicator 6.4.1): analysis and interpretation of preliminary results in key regions and countries", SDG 6.4 Monitoring Sustainable Use of Water Resources Papers).

Arnstein, S. R. 1969. 'A Ladder of Citizen Participation'. Journal of American Institute of Planners 35, no. 4: 216–24.

Awash Basin Strategic Water Allocation Plan (2008 EC)

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

Azazh, B. (2008). Water allocation study of upper awash. Addis Ababa: Addis Ababa University.

Babel MS, Das Gupta A, Nayak DK (2005) A model for optimal allocation of water to competing demands. Water Resources Manag 19:693–712.

Bahram Saedian,Mohammedi Saadi & Mostafa Ghodousi. (2015). optimal allocation of water to the cultivation Farms using Genetic Algorithm.

Berhanu Azazh. 2008. Water Allocation Study of Upper Awash Valley for Existing and Future Demands, Addis Ababa University. Addis Abab

Betelhem Wondimneh (2017). Maximizing Water Use Efficiency through Intra-Basin Canal System: The Case of Awash River Basin. Master thesis. Addis Abeba University, Ethiopi

Bryson, J. M. 2004. 'What to do when stakeholders matter: Stakeholder identification and analysis techniques'. Public Management Review 6, no. 1: 121–53. 3.

Burgin, Shelley., Daniel Williamson and Basant Maheshwari. 2010. 'Natural spaces – how do they influence stewardship attitudes and actions of university students?'. International Journal of Environmental Studies 67, no. 1: 63–78. DOI: 10.1080/00207230902738925

Canter, L.W. 1996. Environmental Impact assessment. McGraw-Hill, Inc.

Carmona,G., Varela-Ortega, C. and Bromley J. 2013. 'Participatory modeling to support decision making in water management under uncertainty: Two comparative case studies in the Gudiana river basin, Spain'. Journal of Environmental Management 128: 400–412

Carr, Dafna., Arlene Howells, Melissa Chang, Nadir Hirji and Ann English. 2009. 'An Integrated Approach to Stakeholder Engagement'. Healthcare Quarterly 12(special issue)

CDP, Cleaning Up Their Act: Are Companies Responding to the Risks and Opportunities Posed by Water Pollution? (London, CDP Worldwide, 2020).

D. K. Weragala, Neelanga. Water Allocation Challenges in Rural River Basins: A Case Study from the Walawe River Basin, Sri Lanka. Ph.D. thesis, Civil and Environmental Engineering, Utah State University Logan, Utah. (2010).

D. Myronidis, D. Stathis, K. Ioannou, D. Fotakis, Water Resour. Manag. 26 (2012) 4587–4605

Daniel EB, Camp JV, Leboeuf EJ et al (2011) Watershed modeling and its applications: a state-of-the-art review. Open Hydrol J 5:26–50. https://

Davijani, M.H.;Banihabib, M.E. Multi-Objective Optimization Model for the Allocation of Water Resources in Arid Regions Based on the Maximization of Socioeconomic E_ciency. Water Resour. Manag. **2016**, 30, 927–946.

Diego J. Rodriguez and others, “Thirsty energy”, Water Papers, No. 78923 (Washington, D.C., World Bank, 2013)

Durrans SR., (2003). Storm water Conveyance Modeling and Design. Haestad Press, Waterbury, CT

Environmental Flows for Hydropower Projects: Guidance for the Private Sector in Emerging Markets (Washington, D.C., World Bank, 2018).

EPCC (2015). First Assessment Report-Working Group II Water and Energy, Published by the Ethiopian Academy of Sciences. Ethiopian Panel on Climate Change (EPCC), Addis Abeba

Erdogan, R. 2013. ‘Stakeholder Involvement in Sustainable Watershed Management (Chapter 6), Advances in Landscape Architecture, INTECH.

FAO (Food and Agriculture Organization), 1998. Crop evapotranspiration: Guidelines for computing crop water requirements. By Richard Allen, Luis Pereira, Dirk Raes and Martin Smith. FAO Irrigation and Drainage Paper 56. Rome, Italy.

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

Faust, K., D. M. Abraham, and D. De Laurentis. 2013. ‘Assessment of stakeholder perceptions in water infrastructure projects using systems-of-systems and binary probit analyses: A case study’, Journal of Environmental Management 128: 866–87

Federal Democratic Republic of Ethiopia Population Census Commission 2008, Summary and Statistical report of the 2014 population and housing census. Addis Ababa, Ethiopia.

Flint LE, Flint AL, Stolp BJ, Danskin WR (2012) A basin-scale approach for assessing water resources in a semiarid environment: San Diego region, California and Mexico. Hydrol Earth Syst Sci 16:3817–3833

Gedefaw M et al (2019) Water resources allocation systems under irrigation expansion and climate change scenario in Awash River Basin of Ethiopia. GTP-2, 2015. Growth and transformation plan-2 for water sector, Addis Ababa, Ethiopia.

Gudowsky, N. and Bechtold U. 2013. 'The Role of information in Public Participation'. Journal of Public Deliberation 9, no. 1.

Gutrich, J., Donovan D., Finucane M., Focht W., Hitzhusen F., Manopimoke S., McCauley D., Norton B., Sabatier P., Salzman J., and Sasmitawidjaja V. 2005. 'Science in the public process of ecosystem management: lessons from Hawaii, Southeast Asia, Africa and the US Mainland'. Journal of Environmental Management 76: 197–209.

GWP (2009) A handbook for integrated water resources management in basins. Global Water Partnership (GWP), International Network of Basin Organizations (INBO), International Water Association, London. https://www.inbo-news.org/IMG/pdf/GWP-INBOH andbookForIWRMinBasins.pdf

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.

Halcrow (1983). Water Management Manual. Amibara Irrigation Project. Water Resources Development Authority, Ethiopia. Halcrow (1989). Master Plan for the Development of Surface Water Resources in the Awash Basin. Final Reports: Volume 4. Ethiopian Valley Development Studies Authority.

Hamlat A, Errih M, Guidoum A (2013) Simulation of water resources management scenarios in western Algeria watersheds using WEAP model. Arab J Geosci 6(7):2225–2236. https://doi.org/ 10.1007/s12517-012-0539-0

Hripad Dharmadhikary, Environmental Flows in the Context of Transboundary Rivers 2017: Exploring Existing International Best Practices and How They Could be Applied in South Asia (Berkeley, California, International Rivers, 2017).:

Jemal, M. (2013). Long Term Demand - Forecasting and Generation Expansion Planning of the Ethiopian Electric Power (EEP). Addis Ababa Institute of Technology (AAiT). Addis Abeba, Ethiopia.

Liu G, Zhang Y, Knibbe WJ, Feng C, Liu W, Medema G, van der Meer W (2017) Potential impacts of charging supply-water quality on drinking water distribution: a review.

MacDonald, A., Bonsor, H., Dochartaigh, B.E.O., & Taylor, R. (2012). Quantitative maps of groundwater resources in Africa.Environmental Research Letters, 7(2), 02400

Marga Abdata. 2019. Estimation of Surface Water Potential and Demands in Middle Awash River Basin, Northeast Ethiopi

Mccartney MP, Arranz R (2007) Evaluation of historic, current and future water demand in the Olifants River Catchment, South Africa

Montreal, (2020).Secretariat of the Convention on Biological Diversity, Global Biodiversity Outlook 5

MoWIE (2018). Assessment of national water used and demand forecast. Part ii: water uses and demand forecast; ii-c: Agricultural sector water use & demand forecast. Draft Final Report. Ministry of Water, Irrigation and Electricity (MoWIE) in consultation with Generation Integrated Rural Development Consultant (GIRDC). Federal Democratic Republic of Ethiopia, Addis Ababa

MoWIE and JICA (2015). The Project for Groundwater Resources Assessment in the Middle Awash River Basin in the Federal Democratic Republic Of Ethiopia. Final Report Executive Summary. Japan International Cooperation Agency Kokusai Kogyo Co., Ltd. The Federal Democratic Republic of Ethiopia Ministry of Water, Irrigation and Electricity.

MoWR, 2006. Universal access Plan for water supply and sanitation service 2006-2011. Addis Ababa, Ethiopia.

Mussa Kurkura, June 2011. Water balance of upper awash basin based on satellite derived data (remote sensing).

Mussa Kurkura, June 2011. Water balance of upper awash basin based on satellite derived data (remote sensing).

Neitsch et al, S. A. (2011). Soil and Water Assessment Tool Theoretical Documentation. Texas A & M University.

OECD. (2015). Water Resources Allocation: Sharing risks and opportunities. Paris: OECD Publishing.

OIDA (2018). Oromiya Irrigation Potential Assessment Project (Awash Basin Groundwater). Final Report Volume III. The National Regional State of Oromiya

Pearson, L. J., A. Coggan, W. Proctor, and T. F. Smith. 2010. 'A Sustainable Decision Support Framework for Urban Water Management'. Water Resource Manage 24: 363– 376.

Pinto, U., and B. L. Maheshwari. 2010. 'Reuse of greater for irrigation around homes in Australia: Understanding community views, issues and practices'. Urban Water Journal 7, no. 2: 141-153. DOI:10.1080/15730620903447639

Roa-García MC (2014) Equity, efficiency and sustainability in water allocation in the Andes: trade-ofs in a full world. Water Altern 7:298–319

Secretariat of the Convention on Biological Diversity, Drinking Water, Biodiversity and Development: A Good Practice Guide (Montreal, 2010), p. 1. See also, generally, Alistair Rieu-Clarke and Christopher Spray, "Ecosystem services and international water law: towards a more effective determination and implementation of equity?", Potchefstroom Electronic Law Journal, vol. 16, No. 2 (2013), p. 12–65

SEI (2011). Water Evaluation and Planning System: User Guide. Stockholm Environment Institute, U.S. Center. Retrieved from http://www.weap21.org.

SEI (2015). Water evaluation and planning system – user guide. Stockholm Environment Institute. Boston,USA.

SEI (Stockholm Environment Institute) (2012). WEAP (Water Evaluation and Planning System): Guideline and Tutorial of WEAP model.

Seifu Kebede and Alexandros Makarigakis (2011). Groundwater in Ethiopia; State of knowledge and capacity gaps. December 2011, Addis Ababa, Ethiopia

Seleshi et al., (2010).water resources and irrigation development in Ethiopia

Sieber, J. Y. (2005). WEAP21 - A Demand, Priority, and Preference-Driven Water Planning Model Part 1: Model Characteristics. Water International, Pages 487–500

Singh, A. (2012). An overview of the optimization modeling applications. *Journal of Hydrology*, *466*, 167-182.

Speed, R. Y. (2013). Basin water allocation planning: Principles, procedures and approaches for basin allocation planning. Asian Development Bank, GIWP, UNESCO, and WWF-UK

Tadesse N (2006) Surface Waters Potential of the Hantebet Basin, Tigray, Northern Ethiopia. Agric Eng Int CIGR VIII(May):1–31.

Tadesse, F. (2020). Development of Water Allocation and Utilization System for Koka Reservoir under Climate Change and Irrigation Development Scenarios./IJES/ 9(4) 2020 109-116

Taffa T., (2002). Soil and Water Conservation for Sustainable Agriculture. Mega Publishing Enterprise, CTA, Postbus 380, 6700 AJ Wageningen, the Netherlands.

UNECE, Policy Guidance Note on the Benefits of Trans boundary Water Cooperation (2015)

UNESCAP (2000) Principles and practices of water allocation among water-use sectors. ESCAP water resources series no 80, Bangkok van Vuuren DP, Edmonds J, Kainuma M et al. (2011) The representative concentration pathways: an overview. Clim Change 109:5–31. https://doi.org/10.1007/s10584-011-0148-z

Wang, H.; Wang, J.; Liu, J.H.; Mei, C. Analysis of urban water cycle evolution and countermeasures. J. Hydraulic. Eng. 2021, 52, 3–11. [CrossRef]

Webb, Tony., Shelly Burgin, and Basant Maheswari. 2009. 'Action Research for Sustainable Water Futures in Western Sydney: Reaching Beyond Traditional Stakeholder Engagement to Understand Community Stakeholder Language and its Implications for Action'. SystPract Action Res. 22: 1–14, DOI 10.1007/s11213-008- 9102-

Weragala, D.K. 2010. Water Allocation Challenges in Rural River Basins: A Case Study from the Walawe River Basin, Sri Lanka.

WHO (World Health Organization), 2003. Right to water retrieved from office of United Nation Commissioner for Human Rights: http/: www.ohchr.org /English /issues/ water/ does/Right-to-water.

Williams, M. (2010). Forest and tree cover. (Pages 97-124), in Meyer WB, turnerBL II, eds.Changes in Land use and Land Cover: A global perspective. Cambridge University press.

WMO (2012) Technical material for water resources assessment (WMO-No.1095). Geneva

WWDSE (2014). Tendaho Sugarcane Irrigation Expansion Project: Final Basin Water Balance Assessment Report. Water Works Design and Supervision Enterprise. Addis Ababa, Ethiopia.

WWDSE (2016). Hydrology Study Report; Study and Design of Diversion Structures Project in Upper and Middle Awash Basin. Water Works Design and Supervision Enterprise. Addis Ababa, Ethiopia.

Yan, D.; Ludwig, F.; Huang, H.Q.; Werners, S.E. Many-objective robust decision making for water allocation under climate change. Sci. Total Environ. **2017**, 607, 294–303.

Yandamuri SR, Srinivasan K, Murty Bhallamudi S (2006) Multiobjective optimal waste load allocation models for rivers using nondominated sorting genetic algorithm-II. J Water Resour Plan Manag 132:133–143

Yang H, Zehnder (2007) Virtual water: an unfolding concept in integrated water resources management. Water Resour Res.

Yates,D. (2005). "WEAP21-A demand-, priority-, and preference-driven water planning model: part 1: model characteristics." Water International 30(4): 487-500.

Zemede, 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)

Zhanqi wang,Jun yang,Xiangzhang Deng and Xilan. (2015). optimal water resources allocation under the constraint of land use in Heihe river Basin catchment . Sustainablity 7, 1558-1575.

Zhao Kai, Liu Huazhen, Zhou Ting, Xiang Bo, Xie Yan, Shi Qing, Liu Na, Wu Yan, Dai Li (2015). Hydropower Potential General Survey in Ethiopia. Hydro China Corporation, Power China Beijing Engineering Corporation Limited

Zinash Sileshi, Azage Tegegne, and Getnet Tekle Tsadik, 2003. Water resources for livestock in Ethiopia: Implications for research and development. Ethiopian Agricultural Research Organization (EARO), Addis Ababa, Ethiopia: 66- 79.

Zorrilla, P., G. Carmona, A. D. Hera, C. Varela-Ortega, P. Martinez-Santos, J Bromley and J Henriksen. 2010. ‘Evaluation of Bayesian Networks in Participatory Water Resources Management, Upper Guadiana Basin, Spain’. Ecology and Society 15, no. 3

**APPENDIX-1 Meteorological Data**

Station name Hombole Element:

Monthly total stream flow (m3/s)

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | 3.46 | 12.87 | 18.78 | 24.16 | 4.94 | 11.11 | 87.00 | 235.20 | 116.76 | 17.06 | 4.02 | 2.94 | 538.29 |
| 1991 | 2.77 | 5.07 | 9.13 | 2.72 | 2.52 | 10.41 | 98.42 | 256.19 | 153.69 | 9.58 | 3.63 | 3.29 | 557.43 |
| 1992 | 3.43 | 6.52 | 3.37 | 4.40 | 4.15 | 10.91 | 72.43 | 203.35 | 143.68 | 16.43 | 4.20 | 3.23 | 476.11 |
| 1993 | 2.92 | 4.89 | 2.50 | 10.28 | 12.13 | 27.87 | 124.45 | 265.14 | 191.18 | 31.79 | 8.01 | 4.06 | 685.21 |
| 1994 | 2.82 | 2.31 | 2.43 | 4.75 | 4.29 | 10.33 | 74.00 | 157.52 | 144.93 | 16.53 | 5.01 | 4.83 | 429.74 |
| 1995 | 4.26 | 4.52 | 3.09 | 14.90 | 5.49 | 10.69 | 72.23 | 190.23 | 75.44 | 7.76 | 3.28 | 2.86 | 394.73 |
| 1996 | 5.42 | 4.15 | 5.87 | 12.49 | 21.65 | 84.06 | 194.47 | 348.26 | 133.88 | 13.22 | 5.89 | 3.99 | 833.35 |
| 1997 | 4.04 | 3.22 | 2.97 | 5.50 | 4.11 | 15.69 | 57.71 | 119.28 | 32.38 | 10.03 | 10.68 | 6.10 | 271.70 |
| 1998 | 5.01 | 3.69 | 11.16 | 8.21 | 11.31 | 24.62 | 137.37 | 366.56 | 161.03 | 41.71 | 9.09 | 5.46 | 785.23 |
| 1999 | 4.98 | 4.10 | 4.58 | 3.44 | 3.56 | 20.80 | 110.43 | 269.34 | 62.90 | 47.58 | 8.64 | 5.12 | 545.44 |
| 2000 | 4.15 | 3.75 | 1.94 | 3.16 | 5.67 | 12.57 | 63.10 | 178.61 | 90.99 | 30.79 | 12.48 | 6.04 | 413.21 |
| 2001 | 5.73 | 5.24 | 11.07 | 7.52 | 11.73 | 43.33 | 140.46 | 189.32 | 78.70 | 11.72 | 8.21 | 6.12 | 519.15 |
| 2002 | 5.81 | 4.21 | 4.88 | 5.69 | 5.16 | 12.01 | 59.54 | 143.31 | 49.31 | 9.59 | 7.58 | 3.82 | 310.90 |
| 2003 | 3.61 | 3.20 | 4.83 | 10.32 | 6.66 | 22.77 | 119.50 | 184.30 | 103.20 | 15.67 | 8.86 | 6.00 | 488.91 |
| 2004 | 3.68 | 2.85 | 3.90 | 14.74 | 5.29 | 20.49 | 88.59 | 166.73 | 87.11 | 16.74 | 9.33 | 4.49 | 423.93 |
| 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 | 529.67 |
| 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 | 682.45 |
| 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 | 659.19 |
| 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 | 579.91 |
| 2009 | 9.51 | 4.25 | 3.44 | 9.52 | 5.31 | 7.42 | 45.25 | 185.45 | 111.66 | 25.89 | 6.16 | 6.77 | 420.62 |
| 2010 | 4.54 | 12.56 | 10.97 | 21.57 | 19.45 | 35.68 | 162.37 | 178.78 | 153.67 | 18.51 | 9.99 | 5.36 | 633.45 |
| 2011 | 4.83 | 3.96 | 5.43 | 3.78 | 11.23 | 27.06 | 68.99 | 202.57 | 126.23 | 21.68 | 9.78 | 5.78 | 491.30 |
| 2012 | 4.27 | 3.74 | 3.15 | 10.67 | 8.25 | 12.19 | 93.95 | 166.05 | 107.90 | 19.20 | 7.73 | 5.21 | 442.33 |
| 2013 | 4.22 | 3.39 | 6.42 | 13.63 | 11.81 | 31.92 | 93.58 | 169.78 | 137.59 | 40.52 | 12.16 | 4.98 | 530.00 |
| 2014 | 3.86 | 4.45 | 4.74 | 6.52 | 10.31 | 14.20 | 55.98 | 147.20 | 84.69 | 32.04 | 10.02 | 4.68 | 378.68 |
| 2015 | 3.94 | 3.25 | 4.83 | 3.72 | 9.65 | 23.81 | 45.77 | 118.51 | 63.50 | 16.53 | 5.74 | 3.97 | 303.20 |
| Mean | 4.47 | 4.75 | 6.08 | 9.17 | 9.53 | 23.03 | 99.71 | 206.70 | 114.08 | 21.19 | 8.73 | 5.01 | 512.47 |

Station name Mojo Element:

Monthly total stream flow (m3/s)

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | 0.26 | 4.603 | 0.52 | 8.534 | 0.226 | 0.387 | 54.63 | 102.33 | 45.49 | 0.362 | 0.231 | 0.297 | 217.868 |
| 1991 | 0.283 | 0.37 | 0.61 | 0.339 | 0.205 | 0.435 | 80.36 | 146.05 | 70.32 | 0.355 | 0.399 | 0.685 | 300.417 |
| 1992 | 0.623 | 0.682 | 0.37 | 0.653 | 0.252 | 5.348 | 21.466 | 112.15 | 87.08 | 0.525 | 0.284 | 0.314 | 229.741 |
| 1993 | 0.292 | 0.315 | 0.22 | 6.151 | 9.414 | 0.534 | 72.413 | 130.32 | 113.5 | 7.983 | 0.384 | 0.298 | 341.86 |
| 1995 | 0.222 | 0.186 | 0.32 | 0.255 | 0.35 | 0.79 | 39.638 | 117.06 | 53.23 | 0.465 | 0.355 | 0.344 | 213.218 |
| 1996 | 0.306 | 0.351 | 0.48 | 0.604 | 45.816 | 97.312 | 57.078 | 109.69 | 73.63 | 126.7 | 131.6 | 132.437 | 776.036 |
| 1997 | 0.456 | 0.29 | 0.39 | 4.347 | 0.326 | 13.982 | 69.759 | 107.94 | 1.258 | 4.763 | 0.505 | 0.4 | 204.413 |
| 1998 | 0.405 | 0.568 | 0.63 | 8.773 | 0.518 | 17.791 | 101.32 | 216.45 | 81.24 | 26.54 | 0.525 | 0.479 | 455.24 |
| 1999 | 0.485 | 0.414 | 0.54 | 0.396 | 0.432 | 14.703 | 111.85 | 172.71 | 25.83 | 4.448 | 0.357 | 0.318 | 332.478 |
| 2000 | 0.357 | 0.314 | 0.28 | 0.279 | 0.443 | 8.852 | 82.015 | 91.07 | 16.66 | 0.632 | 0.408 | 0.361 | 201.665 |
| 2001 | 0.363 | 0.33 | 2.44 | 0.414 | 1.343 | 7.2 | 18.144 | 34.11 | 8.187 | 0.5 | 0.429 | 0.429 | 73.892 |
| 2022 | 0.442 | 0.38 | 0.48 | 0.405 | 0.448 | 1.791 | 12.242 | 14.215 | 2.244 | 0.43 | 0.37 | 0.461 | 33.91 |
| 2003 | 0.557 | 0.457 | 0.72 | 1.141 | 0.598 | 2.717 | 26.935 | 50.075 | 9.091 | 0.536 | 0.393 | 0.439 | 93.659 |
| 2004 | 0.403 | 0.228 | 0.62 | 1.822 | 0.292 | 1.282 | 7.082 | 27.008 | 3.121 | 0.56 | 0.392 | 0.397 | 43.209 |
| 2005 | 0.46 | 0.188 | 1.49 | 2.661 | 5.355 | 2.637 | 13.693 | 20.961 | 7.823 | 0.56 | 0.538 | 0.455 | 56.821 |
| 2006 | 0.418 | 0.597 | 0.78 | 2.408 | 1.523 | 2.366 | 20.22 | 19.038 | 8.245 | 0.615 | 0.492 | 0.464 | 57.167 |
| 2007 | 0.359 | 0.463 | 0.43 | 1.05 | 3.078 | 7.323 | 13.426 | 35.685 | 18.6 | 1.086 | 0.615 | 0.645 | 82.764 |
| 2008 | 0.613 | 0.221 | 0.09 | 0.483 | 0.687 | 2.05 | 11.798 | 24.076 | 7.156 | 0.732 | 0.984 | 0.514 | 49.40805 |
| 2009 | 0.518 | 0.212 | 0.17 | 0.861 | 0.444 | 0.431 | 6.464 | 17.906 | 8.042 | 1.431 | 0.382 | 0.46 | 37.319 |
| 2010 | 0.325 | 0.304 | 0.64 | 2.211 | 3.096 | 3.088 | 14.53 | 24.933 | 13.04 | 0.642 | 0.434 | 0.353 | 63.5905 |
| 2011 | 0.224 | 0.38 | 0.57 | 1.165 | 0.796 | 3.328 | 14.058 | 14.421 | 8.696 | 0.954 | 0.912 | 0.51 | 46.0106 |
| 2012 | 0.454 | 0.25 | 0.2 | 0.685 | 0.503 | 1.812 | 8.355 | 26.66 | 5.483 | 0.553 | 0.456 | 0.386 | 45.801 |
| 2013 | 0.31 | 0.197 | 0.62 | 0.595 | 0.646 | 3.878 | 26.349 | 9.465 | 6.5 | 1.089 | 1.045 | 0.786 | 51.475 |
| 2014 | 0.643 | 0.916 | 0.54 | 0.412 | 1.512 | 1.337 | 30.363 | 19.261 | 9.657 | 2.243 | 1.037 | 0.517 | 68.434 |
| 2015 | 1.058 | 0.525 | 0.34 | 0.281 | 3.444 | 4.406 | 5.255 | 13.959 | 2.414 | 0.711 | 0.683 | 0.599 | 33.671 |
| Mean | 0.433 | 0.55 | 0.58 | 1.877 | 3.2699 | 8.2312 | 36.778 | 66.301 | 27.46 | 7.417 | 5.77 | 5.73392 | 164.4027 |

**Average Kc values of different 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 | 0.77 |
| Grass land | 0.69 | 0.81 | 0.91 | 0.91 | 0.91 | 0.91 | 0.91 | 0.91 | 0.91 | 0.89 | 0.66 | 0.66 |
| Irrigated cultivated | 0.82 | 0.85 | 0.88 | 0.92 | 0.91 | 0.74 | 0.81 | 0.96 | 0.87 | 0.68 | 0.9 | 1.01 |
| Rain fed cultivated | | | | | 0.35 | 0.64 | 1 | 1.06 | 1.04 | 0.52 | | |
| Shrub land | 0.65 | 0.66 | 0.77 | 0.77 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.77 | 0.77 |
| Urban or Exposed rocky | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| 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 |

Estimated of Koka Reservoir Evaporation (mm)

| Reservoir | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Koka reservoir | 30.2 | 26.4 | 34.3 | 27.5 | 33.5 | 35.6 | 30.1 | 17.1 | 36.2 | 50.8 | 33.4 | 34.2 | 389.3 |

**APPENDIX-2 Meteorological Data**

Station name: Adama

Element: Monthly total rainfall (mm)

| year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | annual rainfall (mm/year) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | 1.3 | 23 | 21.7 | 146 | 52.5 | 122.2 | 345.4 | 103.9 | 135 | 0.9 | 53.7 | 0 | 1005.6 |
| 1991 | 0 | 38.9 | 121.8 | 36.4 | 110.6 | 31.9 | 250 | 207.5 | 224.8 | 9.1 | 0 | 0 | 1031.0 |
| 1992 | 0 | 13 | 0 | 108.2 | 42.4 | 107.6 | 221.3 | 179.8 | 51.2 | 1.2 | 18.8 | 1.5 | 745.0 |
| 1993 | 0 | 0 | 0 | 0 | 0 | 112.8 | 317.6 | 0 | 283.9 | 23.4 | 93.6 | 0 | 831.3 |
| 1994 | 0 | 0 | 0 | 76.4 | 0 | 103.3 | 344 | 307.5 | 62.8 | 8.1 | 0 | 0 | 902.1 |
| 1995 | 0 | 36.5 | 46.9 | 127.2 | 33 | 46.5 | 203.1 | 251.4 | 88.2 | 14.7 | 0 | 2.8 | 850.3 |
| 1996 | 27.2 | 0 | 111.5 | 65.1 | 115.2 | 120.2 | 220.2 | 250 | 93.9 | 0 | 7.9 | 0 | 1011.2 |
| 1997 | 14.4 | 0 | 75.3 | 28.5 | 6.9 | 94 | 193.1 | 240.9 | 75.5 | 116.5 | 31.5 | 0 | 876.6 |
| 1998 | 11.8 | 25.6 | 105.2 | 19.8 | 49.3 | 55.3 | 196.5 | 220.6 | 144.7 | 132.8 | 0 | 0 | 961.6 |
| 1999 | 9.2 | 0 | 34.6 | 1.2 | 18.6 | 74 | 283.2 | 194.4 | 66.3 | 164.7 | 3.1 | 0 | 849.3 |
| 2000 | 0 | 0 | 20.2 | 16.1 | 51.5 | 60.8 | 355.1 | 269 | 133.6 | 85.7 | 57.8 | 12.9 | 1062.7 |
| 2001 | 0 | 6.2 | 108.3 | 28.7 | 177 | 51.2 | 216.8 | 145.3 | 107.8 | 1.7 | 0 | 6.6 | 849.6 |
| 2002 | 20.9 | 11.1 | 21.9 | 51.3 | 22.5 | 50.2 | 129.9 | 205.7 | 65.3 | 1.1 | 0 | 34.5 | 614.4 |
| 2003 | 46.5 | 69.1 | 151.2 | 88.9 | 3.6 | 75.2 | 235.6 | 279.7 | 122.8 | 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 | 68.4 | 6 | 5.3 | 0 | 720.5 |
| 2006 | 17.6 | 88.4 | 64.6 | 88.7 | 27.8 | 58.7 | 173.5 | 225 | 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 | 25.6 | 7.5 | 0 | 1107.2 |
| 2008 | 9.6 | 0 | 0 | 79.9 | 69.5 | 71.3 | 353.1 | 302.2 | 100.3 | 37.5 | 69.5 | 0 | 1092.9 |
| 2009 | 62.6 | 0 | 3.1 | 2.3 | 22.1 | 50 | 156.1 | 113.3 | 34 | 132.7 | 0 | 12.5 | 588.7 |
| 2010 | 0 | 97.3 | 88.8 | 27.4 | 68.1 | 100.6 | 227.8 | 242.9 | 164.7 | 0 | 17.6 | 0.3 | 1035.5 |
| 2011 | 0 | 0 | 10.4 | 17.6 | 68.7 | 54.8 | 215.1 | 155.8 | 192.1 | 0 | 30.2 | 0 | 744.7 |
| 2012 | 56 | 0 | 39.8 | 78.2 | 48.8 | 33 | 508.9 | 313 | 130.2 | 1.4 | 0.5 | 3.9 | 1213.7 |
| 2013 | 4.4 | 0.2 | 69.2 | 35.1 | 36 | 38.9 | 443.2 | 105.2 | 132.8 | 34 | 5.2 | 0 | 904.2 |
| 2014 | 0 | 4.8 | 123 | 7.1 | 62.3 | 7.7 | 211.7 | 180 | 150.6 | 91.7 | 8.9 | 0 | 847.8 |
| 2015 | 0 | 0 | 11 | 3.6 | 190.2 | 74.9 | 131.3 | 207.9 | 78.6 | 2.7 | 47 | 10.5 | 757.7 |
| **Ave.** | 19.27 | 18.11 | 63.55 | 45.85 | 57.56 | 61.60 | 235.17 | 220.90 | 109.22 | 43.69 | 14.79 | 7.76 | 897.5 |

Station name: Akaki

Element: Monthly total rainfall (mm)

| year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | annual rainfall (mm/year) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | 7.7 | 121 | 48.4 | 159 | 37.3 | 78.9 | 280.7 | 222.9 | 107.3 | 5.8 | 1.2 | 0 | 1069.9 |
| 1991 | 0 | 37.6 | 62.4 | 11.6 | 45.6 | 90.4 | 263.7 | 308.5 | 113.3 | 4.4 | 0 | 57 | 994.0 |
| 1992 | 33.5 | 24.2 | 30.5 | 15.5 | 25.6 | 100.4 | 218.4 | 276 | 86.7 | 43.3 | 0.2 | 0 | 854.3 |
| 1993 | 1.2 | 53.9 | 5.6 | 118 | 54.6 | 116.5 | 218 | 251.5 | 118.3 | 20.5 | 0 | 0 | 958.5 |
| 1994 | 0 | 0 | 62.7 | 72.2 | 20.2 | 131.2 | 219.3 | 181 | 94.5 | 0 | 11 | 0 | 792.1 |
| 1995 | 25.4 | 62.7 | 102 | 20.9 | 95.7 | 279 | 242.3 | 79.5 | 0 | 0 | 4.8 | | 912.4 |
| 1996 | 15.3 | 0.3 | 79.7 | 38.8 | 90.5 | 240.1 | 292.5 | 234.1 | 119 | 1.9 | 0 | 0 | 1112.2 |
| 1997 | 27.6 | 0 | 29.5 | 103 | 25.2 | 57 | 203.6 | 203.4 | 82.5 | 115 | 10 | 0 | 856.7 |
| 1998 | 32.7 | 30.2 | 19.6 | 69.3 | 160 | 116.9 | 207.8 | 280 | 118.5 | 36.9 | 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 | 955.2 |
| 2000 | 0 | 0 | 29.1 | 93 | 64.9 | 100.1 | 188.9 | 210 | 124.1 | 17.2 | 23 | 3.8 | 854.5 |
| 2001 | 0 | 20.7 | 121 | 23.6 | 118 | 142.6 | 257.5 | 145 | 64.9 | 2.2 | 0 | 0 | 895.7 |
| 2002 | 31.1 | 10.5 | 87.8 | 53.9 | 76.6 | 108 | 167.1 | 166.3 | 52.3 | 0 | 0 | 18 | 771.3 |
| 2003 | 19.6 | 24.8 | 23.9 | 114 | 1.4 | 125.4 | 325.1 | 307.4 | 113.4 | 0 | 0 | 41 | 1095.8 |
| 2004 | 15.6 | 15.8 | 61.4 | 155 | 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 | 141 | 139.9 | 218.7 | 231.4 | 152.7 | 9.1 | 15 | 0 | 1103.9 |
| 2006 | 2.6 | 44.2 | 56.3 | 79.7 | 22 | 84.3 | 276.4 | 262.6 | 148.1 | 38 | 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 | 1018.7 |
| 2008 | 0 | 0 | 34.2 | 0.6 | 62.4 | 140.2 | 253.5 | 252.3 | 191.4 | 7.2 | 65 | 0 | 1006.6 |
| 2009 | 60.2 | 0 | 10 | 119 | 47.7 | 63.5 | 235.3 | 322.4 | 71.3 | 32.8 | 4 | 17 | 982.7 |
| 2010 | 0 | 63.8 | 126 | 170 | 95.2 | 164.8 | 334.4 | 169.8 | 154.1 | 5.2 | 15 | 7.8 | 1306.1 |
| 2011 | 0 | 2.5 | 45.2 | 20.7 | 129 | 60 | 204.3 | 304 | 194.5 | 0 | 4.7 | 0 | 964.6 |
| 2012 | 0 | 0 | 29 | 61 | 26.1 | 80.6 | 228 | 243.9 | 122.9 | 0 | 0 | 0 | 791.5 |
| 2013 | 0 | 0 | 77 | 89.1 | 73.4 | 111.5 | 179.6 | 242.4 | 142.4 | 20.6 | 0 | 0.2 | 936.2 |
| 2014 | 0 | 39.4 | 76 | 13.9 | 0 | 52.6 | 176.8 | 281.6 | 115.3 | 52.3 | 0 | 0 | 807.9 |
| 2015 | 0 | 0 | 13.7 | 2.3 | 96.5 | 158 | 187.8 | 247.5 | 70 | 0 | 15 | 0 | 790.3 |
| Ave. | 12.95 | 22.50 | 53.72 | 70.18 | 62.83 | 117.79 | 233.34 | 235.97 | 109.56 | 19.09 | 6.68 | 5.90 | 950.28 |

Station name: Alemtena

Element: Monthly total rainfall (mm)

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual rain fall (mm/year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | 0 | 121.29 | 47.46 | 89.65 | 15.82 | 58.01 | 179.3 | 247.85 | 142.38 | 42.19 | 0 | 5.27 | 949.22 |
| 1991 | 0 | 5.27 | 63.28 | 26.37 | 36.91 | 47.46 | 216.21 | 200.39 | 116.02 | 0 | 0 | 0 | 711.91 |
| 1992 | 36.91 | 42.19 | 0 | 79.1 | 31.64 | 105.47 | 152.93 | 210.94 | 47.46 | 42.19 | 5.27 | 5.27 | 759.38 |
| 1993 | 15.82 | 15.82 | 10.55 | 137.11 | 89.65 | 142.38 | 205.66 | 232.03 | 131.84 | 36.91 | 0 | 10.55 | 1028.32 |
| 1994 | 0 | 0 | 26.37 | 73.83 | 42.19 | 116.02 | 226.76 | 216.21 | 137.11 | 5.27 | 5.27 | 0 | 849.02 |
| 1995 | 0 | 36.91 | 21.09 | 84.38 | 15.82 | 73.83 | 152.93 | 247.85 | 110.74 | 5.27 | 0 | 5.27 | 754.1 |
| 1996 | 15.82 | 0 | 105.47 | 89.65 | 116.02 | 189.84 | 253.12 | 232.03 | 174.02 | 5.27 | 5.27 | 0 | 1186.52 |
| 1997 | 10.55 | 0 | 42.19 | 105.47 | 58.01 | 110.74 | 152.93 | 174.02 | 58.01 | 189.84 | 26.37 | 0 | 928.12 |
| 1998 | 21.09 | 42.19 | 15.82 | 42.19 | 58.01 | 94.92 | 284.77 | 210.94 | 147.66 | 152.93 | 0 | 0 | 1070.51 |
| 1999 | 10.55 | 0 | 36.91 | 15.82 | 42.19 | 110.74 | 189.84 | 174.02 | 79.1 | 121.29 | 0 | 0 | 780.47 |
| 2000 | 0 | 0 | 0 | 36.91 | 36.91 | 52.73 | 121.29 | 152.93 | 58.01 | 31.64 | 0 | 5.27 | 495.7 |
| 2001 | 0 | 15.82 | 116.02 | 15.82 | 52.73 | 26.37 | 137.11 | 73.83 | 52.73 | 15.82 | 0 | 0 | 506.25 |
| 2002 | 0 | 0 | 52.73 | 47.46 | 10.55 | 42.19 | 63.28 | 100.2 | 15.82 | 0 | 0 | 10.55 | 342.77 |
| 2003 | 10.55 | 10.55 | 36.91 | 21.09 | 0 | 31.64 | 105.47 | 131.84 | 52.73 | 0 | 5.27 | 31.64 | 437.7 |
| 2004 | 0 | 0 | 58.01 | 36.91 | 0 | 36.91 | 105.47 | 94.92 | 42.19 | 26.37 | 0 | 10.55 | 411.33 |
| 2005 | 21.09 | 0 | 58.01 | 79.1 | 110.74 | 10.55 | 163.48 | 94.92 | 47.46 | 21.09 | 0 | 0 | 606.45 |
| 2006 | 10.55 | 73.83 | 73.83 | 84.38 | 36.91 | 84.38 | 258.4 | 158.2 | 84.38 | 36.91 | 5.27 | 21.09 | 928.12 |
| 2007 | 5.27 | 42.19 | 63.28 | 52.73 | 94.92 | 73.83 | 184.57 | 200.39 | 105.47 | 15.82 | 21.09 | 0 | 859.57 |
| 2008 | 0 | 0 | 0 | 26.37 | 47.46 | 68.55 | 221.48 | 232.03 | 110.74 | 26.37 | 58.01 | 0 | 791.02 |
| 2009 | 36.91 | 0 | 15.82 | 31.64 | 21.09 | 36.91 | 158.2 | 158.2 | 84.38 | 79.1 | 0 | 36.91 | 659.18 |
| 2010 | 0 | 73.83 | 63.28 | 105.47 | 79.1 | 126.56 | 221.48 | 174.02 | 137.11 | 0 | 5.27 | 10.55 | 996.68 |
| 2011 | 0 | 5.27 | 42.19 | 15.82 | 79.1 | 84.38 | 94.92 | 105.47 | 47.46 | 0 | 15.82 | 0 | 490.43 |
| 2012 | 0 | 0 | 5.27 | 89.65 | 15.82 | 58.01 | 247.85 | 237.3 | 131.84 | 0 | 0 | 0 | 785.74 |
| 2013 | 10.55 | 0 | 73.83 | 131.84 | 73.83 | 116.02 | 232.03 | 168.75 | 105.47 | 58.01 | 31.64 | 0 | 1001.95 |
| 2014 | 0 | 15.82 | 36.91 | 47.46 | 79.1 | 73.83 | 174.02 | 179.3 | 137.11 | 79.1 | 10.55 | 0 | 833.2 |
| 2015 | 0 | 0 | 0 | 0 | 100.2 | 89.65 | 152.93 | 137.11 | 42.19 | 10.55 | 21.09 | 0 | 553.71 |
| Ave | 7.91 | 19.268 | 40.97 | 60.239 | 51.72 | 79.305 | 179.09 | 174.83 | 92.286 | 38.536 | 8.315 | 5.882 | 758.36 |

Station name: Awash 7 kilo

Element: Monthly total rainfall (mm)

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual rain fall (mm/year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | 0 | 137.11 | 68.55 | 79.1 | 10.55 | 10.55 | 131.84 | 205.66 | 105.47 | 31.64 | 0 | 5.27 | 785.7 |
| 1991 | 5.27 | 26.37 | 79.1 | 84.38 | 58.01 | 21.09 | 168.75 | 179.3 | 79.1 | 0 | 0 | 26.37 | 727.7 |
| 1992 | 26.37 | 58.01 | 21.09 | 73.83 | 36.91 | 36.91 | 137.11 | 232.03 | 63.28 | 10.55 | 5.27 | 5.27 | 706.6 |
| 1993 | 21.09 | 21.09 | 21.09 | 168.75 | 84.38 | 68.55 | 168.75 | 195.12 | 84.38 | 47.46 | 0 | 15.82 | 896.5 |
| 1994 | 0 | 0 | 21.09 | 84.38 | 73.83 | 31.64 | 168.75 | 184.57 | 126.56 | 5.27 | 36.91 | 0 | 733.0 |
| 1995 | 0 | 58.01 | 47.46 | 110.74 | 21.09 | 5.27 | 152.93 | 200.39 | 68.55 | 5.27 | 0 | 36.91 | 706.6 |
| 1996 | 21.09 | 5.27 | 168.75 | 110.74 | 79.1 | 79.1 | 200.39 | 232.03 | 94.92 | 5.27 | 31.64 | 0 | 1028.3 |
| 1997 | 15.82 | 0 | 63.28 | 89.65 | 73.83 | 116.02 | 142.38 | 131.84 | 21.09 | 237.3 | 52.73 | 0 | 944.0 |
| 1998 | 26.37 | 47.46 | 42.19 | 42.19 | 68.55 | 47.46 | 205.66 | 195.12 | 121.29 | 116.02 | 0 | 0 | 912.3 |
| 1999 | 5.27 | 0 | 100.2 | 21.09 | 10.55 | 58.01 | 142.38 | 168.75 | 68.55 | 84.38 | 0 | 0 | 659.2 |
| 2000 | 0 | 0 | 0 | 31.64 | 15.82 | 10.55 | 73.83 | 105.47 | 31.64 | 26.37 | 0 | 5.27 | 300.6 |
| 2001 | 0 | 0 | 100.2 | 10.55 | 31.64 | 26.37 | 94.92 | 79.1 | 58.01 | 15.82 | 5.27 | 0 | 421.9 |
| 2002 | 5.27 | 0 | 73.83 | 42.19 | 15.82 | 15.82 | 63.28 | 73.83 | 5.27 | 0 | 0 | 0 | 295.3 |
| 2003 | 5.27 | 21.09 | 31.64 | 47.46 | 5.27 | 5.27 | 36.91 | 121.29 | 42.19 | 0 | 5.27 | 36.91 | 358.6 |
| 2004 | 0 | 0 | 58.01 | 26.37 | 0 | 15.82 | 68.55 | 52.73 | 52.73 | 5.27 | 5.27 | 21.09 | 305.9 |
| 2005 | 5.27 | 0 | 52.73 | 126.56 | 89.65 | 0 | 58.01 | 31.64 | 10.55 | 10.55 | 15.82 | 0 | 400.8 |
| 2006 | 5.27 | 63.28 | 94.92 | 94.92 | 31.64 | 26.37 | 152.93 | 121.29 | 36.91 | 52.73 | 5.27 | 31.64 | 717.2 |
| 2007 | 5.27 | 42.19 | 52.73 | 100.2 | 68.55 | 10.55 | 147.66 | 137.11 | 52.73 | 21.09 | 10.55 | 0 | 648.6 |
| 2008 | 15.82 | 0 | 0 | 42.19 | 15.82 | 21.09 | 163.48 | 184.57 | 63.28 | 36.91 | 52.73 | 0 | 595.9 |
| 2009 | 21.09 | 0 | 36.91 | 42.19 | 0 | 21.09 | 142.38 | 131.84 | 73.83 | 68.55 | 5.27 | 36.91 | 580.1 |
| 2010 | 0 | 105.47 | 94.92 | 100.2 | 36.91 | 58.01 | 179.3 | 210.94 | 147.66 | 0 | 10.55 | 0 | 944.0 |
| 2011 | 0 | 0 | 36.91 | 58.01 | 52.73 | 15.82 | 63.28 | 63.28 | 21.09 | 5.27 | 10.55 | 0 | 327.0 |
| 2012 | 0 | 0 | 0 | 58.01 | 15.82 | 21.09 | 147.66 | 226.76 | 94.92 | 5.27 | 0 | 0 | 569.5 |
| 2013 | 10.55 | 0 | 36.91 | 110.74 | 26.37 | 42.19 | 226.76 | 195.12 | 68.55 | 31.64 | 58.01 | 0 | 806.8 |
| 2014 | 0 | 10.55 | 36.91 | 58.01 | 68.55 | 10.55 | 137.11 | 121.29 | 100.2 | 58.01 | 0 | 0 | 601.2 |
| 2015 | 5.27 | 0 | 21.09 | 5.27 | 68.55 | 94.92 | 42.19 | 126.56 | 15.82 | 5.27 | 42.19 | 15.82 | 443.0 |
| Ave | 7.71 | 22.92 | 52.33 | 69.98 | 40.77 | 33.47 | 131.43 | 150.29 | 65.71 | 34.07 | 13.59 | 9.13 | 631.4 |

Station name: Bishoftu

Element: Monthly total rainfall (mm)

| year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | annual rainfall (mm/year) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | 29.6 | 25.5 | 16.5 | 236.5 | 91.4 | 125.8 | 309.2 | 85.3 | 88.3 | 1.05 | 0.34 | 0.09 | 1009.58 |
| 1991 | 0 | 99.1 | 31.8 | 54.8 | 111.8 | 51 | 233.6 | 207.8 | 157.3 | 3 | 2.5 | 0 | 952.7 |
| 1992 | 31 | 2.5 | 0.77 | 4.53 | 3.35 | 154.2 | 213.2 | 201.3 | | 6.7 | 28.5 | 2.6 | 648.65 |
| 1993 | 0 | 0.31 | 1.58 | 37 | 67.4 | 118.3 | 135 | 227.2 | 157.3 | 1.11 | 1.57 | 32.8 | 779.57 |
| 1994 | 3.2 | 0 | 33.6 | 163.5 | 54.8 | 75.2 | 338.8 | 282.3 | 61.2 | 0 | 0 | 0 | 1012.6 |
| 1995 | 0 | 57.4 | 163.4 | 94.7 | 12.9 | 46.1 | 156.1 | 310.2 | 135.5 | 12.1 | 0 | 3.5 | 991.9 |
| 1996 | 92.1 | 0.24 | 180 | 91.5 | 168.8 | 86.1 | 200.7 | 150.6 | 73.6 | 42.5 | 42.5 | 0.08 | 1128.72 |
| 1997 | 29.8 | 0 | 38.2 | 23.2 | 44.7 | 145.7 | 255.3 | 131.1 | 88.6 | 117.8 | 51.8 | 0.21 | 926.41 |
| 1998 | 41.6 | 40.6 | 0.78 | 33.5 | 47 | 48.1 | 154.4 | 336.4 | 197.2 | 179 | 0 | 0.02 | 1078.6 |
| 1999 | 11.1 | 0.02 | 104.1 | 1.04 | 2.61 | 39.1 | 246.5 | 232.9 | 52 | 167.4 | 3.6 | 0.1 | 860.47 |
| 2000 | 0.01 | 0 | 15.5 | 18.4 | 47.9 | 58.4 | 215 | 249.5 | 110.9 | 96.3 | 30.5 | 6.1 | 848.51 |
| 2001 | 0.34 | 13.6 | 128 | 20 | 65.9 | 76.5 | 204.1 | 214.2 | 113.2 | 0.6 | 10 | 0 | 846.44 |
| 2002 | 0.69 | 0 | 48.9 | 61.4 | 10 | 18.7 | 166.2 | 231.8 | 36 | 0.18 | 0.09 | 97.7 | 671.66 |
| 2003 | 32.5 | 32.1 | 119.6 | 152.6 | 0.39 | 61.2 | 396.2 | 321.7 | 7.5 | 0.05 | 0.31 | 28.3 | 1152.45 |
| 2004 | 47.3 | 81.4 | 146.9 | 235 | 0.53 | 91.8 | 287 | 295 | 94 | 52 | 0 | 18.2 | 1349.13 |
| 2005 | 30 | 24 | 93 | 72.1 | 138.4 | 97.5 | 69.4 | 123.1 | 50.6 | 0.4 | 2.3 | 0 | 700.8 |
| 2006 | 9.4 | 32.2 | 42.9 | 75.9 | 17.9 | 11.8 | 142 | 144.6 | 53.8 | 6.1 | 0 | 25.6 | 562.2 |
| 2007 | 30.2 | 28.7 | 49.7 | 86.8 | 29.5 | 116 | 210.4 | 273.1 | 94.3 | 1.02 | 0.46 | 0 | 920.18 |
| 2008 | 18.3 | 0.07 | 4 | 59.6 | 53.1 | 20.6 | 376.3 | 271.9 | 59.3 | 59.8 | 49.2 | 0.08 | 972.25 |
| 2009 | 95.1 | 0.17 | 22 | 19 | 15.1 | 16.2 | 133.4 | 123 | 45.5 | 116.8 | 0 | 61.3 | 647.57 |
| 2010 | 0.03 | 87 | 107.7 | 18.4 | 74.7 | 67.6 | 191.1 | 175.7 | 156 | 0.85 | 50.2 | 0.51 | 929.79 |
| 2011 | 0.14 | 0.34 | 56 | 6.3 | 67.1 | 28 | 178.4 | 175.3 | 140.4 | 0.34 | 13.5 | 0.03 | 665.85 |
| 2012 | 0.01 | 0 | 20 | 31 | 18.7 | 73.4 | 326.2 | 253 | 88.7 | 7.8 | 0 | 3.5 | 822.31 |
| 2013 | 11 | 1.7 | 72.2 | 38.6 | 46.5 | 44.6 | 437.9 | 139.7 | 118.5 | 60.6 | 16.2 | 0.01 | 987.51 |
| 2014 | 0 | 2.6 | 101.4 | 2.2 | 34.5 | 7.2 | 169.9 | 207.4 | 152.4 | 93.6 | 26.6 | 0.56 | 798.36 |
| 2015 | 0 | 0 | 8.4 | 6.9 | 139.2 | 66.8 | 157.3 | 140.7 | 44.4 | 0.2 | 4 | 8.6 | 576.5 |
| Ave. | 21.41 | 19.15 | 72.51 | 54.67 | 49.31 | 58.16 | 222.56 | 214.33 | 91.07 | 48.35 | 14.35 | 12.11 | 877.98 |

Station name: Hombole

Element: Monthly total rainfall (mm)

| year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | annual rainfall (mm/year) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | 8.9 | 0.52 | 5.4 | 151.9 | 114 | 75.8 | 330.9 | 70.7 | 66.3 | 0.81 | 0.37 | 0.09 | 825.69 |
| 1991 | 0 | 32.1 | 146.8 | 20.4 | 124.7 | 40.1 | 213.6 | 168.9 | 155.1 | 1.04 | 0.25 | 0.17 | 903.16 |
| 1991 | 0 | 14.6 | 55 | 190.3 | 93.6 | 139 | 100.4 | 149.4 | 23.5 | 3.5 | 4.1 | 0 | 773.4 |
| 1991 | 0 | 0.28 | 1.5 | 2.9 | 1.09 | 87.4 | 257.6 | 184.1 | 219.9 | 1.03 | 1.5 | 0.63 | 757.93 |
| 1991 | 0.12 | 0.27 | 95.9 | 124 | 108.3 | 91.2 | 388.8 | 218.8 | 106.7 | 0.93 | 0.24 | 0.26 | 1135.52 |
| 1995 | 0 | 1.52 | 1.15 | 3.24 | 1.05 | 113.0 | 138.0 | 224.9 | 111.2 | 0.44 | 0.17 | 0.32 | 594.99 |
| 1996 | 0.85 | 0.2 | 3.65 | 3.16 | 4.05 | 95.1 | 213.50 | 257 | 198 | 0.74 | 0.49 | 0.08 | 776.82 |
| 1997 | 0.62 | 0 | 1.28 | 3.86 | 2.79 | 106.50 | 206.60 | 210.50 | 162.3 | 22 | 3 | 0.02 | 719.47 |
| 1998 | 17.6 | 26.3 | 52 | 43.8 | 38 | 66.4 | 224.6 | 284.3 | 57 | 62.1 | 0.21 | 0.01 | 872.32 |
| 1999 | 3.4 | 0.01 | 8.6 | 4.2 | 0.8 | 93.9 | 200.9 | 188.8 | 42.2 | 116.5 | 0.06 | 0.1 | 659.47 |
| 2000 | 0.01 | 0 | 0.14 | 1.73 | 1.19 | 83.2 | 194.3 | 158.4 | 115.8 | 16.9 | 0.13 | 0.39 | 572.19 |
| 2001 | 0 | 16.4 | 116.5 | 63.8 | 123.8 | 158.7 | 187.7 | 102.8 | 26.6 | 0.73 | 0.18 | 0.07 | 797.28 |
| 2002 | 0.54 | 0.03 | 1.85 | 32.3 | 38.2 | 68.5 | 220.5 | 147.6 | 61.3 | 0.16 | 0.08 | 15.6 | 586.66 |
| 2003 | 15.2 | 14.8 | 58.3 | 150.9 | 13.7 | 107.5 | 326.1 | 160.9 | 28.9 | 0.03 | 0.32 | 18.3 | 894.95 |
| 2004 | 0 | 28.9 | 144.9 | 0 | 101.2 | 119.9 | 147.6 | 60.2 | 49.2 | 0.94 | 0.25 | 0.68 | 653.77 |
| 2005 | 0.73 | 0.16 | 1.96 | 65.2 | 71.825 | 81 | 188.1 | 196.4 | 45.3 | 0.79 | 0.11 | 0 | 651.6 |
| 2006 | 0.33 | 45.4 | 2.77 | 112.3 | 58.9 | 87.4 | 215.4 | 120 | 89.5 | 1.98 | 0.44 | 19.9 | 754.32 |
| 2007 | 40.2 | 3.8 | 43.4 | 26.7 | 113.5 | 180.4 | 135 | 159.2 | 106.6 | 15.5 | 0 | 0 | 824.3 |
| 2008 | 0.19 | 0.05 | 0.05 | 1.73 | 56.8 | 69.4 | 232.4 | 202.6 | 91.2 | 8.7 | 133.2 | 0.07 | 796.39 |
| 2009 | 98.9 | 0.12 | 8.2 | 18.3 | 34.8 | 103.575 | 180.675 | 157.7 | 114.55 | 93.3 | 0 | 8.6 | 818.72 |
| 2010 | 0.02 | 73.4 | 96.4 | 132.4 | 74.7 | 95.7 | 165.4 | 156.2 | 137.9 | 0.6 | 0.38 | 0.38 | 933.48 |
| 2011 | 3.6 | 0.23 | 46.7 | 45 | 41.2 | 68.8 | 189.9 | 174.4 | 103.7 | 0 | 14.1 | 0.02 | 687.65 |
| 2012 | 0.01 | 0 | 0.39 | 61.1 | 29.7 | 55.8 | 333.4 | 150.2 | 142.8 | 4.9 | 0.3 | 0.26 | 778.86 |
| 2013 | 0.47 | 0.05 | 168.3 | 17.3 | 55.9 | 115.7 | 201.6 | 154.4 | 127.2 | 27.5 | 1.29 | 0 | 869.71 |
| 2014 | 0.05 | 1.2 | 30.4 | 22.1 | 53.1 | 146.3 | 185.6 | 106.7 | 131.2 | 2.74 | 0.57 | 0.32 | 680.28 |
| 2015 | 0.1 | 0.08 | 39.3 | 23.5 | 139.6 | 170.1 | 149.8 | 219.2 | 79.5 | 0.71 | 0.82 | 0.29 | 823 |
| **Ave.** | 8.71 | 10.13 | 39.34 | 39.65 | 50.23 | 104.14 | 201.77 | 171.07 | 96.28 | 17.96 | 7.43 | 3.11 | 749.8 |

Station name: Jeju

Element: Monthly total rainfall (mm)

| YEAR | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC | ANN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | 10.55 | 15.82 | 21.09 | 189.84 | 100.20 | 21.09 | 142.38 | 121.29 | 84.38 | 10.55 | 15.82 | 5.27 | 738.28 |
| 1991 | 0.00 | 26.37 | 52.73 | 21.09 | 105.47 | 42.19 | 158.20 | 142.38 | 195.12 | 42.19 | 10.55 | 0.00 | 796.29 |
| 1992 | 0.00 | 26.37 | 36.91 | 137.11 | 63.28 | 73.83 | 73.83 | 152.93 | 36.91 | 21.09 | 42.19 | 0.00 | 664.45 |
| 1993 | 0.00 | 5.27 | 47.46 | 68.55 | 31.64 | 84.38 | 68.55 | 210.94 | 163.48 | 47.46 | 47.46 | 42.19 | 817.38 |
| 1994 | 0.00 | 5.27 | 26.37 | 189.84 | 110.74 | 89.65 | 163.48 | 216.21 | 110.74 | 10.55 | 5.27 | 15.82 | 943.95 |
| 1995 | 0.00 | 26.37 | 26.37 | 73.83 | 21.09 | 21.09 | 126.56 | 200.39 | 63.28 | 0.00 | 0.00 | 5.27 | 564.26 |
| 1996 | 10.55 | 0.00 | 100.20 | 79.10 | 84.38 | 137.11 | 189.84 | 221.48 | 105.47 | 5.27 | 21.09 | 0.00 | 954.49 |
| 1997 | 10.55 | 0.00 | 26.37 | 100.20 | 73.83 | 89.65 | 147.66 | 126.56 | 21.09 | 195.12 | 42.19 | 0.00 | 833.20 |
| 1998 | 21.09 | 21.09 | 10.55 | 26.37 | 52.73 | 100.20 | 247.85 | 195.12 | 126.56 | 137.11 | 5.27 | 0.00 | 943.95 |
| 1999 | 10.55 | 0.00 | 68.55 | 15.82 | 21.09 | 73.83 | 174.02 | 163.48 | 58.01 | 110.74 | 0.00 | 0.00 | 696.09 |
| 2000 | 0.00 | 0.00 | 0.00 | 36.91 | 21.09 | 26.37 | 94.92 | 126.56 | 31.64 | 36.91 | 0.00 | 0.00 | 374.41 |
| 2001 | 0.00 | 5.27 | 94.92 | 10.55 | 47.46 | 36.91 | 147.66 | 84.38 | 68.55 | 21.09 | 5.27 | 0.00 | 522.07 |
| 2002 | 0.00 | 0.00 | 47.46 | 42.19 | 10.55 | 36.91 | 73.83 | 68.55 | 10.55 | 0.00 | 0.00 | 10.55 | 300.59 |
| 2003 | 5.27 | 26.37 | 36.91 | 36.91 | 0.00 | 21.09 | 73.83 | 116.02 | 31.64 | 0.00 | 10.55 | 36.91 | 395.51 |
| 2004 | 0.00 | 0.00 | 42.19 | 15.82 | 0.00 | 10.55 | 100.20 | 79.10 | 36.91 | 15.82 | 15.82 | 21.09 | 337.50 |
| 2005 | 15.82 | 0.00 | 31.64 | 94.92 | 73.83 | 5.27 | 105.47 | 63.28 | 15.82 | 15.82 | 0.00 | 0.00 | 421.88 |
| 2006 | 5.27 | 52.73 | 58.01 | 73.83 | 31.64 | 42.19 | 221.48 | 147.66 | 47.46 | 31.64 | 10.55 | 31.64 | 754.10 |
| 2007 | 10.55 | 21.09 | 52.73 | 47.46 | 58.01 | 26.37 | 174.02 | 137.11 | 68.55 | 15.82 | 26.37 | 0.00 | 638.09 |
| 2008 | 5.27 | 0.00 | 0.00 | 26.37 | 21.09 | 15.82 | 184.57 | 168.75 | 73.83 | 42.19 | 68.55 | 0.00 | 606.45 |
| 2009 | 36.91 | 0.00 | 21.09 | 36.91 | 0.00 | 26.37 | 163.48 | 137.11 | 73.83 | 84.38 | 0.00 | 36.91 | 616.99 |
| 2010 | 0.00 | 68.55 | 73.83 | 79.10 | 26.37 | 79.10 | 189.84 | 168.75 | 94.92 | 0.00 | 0.00 | 5.27 | 785.74 |
| 2011 | 0.00 | 0.00 | 21.09 | 26.37 | 47.46 | 52.73 | 73.83 | 68.55 | 21.09 | 5.27 | 15.82 | 0.00 | 332.23 |
| 2012 | 0.00 | 0.00 | 0.00 | 52.73 | 15.82 | 26.37 | 189.84 | 200.39 | 68.55 | 5.27 | 0.00 | 0.00 | 558.98 |
| 2013 | 5.27 | 0.00 | 26.37 | 89.65 | 42.19 | 52.73 | 210.94 | 179.30 | 58.01 | 26.37 | 47.46 | 0.00 | 738.28 |
| 2014 | 0.00 | 5.27 | 36.91 | 31.64 | 36.91 | 26.37 | 121.29 | 147.66 | 79.10 | 58.01 | 10.55 | 0.00 | 553.71 |
| 2015 | 0.00 | 0.00 | 5.27 | 0.00 | 63.28 | 84.38 | 63.28 | 126.56 | 26.37 | 21.09 | 42.19 | 5.27 | 437.70 |
| | 5.68 | 11.76 | 37.12 | 61.66 | 44.62 | 50.10 | 141.57 | 145.02 | 68.15 | 36.91 | 17.04 | 8.32 | 627.95 |

Station name: Koka Dam

Element: Monthly total rainfall (mm)

| year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | annual rainfall (mm/year) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | 0.8 | 0 | 15.3 | 95.4 | 153.2 | 92.3 | 350.5 | 77.9 | 102.8 | 0 | 6.5 | 0.22 | 894.92 |
| 1991 | 0 | 1.3 | 1.89 | 6.4 | 147.5 | 50.9 | 268 | 318.4 | 207.1 | 6.4 | 0 | 0.12 | 1008.01 |
| 1992 | 0.07 | 1.1 | 1.39 |  | 23.1 | 115.8 | 142.7 | 183 | 57 | 57 | 9.4 | 0.09 | 590.65 |
| 1993 | 0 | 0.32 | 1.65 | 78.5 | 40.2 | 125.5 | 168.4 | 215.2 | 5.08 | 1.77 | 1.82 | 1.35 | 639.79 |
| 1994 | 0.22 | 0 | 63.6 | 157.6 | 0 | 171.1 | 294.5 | 288.5 | 73.3 | 0 | 0 | 8.2 | 1057.02 |
| 1995 |  | 29.2 | 1.25 | 2.85 | 1.27 | 9.2 | 225.4 | 88.2 | 9.5 | 0.56 | 0.28 | 0.45 | 368.16 |
| 1996 | 0.57 | 0.15 | 3.39 | 48.1 | 10.2 | 39 | 116.2 | 260.6 | 49.3 | 0.64 | 0.67 | 0.08 | 528.9 |
| 1997 | 25.7 | 0 | 41.5 | 39.3 | 10.7 | 145.4 | 210.9 | 259.2 | 51.5 | 66.6 | 24.7 | 0.02 | 875.52 |
| 1998 | 31 | 37.6 | 17.9 | 27.2 | 130.3 | 65.8 | 245.4 | 399.1 | 71.5 | 167.9 | 0.41 | 0.02 | 1194.13 |
| 1999 | 15.6 | 1.05 | 3.5 | 1.08 | 10 | 110.2 | 219.3 | 211.4 | 67 | 177.6 | 0.11 | 0.16 | 817 |
| 2000 | 0.01 | 0 | 1.6 | 57.9 | 122.7 | 90.6 | 337 | 264.9 | 212.1 | 0 | 67.8 | 10.1 | 1164.71 |
| 2001 | 0.17 | 141.2 | 40.9 | 154.7 | 178.3 | 501 | 436 | 119 | 13.3 | 5.9 | 21.7 |  | 1612.17 |
| 2002 | 19.8 | 32.3 | 13.1 | 58.3 | 8.9 | 13 | 217 | 175.6 | 63.1 | 0.6 | 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 | 3.8 | 55.7 | 1007.5 |
| 2004 | 6.3 | 0.2 | 68.8 | 84.5 | 0 | 103.4 | 153.9 | 272.1 | 47.5 | 35.7 | 4.2 | 0 | 776.6 |
| 2005 | 47.9 | 0.17 | 34.8 | 30.4 | 10.6 | 0 | 92.8 | 141.7 | 61.2 | 0 | 5.8 | 0 | 425.37 |
| 2006 | 0.3 | 11 | 38.1 | 68.3 | 62 | 131.3 | 234.5 | 171.4 | 86.6 | 4.5 | 0 | 25 | 833 |
| 2007 | 44.7 | 8.5 | 83.2 | 37.2 | 94.4 | 69.1 | 151.7 | 179.6 | 140.2 | 23 | 1.3 | 0 | 832.9 |
| 2008 | 5.1 | 0.03 | 0 | 26.5 | 100.3 | 94.2 | 302.3 | 292 | 165.7 | 59 | 77 | 0 | 1122.13 |
| 2009 | 27.8 | 0.12 | 1.5 | 32.8 | 27.5 | 65.7 | 191.7 | 156.9 | 49.6 | 87.4 | 1.5 | 47.1 | 689.62 |
| 2010 | 0.02 | 69.7 | 90.1 | 80.4 | 80.2 | 87.5 | 236.8 | 272.3 | 201.7 | 0 | 1.4 | 0.21 | 1120.33 |
| 2011 | 0.09 | 0.09 | 72.1 | 18.2 | 51.4 | 100.3 | 256.8 | 198.7 | 214.7 | 0 | 38.8 | 0.02 | 951.2 |
| 2012 | 0.01 | 0.01 | 0 | 33.3 | 42.2 | 38.4 | 501 | 300.2 | 103.8 | 0 | 0 | 0.22 | 1019.14 |
| 2013 | 0.41 | 0.41 | 36.7 | 12.6 | 54.9 | 55.2 | 297.9 | 172.7 | 115.6 | 17.5 | 1.6 | 0.02 | 765.54 |
| 2014 | 0.03 | 3.5 | 87.3 | 0.5 | 54.9 | 5.3 | 260.5 | 195.9 | 2.81 | 2.35 | 0.57 | 0.36 | 614.02 |
| 2015 | 0.16 | 0 | 0 | 0 | 205.6 | 10.7 | 103.1 | 162.2 | 86.1 | 0 | 11 | 3.4 | 582.26 |
| **Ave.** | 13.6 | 19.1 | 35.2 | 40.1 | 59.9 | 88.4 | 241.2 | 217.5 | 87.9 | 30.9 | 12.5 | 7.8 | 854.2 |

Station name: Mojo

Element: Monthly total rainfall (mm)

| year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | annual rainfall (mm/year) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | 12.1 | 32.7 | 18.2 | 258.7 | 83.6 | 117.7 | 531.6 | 112.9 | 76.8 | 0 | 31.5 | 0.22 | 1276.02 |
| 1991 | 0 | 32.9 | 57.4 | 17.8 | 155.2 | 44.1 | 319.1 | 211.6 | 198.3 | 0 | 0 | 0.12 | 1036.52 |
| 1992 | 0.07 | 1.1 | 1.39 | 4.71 | 2.11 | 134.3 | 463.8 | 261 | 238.6 | 0.89 | 1.81 | 17.1 | 1126.88 |
| 1993 | 0 | 0.32 | 18.4 | 0 | 4.2 | 90.9 | 541.5 | 362 | 67.4 | 87.4 | 0 | 0 | 1172.12 |
| 1994 | 0.22 | 0.44 | 12 | 10.1 | 33.2 | 128 | 285.9 | 230.8 | 114.1 | 12.6 | 25.4 | 0 | 852.76 |
| 1995 | 0 | 45.6 | 37 | 73.4 | 31.4 | 32.7 | 185.8 | 143.7 | 70.9 | 2.5 | 0 | 0.45 | 623.45 |
| 1996 | | | 97.5 | 72.2 | 127 | 214.9 | 221.3 | 220.9 | 79.5 | 0 | 3 | 0.08 | 1036.38 |
| 1997 | 30.4 | 0 | 37.6 | 16.8 | 16.1 | 130.6 | 216.1 | 158.6 | 77.8 | 55.3 | 21 | 0.24 | 760.54 |
| 1998 | 32.3 | 7.6 | 50.7 | 46 | 46 | 112.1 | 161.3 | 274.8 | 149 | 154.1 | 0 | 0.02 | 1033.92 |
| 1999 | 0.53 | 0 | 18.4 | 0 | 4.2 | 90.9 | 541.5 | 362 | 67.4 | 87.4 | 0 | 0.16 | 1172.49 |
| 2000 | 0.01 | 0 | 12 | 10.1 | 33.2 | 128 | 285.9 | 230.8 | 114.1 | 12.6 | 25.4 | 0.29 | 852.4 |
| 2001 | 0.17 | 28.5 | 79.4 | 22.5 | 111 | 131.5 | 184.7 | 175.6 | 54.9 | 1.15 | 0.24 | 0.09 | 789.75 |
| 2002 | 0.38 | 0 | 8.9 | 13.7 | 6.5 | 62.4 | 193.5 | 169.2 | 95.2 | 0.33 | 0.19 | 14.9 | 565.2 |
| 2003 | 40.6 | 55.9 | 74.9 | 84.3 | 23.2 | 129 | 393.2 | 148.6 | 96.1 | 0.07 | 0.62 | 14.3 | 1060.79 |
| 2004 | 15.5 | 0 | 99.3 | 114.6 | 9.8 | 1.26 | 393.8 | 201.2 | 116.9 | 99.1 | 32.4 | | 1083.86 |
| 2005 | 0.58 | 19.1 | 160.5 | 149.6 | 195.4 | 200.5 | 320.6 | 308.7 | 143.5 | 14.6 | 10.9 | 0 | 1523.98 |
| 2006 | 1.6 | 38.5 | 90.5 | 61.6 | 19.2 | 109 | 344.4 | 362.7 | 131.8 | 24.9 | 2.6 | 12.3 | 1199.1 |
| 2007 | 54.1 | 23.7 | 83.8 | 49.6 | 111 | 129.7 | 222.8 | 227.9 | 91.4 | 7.6 | 0 | 0 | 1001.6 |
| 2008 | 1.5 | 0 | 0 | 61.9 | 76.7 | 137 | 431 | 404.4 | 188.7 | 89.4 | 50.8 | 0.05 | 1441.45 |
| 2009 | 39.2 | 6 | 26.3 | 62.9 | 12.7 | 95.3 | 213.8 | 330.3 | 66.2 | 214.5 | 6.5 | 34.6 | 1108.3 |
| 2010 | 0.02 | 85.2 | 7.7 | 151.9 | 119.5 | 73.4 | 254.2 | 170.4 | 246.7 | 0.59 | 1.4 | 0.21 | 1111.22 |
| 2011 | 0.09 | 0.12 | 47.4 | 54.9 | 122 | 54.6 | 193 | 175.6 | 170.4 | 0.41 | 0.81 | 0.02 | 819.35 |
| 2012 | 0.01 | 0.01 | 37.8 | 43 | 0.67 | 1.39 | 524.4 | 419.7 | 147 | 0.33 | 0.05 | 0.22 | 1174.58 |
| 2013 | 0.41 | 0.04 | 85.8 | 32.9 | 121.3 | 98.5 | 420 | 232.3 | 69.2 | 36.4 | 1.84 | 0.02 | 1098.71 |
| 2014 | 0.03 | 16.8 | 51.9 | 2.9 | 7.6 | 27.4 | 260.7 | 257.2 | 154.3 | 96.3 | 0.57 | 0.36 | 876.06 |
| 2015 | 0.16 | 0.1 | 0.34 | 0.4 | 186.3 | 117.6 | 156.9 | 275.2 | 93.9 | 8.5 | 21 | 0.57 | 860.97 |
| **Ave.** | 10.88 | 16.36 | 52.75 | 53.58 | 65.75 | 98.94 | 291.38 | 249.99 | 115.47 | 43.15 | 8.54 | 3.94 | 1010.7 |

Station name: Methara

Element: Monthly total rainfall (mm)

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual rain fall (mm/year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | 0 | 137.11 | 68.55 | 79.1 | 10.55 | 10.55 | 131.84 | 205.66 | 105.47 | 31.64 | 0 | 5.27 | 785.7 |
| 1991 | 5.27 | 26.37 | 79.1 | 84.38 | 58.01 | 21.09 | 168.75 | 179.3 | 79.1 | 0 | 0 | 26.37 | 727.7 |
| 1992 | 26.37 | 58.01 | 21.09 | 73.83 | 36.91 | 36.91 | 137.11 | 232.03 | 63.28 | 10.55 | 5.27 | 5.27 | 706.6 |
| 1993 | 21.09 | 21.09 | 21.09 | 168.75 | 84.38 | 68.55 | 168.75 | 195.12 | 84.38 | 47.46 | 0 | 15.82 | 896.5 |
| 1994 | 0 | 0 | 21.09 | 84.38 | 73.83 | 31.64 | 168.75 | 184.57 | 126.56 | 5.27 | 36.91 | 0 | 733.0 |
| 1995 | 0 | 58.01 | 47.46 | 110.74 | 21.09 | 5.27 | 152.93 | 200.39 | 68.55 | 5.27 | 0 | 36.91 | 706.6 |
| 1996 | 21.09 | 5.27 | 168.75 | 110.74 | 79.1 | 79.1 | 200.39 | 232.03 | 94.92 | 5.27 | 31.64 | 0 | 1028.3 |
| 1997 | 15.82 | 0 | 63.28 | 89.65 | 73.83 | 116.02 | 142.38 | 131.84 | 21.09 | 237.3 | 52.73 | 0 | 944.0 |
| 1998 | 26.37 | 47.46 | 42.19 | 42.19 | 68.55 | 47.46 | 205.66 | 195.12 | 121.29 | 116.02 | 0 | 0 | 912.3 |
| 1999 | 5.27 | 0 | 100.2 | 21.09 | 10.55 | 58.01 | 142.38 | 168.75 | 68.55 | 84.38 | 0 | 0 | 659.2 |
| 2000 | 0 | 0 | 0 | 31.64 | 15.82 | 10.55 | 73.83 | 105.47 | 31.64 | 26.37 | 0 | 5.27 | 300.6 |
| 2001 | 0 | 0 | 100.2 | 10.55 | 31.64 | 26.37 | 94.92 | 79.1 | 58.01 | 15.82 | 5.27 | 0 | 421.9 |
| 2002 | 5.27 | 0 | 73.83 | 42.19 | 15.82 | 15.82 | 63.28 | 73.83 | 5.27 | 0 | 0 | 0 | 295.3 |
| 2003 | 5.27 | 21.09 | 31.64 | 47.46 | 5.27 | 5.27 | 36.91 | 121.29 | 42.19 | 0 | 5.27 | 36.91 | 358.6 |
| 2004 | 0 | 0 | 58.01 | 26.37 | 0 | 15.82 | 68.55 | 52.73 | 52.73 | 5.27 | 5.27 | 21.09 | 305.9 |
| 2005 | 5.27 | 0 | 52.73 | 126.56 | 89.65 | 0 | 58.01 | 31.64 | 10.55 | 10.55 | 15.82 | 0 | 400.8 |
| 2006 | 5.27 | 63.28 | 94.92 | 94.92 | 31.64 | 26.37 | 152.93 | 121.29 | 36.91 | 52.73 | 5.27 | 31.64 | 717.2 |
| 2007 | 5.27 | 42.19 | 52.73 | 100.2 | 68.55 | 10.55 | 147.66 | 137.11 | 52.73 | 21.09 | 10.55 | 0 | 648.6 |
| 2008 | 15.82 | 0 | 0 | 42.19 | 15.82 | 21.09 | 163.48 | 184.57 | 63.28 | 36.91 | 52.73 | 0 | 595.9 |
| 2009 | 21.09 | 0 | 36.91 | 42.19 | 0 | 21.09 | 142.38 | 131.84 | 73.83 | 68.55 | 5.27 | 36.91 | 580.1 |
| 2010 | 0 | 105.47 | 94.92 | 100.2 | 36.91 | 58.01 | 179.3 | 210.94 | 147.66 | 0 | 10.55 | 0 | 944.0 |
| 2011 | 0 | 0 | 36.91 | 58.01 | 52.73 | 15.82 | 63.28 | 63.28 | 21.09 | 5.27 | 10.55 | 0 | 327.0 |
| 2012 | 0 | 0 | 0 | 58.01 | 15.82 | 21.09 | 147.66 | 226.76 | 94.92 | 5.27 | 0 | 0 | 569.5 |
| 2013 | 10.55 | 0 | 36.91 | 110.74 | 26.37 | 42.19 | 226.76 | 195.12 | 68.55 | 31.64 | 58.01 | 0 | 806.8 |
| 2014 | 0 | 10.55 | 36.91 | 58.01 | 68.55 | 10.55 | 137.11 | 121.29 | 100.2 | 58.01 | 0 | 0 | 601.2 |
| 2015 | 5.27 | 0 | 21.09 | 5.27 | 68.55 | 94.92 | 42.19 | 126.56 | 15.82 | 5.27 | 42.19 | 15.82 | 443.0 |
| Ave | 7.71 | 22.92 | 52.33 | 69.98 | 40.77 | 33.47 | 131.43 | 150.29 | 65.71 | 34.07 | 13.59 | 9.13 | 631.39 |

Station name: Nura_Ear

Element: Monthly total rainfall (mm)

| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual rain fall (mm/year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | 10.55 | 89.65 | 73.83 | 126.56 | 21.09 | 15.82 | 163.48 | 200.39 | 110.74 | 36.91 | 0.00 | 5.27 | 854.30 |
| 1991 | 0.00 | 21.09 | 68.55 | 79.10 | 121.29 | 21.09 | 184.57 | 200.39 | 89.65 | 5.27 | 15.82 | 36.91 | 843.75 |
| 1992 | 10.55 | 58.01 | 21.09 | 58.01 | 63.28 | 42.19 | 131.84 | 242.58 | 68.55 | 10.55 | 10.55 | 5.27 | 722.46 |
| 1993 | 15.82 | 15.82 | 21.09 | 121.29 | 110.74 | 68.55 | 184.57 | 232.03 | 94.92 | 73.83 | 0.00 | 15.82 | 954.49 |
| 1994 | 0.00 | 0.00 | 15.82 | 126.56 | 84.38 | 42.19 | 195.12 | 216.21 | 142.38 | 15.82 | 42.19 | 0.00 | 880.66 |
| 1995 | 0.00 | 42.19 | 52.73 | 116.02 | 31.64 | 15.82 | 126.56 | 216.21 | 84.38 | 10.55 | 10.55 | 21.09 | 727.73 |
| 1996 | 10.55 | 5.27 | 152.93 | 105.47 | 121.29 | 94.92 | 216.21 | 242.58 | 121.29 | 5.27 | 31.64 | 0.00 | 1107.42 |
| 1997 | 5.27 | 0.00 | 42.19 | 147.66 | 89.65 | 94.92 | 147.66 | 131.84 | 15.82 | 284.77 | 63.28 | 0.00 | 1023.05 |
| 1998 | 36.91 | 15.82 | 21.09 | 36.91 | 79.10 | 100.20 | 242.58 | 200.39 | 158.20 | 168.75 | 15.82 | 0.00 | 1075.78 |
| 1999 | 10.55 | 0.00 | 105.47 | 26.37 | 15.82 | 63.28 | 163.48 | 184.57 | 63.28 | 131.84 | 0.00 | 0.00 | 764.65 |
| 2000 | 0.00 | 0.00 | 0.00 | 47.46 | 31.64 | 26.37 | 68.55 | 126.56 | 26.37 | 47.46 | 0.00 | 5.27 | 379.69 |
| 2001 | 0.00 | 5.27 | 100.20 | 10.55 | 47.46 | 26.37 | 126.56 | 110.74 | 84.38 | 31.64 | 5.27 | 0.00 | 548.44 |
| 2002 | 10.55 | 0.00 | 68.55 | 68.55 | 15.82 | 21.09 | 73.83 | 79.10 | 10.55 | 0.00 | 5.27 | 5.27 | 358.59 |
| 2003 | 5.27 | 26.37 | 26.37 | 73.83 | 5.27 | 5.27 | 58.01 | 137.11 | 52.73 | 0.00 | 21.09 | 42.19 | 453.52 |
| 2004 | 0.00 | 0.00 | 52.73 | 31.64 | 0.00 | 15.82 | 94.92 | 89.65 | 58.01 | 21.09 | 21.09 | 26.37 | 411.33 |
| 2005 | 15.82 | 0.00 | 42.19 | 137.11 | 126.56 | 5.27 | 79.10 | 42.19 | 15.82 | 21.09 | 10.55 | 0.00 | 495.70 |
| 2006 | 5.27 | 47.46 | 84.38 | 110.74 | 47.46 | 31.64 | 195.12 | 126.56 | 52.73 | 63.28 | 15.82 | 42.19 | 822.66 |
| 2007 | 10.55 | 31.64 | 47.46 | 89.65 | 89.65 | 15.82 | 168.75 | 142.38 | 63.28 | 31.64 | 31.64 | 0.00 | 722.46 |
| 2008 | 10.55 | 0.00 | 0.00 | 31.64 | 26.37 | 15.82 | 189.84 | 195.12 | 73.83 | 63.28 | 73.83 | 0.00 | 680.27 |
| 2009 | 42.19 | 0.00 | 26.37 | 68.55 | 5.27 | 26.37 | 168.75 | 131.84 | 79.10 | 89.65 | 5.27 | 52.73 | 696.09 |
| 2010 | 0.00 | 100.20 | 105.47 | 110.74 | 63.28 | 63.28 | 200.39 | 200.39 | 152.93 | 15.82 | 5.27 | 5.27 | 1023.05 |
| 2011 | 0.00 | 0.00 | 26.37 | 47.46 | 73.83 | 31.64 | 73.83 | 73.83 | 15.82 | 10.55 | 26.37 | 0.00 | 379.69 |
| 2012 | 0.00 | 0.00 | 0.00 | 94.92 | 26.37 | 26.37 | 158.20 | 221.48 | 105.47 | 5.27 | 0.00 | 0.00 | 638.09 |
| 2013 | 10.55 | 0.00 | 52.73 | 126.56 | 42.19 | 36.91 | 232.03 | 195.12 | 63.28 | 42.19 | 89.65 | 0.00 | 891.21 |
| 2014 | 0.00 | 5.27 | 42.19 | 84.38 | 68.55 | 15.82 | 121.29 | 126.56 | 94.92 | 94.92 | 15.82 | 0.00 | 669.73 |
| 2015 | 5.27 | 5.27 | 10.55 | 15.82 | 110.74 | 131.84 | 68.55 | 179.30 | 52.73 | 21.09 | 63.28 | 26.37 | 690.82 |
| Ave | 8.32 | 18.05 | 48.48 | 80.52 | 58.41 | 40.56 | 147.45 | 163.27 | 75.04 | 50.10 | 22.31 | 11.15 | 723.68 |

Station name: Wolenchiti

Element: Monthly total rainfall (mm)

| year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | annual rainfall (mm/year) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1990 | 29.6 | 25.5 | 16.5 | 236.5 | 91.4 | 125.8 | 309.2 | 85.3 | 88.3 | 1.05 | 0.34 | 0.09 | 1009.58 |
| 1991 | 0 | 99.1 | 31.8 | 54.8 | 111.8 | 51 | 233.6 | 207.8 | 157.3 | 3 | 2.5 | 0 | 952.7 |
| 1992 | 31 | 2.5 | 0.77 | 4.53 | 3.35 | 154.2 | 213.2 | 201.3 | | 6.7 | 28.5 | 2.6 | 648.65 |
| 1993 | 0 | 0.31 | 1.58 | 37 | 67.4 | 118.3 | 135 | 227.2 | 157.3 | 1.11 | 1.57 | 32.8 | 779.57 |
| 1994 | 3.2 | 0 | 33.6 | 163.5 | 54.8 | 75.2 | 338.8 | 282.3 | 61.2 | 0 | 0 | 0 | 1012.6 |
| 1995 | 0 | 57.4 | 163.4 | 94.7 | 12.9 | 46.1 | 156.1 | 310.2 | 135.5 | 12.1 | 0 | 3.5 | 991.9 |
| 1996 | 92.1 | 0.24 | 180 | 91.5 | 168.8 | 86.1 | 200.7 | 150.6 | 73.6 | 42.5 | 42.5 | 0.08 | 1128.72 |
| 1997 | 29.8 | 0 | 38.2 | 23.2 | 44.7 | 145.7 | 255.3 | 131.1 | 88.6 | 117.8 | 51.8 | 0.21 | 926.41 |
| 1998 | 41.6 | 40.6 | 0.78 | 33.5 | 47 | 48.1 | 154.4 | 336.4 | 197.2 | 179 | 0 | 0.02 | 1078.6 |
| 1999 | 11.1 | 0.02 | 104.1 | 1.04 | 2.61 | 39.1 | 246.5 | 232.9 | 52 | 167.4 | 3.6 | 0.1 | 860.47 |
| 2000 | 0.01 | 0 | 15.5 | 18.4 | 47.9 | 58.4 | 215 | 249.5 | 110.9 | 96.3 | 30.5 | 6.1 | 848.51 |
| 2001 | 0.34 | 13.6 | 128 | 20 | 65.9 | 76.5 | 204.1 | 214.2 | 113.2 | 0.6 | 10 | 0 | 846.44 |
| 2002 | 0.69 | 0 | 48.9 | 61.4 | 10 | 18.7 | 166.2 | 231.8 | 36 | 0.18 | 0.09 | 97.7 | 671.66 |
| 2003 | 32.5 | 32.1 | 119.6 | 152.6 | 0.39 | 61.2 | 396.2 | 321.7 | 7.5 | 0.05 | 0.31 | 28.3 | 1152.45 |
| 2004 | 47.3 | 81.4 | 146.9 | 235 | 0.53 | 91.8 | 287 | 295 | 94 | 52 | 0 | 18.2 | 1349.13 |
| 2005 | 30 | 24 | 93 | 72.1 | 138.4 | 97.5 | 69.4 | 123.1 | 50.6 | 0.4 | 2.3 | 0 | 700.8 |
| 2006 | 9.4 | 32.2 | 42.9 | 75.9 | 17.9 | 11.8 | 142 | 144.6 | 53.8 | 6.1 | 0 | 25.6 | 562.2 |
| 2007 | 30.2 | 28.7 | 49.7 | 86.8 | 29.5 | 116 | 210.4 | 273.1 | 94.3 | 1.02 | 0.46 | 0 | 920.18 |
| 2008 | 18.3 | 0.07 | 4 | 59.6 | 53.1 | 20.6 | 376.3 | 271.9 | 59.3 | 59.8 | 49.2 | 0.08 | 972.25 |
| 2009 | 95.1 | 0.17 | 22 | 19 | 15.1 | 16.2 | 133.4 | 123 | 45.5 | 116.8 | 0 | 61.3 | 647.57 |
| 2010 | 0.03 | 87 | 107.7 | 18.4 | 74.7 | 67.6 | 191.1 | 175.7 | 156 | 0.85 | 50.2 | 0.51 | 929.79 |
| 2011 | 0.14 | 0.34 | 56 | 6.3 | 67.1 | 28 | 178.4 | 175.3 | 140.4 | 0.34 | 13.5 | 0.03 | 665.85 |
| 2012 | 0.01 | 0 | 20 | 31 | 18.7 | 73.4 | 326.2 | 253 | 88.7 | 7.8 | 0 | 3.5 | 822.31 |
| 2013 | 11 | 1.7 | 72.2 | 38.6 | 46.5 | 44.6 | 437.9 | 139.7 | 118.5 | 60.6 | 16.2 | 0.01 | 987.51 |
| 2014 | 0 | 2.6 | 101.4 | 2.2 | 34.5 | 7.2 | 169.9 | 207.4 | 152.4 | 93.6 | 26.6 | 0.56 | 798.36 |
| 2015 | 0 | 0 | 8.4 | 6.9 | 139.2 | 66.8 | 157.3 | 140.7 | 44.4 | 0.2 | 4 | 8.6 | 576.5 |
| Ave. | 21.41 | 19.15 | 72.51 | 54.67 | 49.31 | 58.16 | 222.56 | 214.33 | 91.07 | 48.35 | 14.35 | 12.11 | 877.98 |

**APPENDIX-3** Water Allocated from Koka reservoir for 2022 G.C

| S/no | Name of user | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun. |
|---|---|---|---|---|---|---|---|---|---|
| 1 | wonji main | 4.628 | 4.755 | 4.486 | 4.239 | 3.762 | 3.655 | 4.78 | 4.44 |
| 2 | Dodota pump | 1.68 | 1.56 | 1.62 | 1.83 | 1.81 | 1.93 | 1.49 | 1.28 |
| 3 | waketiyo pump | 0.44 | 0.4 | 0.42 | 0.6 | 0.65 | 0.83 | 0.51 | 0.33 |
| 4 | welenchti intake | 2.15 | 2.4 | 2.27 | 3.27 | 3.19 | 3.05 | 3.18 | 1.65 |
| 5 | wonji kuriftu cooperatives | 0.12 | 0.11 | 0.12 | 0.28 | 0.35 | 0.54 | 0.28 | 0.08 |
| 6 | Boku Kurabo Cooperatives | 0.1 | 0.09 | 0.09 | 0.25 | 0.31 | 0.5 | 0.25 | 0.03 |
| 7 | Adulala Boku Cooperatives | 0.1 | 0.1 | 0.1 | 0.26 | 0.32 | 0.5 | 0.26 | 0.04 |
| 8 | Wake-Mia Cooperatives | 0.15 | 0.14 | 0.15 | 0.31 | 0.36 | 0.53 | 0.3 | 0.05 |
| 9 | Wake-Tiyo Cooperatives | 0.07 | 0.07 | 0.07 | 0.23 | 0.29 | 0.48 | 0.23 | 0.02 |
| 10 | adama wereda | 0.84 | 0.8 | 0.83 | 0.96 | 0.9 | 0.94 | 0.87 | 0.3 |
| 11 | dodota wereda | 0.38 | 0.34 | 0.32 | 0.38 | 0.5 | 0.63 | 0.47 | 0.37 |
| 12 | Boset wereda direct pump | 0.39 | 0.34 | 0.32 | 0.39 | 0.5 | 0.63 | 0.48 | 0.37 |
| 13 | Africa juice @ degaga | 0.1 | 0.1 | 0.1 | 0.26 | 0.32 | 0.51 | 0.26 | 0.04 |
| 14 | Tibila farmers @Tibila diversion | 2.06 | 1.96 | 2.04 | 2.12 | 1.87 | 1.66 | 1.88 | 0.72 |
| 15 | Africa juice @memberehiwot | 0.03 | 0.03 | 0.03 | 0.2 | 0.27 | 0.46 | 0.2 | 0.01 |
| 16 | upper awash Ag.ind @abadiska | 0.36 | 0.32 | 0.3 | 0.38 | 0.5 | 0.64 | 0.49 | 0.39 |
| 17 | upper awash Ag.ind @Nura Hera | 1.32 | 1.17 | 1.09 | 0.95 | 1.18 | 1.26 | 1.84 | 2.02 |
| 18 | Farmers @Nura Hera | 0.44 | 0.39 | 0.36 | 0.42 | 0.54 | 0.66 | 0.52 | 0.42 |
| 19 | Farmers @Merti woreda | 0.39 | 0.34 | 0.32 | 0.39 | 0.5 | 0.63 | 0.47 | 0.37 |
| 20 | Farmers @Jeju woreda | 0.45 | 0.4 | 0.37 | 0.42 | 0.55 | 0.67 | 0.53 | 0.43 |
| 21 | Farmers @merti jeju main canal | 1.56 | 1.39 | 1.29 | 1.06 | 1.32 | 1.21 | 1.41 | 1.24 |
| 22 | upper awash Ag.ind @merti jeju | 0.24 | 0.22 | 0.2 | 0.31 | 0.41 | 0.58 | 0.44 | 0.33 |
| 23 | Awash winery @merti jeju | 0.22 | 0.19 | 0.18 | 0.3 | 0.4 | 0.56 | 0.35 | 0.21 |
| 24 | Fentale project @kawa diversion | 3.12 | 2.51 | 2.67 | 2.24 | 2.74 | 2.22 | 3.03 | 2.55 |
| 25 | Bole gologota main canal | 0.69 | 0.61 | 0.57 | 0.56 | 0.71 | 0.78 | 0.71 | 0.65 |
| 26 | farmers @ abadir | 0.33 | 0.29 | 0.27 | 0.35 | 0.46 | 0.6 | 0.43 | 0.31 |
| 27 | metehara SF @ abadir | 2.95 | 2.61 | 2.58 | 2.39 | 2.79 | 2.65 | 2.89 | 2.43 |
| 28 | metehara SF @ merti canal | 4.44 | 4.32 | 4.36 | 4.27 | 4.96 | 4.53 | 5.2 | 4.59 |
| 29 | farmers @ merti canal | 0.38 | 0.34 | 0.31 | 0.38 | 0.5 | 0.63 | 0.47 | 0.36 |
| 30 | Awash fentale wereda direct pump | 0.23 | 0.21 | 0.19 | 0.3 | 0.4 | 0.56 | 0.35 | 0.22 |
| 31 | Sub total upper awash | 29.6 | 27.8 | 27.6 | 31.1 | 34.4 | 36.1 | 33.8 | 25 |
| 32 | Middle Awash @melka sedi weir | 2.31 | 3.46 | 3.67 | 4.24 | 4.75 | 5.42 | 7.02 | 7.19 |
| 33 | Total irrigation demand from koka | 32 | 31.2 | 31.2 | 35.3 | 39.2 | 41.6 | 40.8 | 32.1 |
| 34 | **Environmental flow** | 3.2 | 3.12 | 3.12 | 3.02 | 3.18 | 2.78 | 3.56 | 3.21 |
| 35 | **Industry** | 3.35 | 4.15 | 4.15 | 4.15 | 4.15 | 4.15 | 4.15 | 4.15 |
| 36 | **Domestic** | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 |
| | Total monthly water demand (m3/s) | 40 | 40 | 40 | 44 | 48 | 50 | 50 | 41 |