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MSc THESIS

ON

IRRIGATION WATER MANAGEMENT STRATEGIES AND PERI-URBAN IRRIGATION PRACTICES OF THE AKAKI CATCHMENT IN THE UPPER AWASH BASIN, ETHIOPIA

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IRRIGATION MANAGEMENT STRATEGIES AND PERI-URBAN IRRIGATION PRACTICES OF THE AKAKI CATCHMENT IN THE UPPER AWASH BASIN, ETHIOPIA

A Thesis Submitted to the School of Graduate Studies, Addis Ababa University, for Partial Fulfillment of the Requirement for the Degree of Master of Science in Water Resource Engineering and Management

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DECLARATION

I here by declare that this thesis entitled “Water Management Strategies and Peri-Urban Irrigation Practices of the Akaki Catchment in the Upper Awash Basin, Ethiopia” was composed by myself, with the guidance of my advisor, that the thesis contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted, in whole or in part, for any other degree or profesional qualification.

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LIST OF ACRONYMS

SSI ------------------------------------Small-Scale Irrigation

SPSS----------------------------------- Statistical Package for Social Science

CWR------------------------------------Crop water requirement

Kc--Crop coefficient

D.E.M.-----------------------------------Digital Elevation Model

ETC--------------------------------------Crop Evapotranspiration

ET--Evapotranspiration

ETo-------------------------------------- Reference Evatraspiration

SWM--------------------------------------Sustainable Water Management

IR---Irriation Requirement

LULC------------------------------------Land Use Land Cover

FGD--------------------------------------Focus Group Discussion

RH--Relative Humidity

WS---Wind Speed

HH--House Hold

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ABSTRACT

This paper investigates and presents irrigation water management strategies and peri-urban irrigation practices in the Akaki catchment, in the upper Awash basin, Ethiopia. The main focus of this work is to assess problems related to irrigation water management, calculate crop water requirements of major crops cultivated, and investigate the impact of improper irrigation practices in the study area. To achieve the objectives, both qualitative and quantitative data sets were used. The results were analyzed using descriptive statistics and inferential statistics (IBM SPSS Version 27 software). Also, the crop water requirement is calculated by the CropWat 8.0 software. According to the frequency analysis, 36.8% of respondents (n=57) stated poor water quality caused by municipal or industrial waste as their top irrigation management problem. High fuel costs were identified as the second biggest concern by 33.5% of respondents (n=52), with 29.7% (n=46) referring to over-flooding after heavy rains as the third major challenge. The results of the study also show that the water requirements of cultivated crops in the area are mismatched with the actual crop water requirements. The irrigation requirement of major crops cultivated in the area, such as cabbage, small vegetables, potatoes, and tomatoes, was scheduled in nine, seven, ten, and seven days, respectively. Furthermore, the result shows that soil salinity, waterlogging, and yield reduction were due to mismanagement of irrigation water in the study area. Efficient irrigation management practices are recommended for sustainable agriculture and optimal water usage.

***Keywords**: Cropwater requirement, CROPWAT8.0 model, crop productivity, irrigation schedule*

1. INTRODUCTION

This study assessed irrigation water management strategies and peri-urban irrigation practices of the Akaki catchment in the upper Awash basin, Ethiopia. Introducing the total study based on the research background and available research and articles. Background statement of the problem, research questions, research objectives, significance of the study, scope of the study, limitations, and structure of the study were the content of this whole chapter.

1.1 Background

Although there are still plenty of water resources in the world (Bekele and Tilahun 2007), as human water demand is continually growing, water scarcity has been a critical concern. In many parts of the world, severe water shortages are emerging, particularly in arid and semiarid areas (Memon and Jamsa 2018; Tegenu 2023). As a result, the biggest challenge for the ensuing periods is maximizing food production with reduced water use, particularly in nations where water supplies are scarce due to existing poor water management practices (Bekele and Tilahun 2007; Tegenu 2023). The current socio-economic development and ecosystems are the providers of water resources facing serious challenges of water shortage, mainly due to inefficient water use systems (Zhang, Ren, and Li 2019). Global warming, urbanization, and population increase are major factors affecting water resources (Mersha 2018; Mali 2023). Increasing the effectiveness of the water used in agriculture is crucial, especially in regions where water is scarce (Minga 2023). Recent studies show that Salinity and water shortages are two of the biggest challenges to agricultural productivity worldwide (L. M. Haile 2019, 2021; Gabr and Fattouh 2021a; Asmamaw et al. 2021).

In Ethiopia, irrigation development is embraced as a potential way to boost agricultural productivity, satisfy the rising demand for food, and raise the income of smallholder farmers (Teklay et al. 2022). Irrigation systems are a viable means of optimizing agricultural outputs to fulfill the demand for food from the country's rising population and increase the standard of living for the majority of smallholder farmers. To achieve these objectives, a variety of irrigation schemes covering a few hectares to many thousands of hectares are being designed in Ethiopia (Ummah 2019). The Ethiopian government has been following irrigation development and management with high investments and special emphasis on the expansion of small-scale community irrigation development as a major strategy in contributing to food security from the local to the national level (Berhe et al. 2022). It is important to know how to get more production by using less water (FAO 2018). Crop development, growth, and productivity are enhanced by irrigation, which allows better control over the quantity and timing of the water supply (Giordano, Namara, and Bassini 2023). Different studies show that Farmers who can use irrigation water can grow a variety of crops throughout the year, obtain non-farm incomes, become more resilient to droughts, and enjoy overall improvements in their quality of life (Belay and Bewket 2013; Nakawuka et al. 2018; Ahmed 2019). Water conservation is improved by understanding crop water needs and creating criteria that enhance irrigation practices through enhancement and precision (Mali 2023). To meet the growing food demand in water-limited environments, it is essential to adopt appropriate water-saving irrigation practices (Asmamaw et al. 2021). According to (Fayaz Hussain 2023), good management of water systems enhances the effectiveness of irrigation and other water usage practices by reducing wastewater and boosting agricultural yields using data on soil, weather, plant, and water availability. To meet the growing food demand in water-limited environments, it is essential to adopt appropriate water-saving irrigation practices (Asmamaw et al. 2021).

In Ethiopia, many farmers use irrigation without knowing crop water requirements, water application methods, or irrigation intervals. Irrigation water management inexperience leads to waterlogging problems on some farms, irrigation water waste, and the deterioration of some infrastructure(Kassie 2020).

It is often known that inadequate irrigation planning, uneven water demand, and inappropriate irrigation techniques are due to insufficient technical skills (Kassie 2020). A lack of knowledge of the right watering amounts and timing during a growth season is one challenge to managing water application for irrigation.

Since water resources may limit the production of food, energy, and other economic sectors, they are a major economic driver in many regions. Hence, effective irrigation and drainage management methods are essential given the world's ongoing rapid population growth and growing demand, along with the subsequent scheduled irrigation development for sustained food security (Gabr and Fattouh 2021b). Peri-urban agriculture has been advantageous for urban farmers, allowing them to address the food shortage by providing fresh vegetables (Mark and Deribie 2015 and Kasa et al. 2011). The management of peri-urban water in developing nations is a significant issue for which there are no long-term fixes (Starkl et al. 2013). Poor water management and prearranged socio-economic structures (such as population growth and expanding economic activities) are the main factors risking the feasibility of the irrigation strategy (Ayenew 2007; Yohannes et al. 2017). The primary reason for the substantial water loss from small-scale systems of irrigation systems was that farmers' water applications did not correspond with crop requirements (Derib et al. 2011). When all crop water requirements are met, the maximum yield can be achieved. If the appropriate period of water application had been chosen, many crops may have been produced with high yields and high water use efficiency. Farmers often over-irrigate, which raises production costs, leads to water loss and yield loss, and washes nutrients out of the root zone (Allen 2006 and Asmamaw et al. 2021).

The present study mainly focuses on the investigation of irrigation water management practices, their challenges, and the identification of crop water requirements of some crops. Additionally, the impact of improper water application and mismanaged irrigation water on crop yield was investigated. Moreover, the water requirements of some crops, such as cabbage, small vegetables (onions and carrots), potatoes, and tomatoes, are identified in the study area. This research used the Cropwat 8.0 model and SPSS software to interpret and analyze the data.

1.2 Statement of the Problem

The country's current problems with drought, diminishing agricultural output, and growing population pressure necessitate focusing on better water resource management and small-scale irrigation development to maintain food production at the family level (Sileshi et al. 2006). Adeline in crop yields is a worrying consequence that affects farmers' livelihoods and overall food security in Ethiopia. Irrigation is widely practiced to enhance crop production and food security. In the Akaki Catchment, farmers depend mainly on peri-urban irrigation using water pumped from rivers. However, problems such as uncontrolled water abstraction, over-irrigation, high fuel cost, and poor scheduling reduce efficiency and sustainability. This problem shows that a comprehensive study of irrigation water management in the study area is urgently needed.

1.3 Research Questions

I. What are the existing irrigation development patterns and management practices in the Akaki catchment?

II. What are the crop water requirements of major crops in the study areas? How can the irrigation water distribution systems' networks be managed so that the required amount of water reaches the crop?

III. How do the current irrigation application systems compare with CWR (Crop water requirement) based irrigation scheduling and improved distribution networks in terms of water saving and crop yields?

IV. What improvements can be suggested for the current irrigation water management practices to enhance efficiency and sustainability?

1.4 General Objective

The general objective of this study is to assess current irrigation practices and management methods, determine the crop water requirements for major cultivated crops, identify the main challenges, and look into effective management options.

1.5 Specific Objectives

- ✓ To assess existing irrigation challenges facing proper irrigated management
- ✓ Identify the water requirements of the major crops cultivated in the Akaki catchment.
- ✓ To assess how crop productivity is affected by water application and management practices
- ✓ Compare effective management strategies with current practice in the sub-basin to make it more sustainable and effective

1.6 Significance of the Study

The study on current irrigation practices and management methods in the Akaki catchment is significant and has significant environmental implications. The current study will be important for researchers, academic reference, farmers, and policymakers. Not only this, even the study will also draw the attention of irrigation water management in the area. The results can make recommendations for better irrigation water management that promote efficient use of water resources and increase crop yields. As poorly maintained irrigation systems and ineffective irrigation methods can ultimately harm the environment, the results of the study will help to enhance our understanding of irrigation water management for sustainable and environmentally friendly methods of managing irrigation water.

1.7 Scope of the Study

This study is geographically delimited to the Akaki catchment upper Awash Basin, Ethiopia. The catchment is located about 20 kilometers from the center of Addis Ababa, with geographical coordinates between 8° 4' 0“N and 9° 2' 0” N latitude and 38° 20' 0“E and 39° 0' 0” E longitude. Conceptually, it covers assessment of existing irrigation development patterns and management, identification of key challenges facing proper irrigation, identification of water requirements of major crops cultivated, assessment of how crop productivity is affected by water application and management practices, and comparison of effective management strategies in the catchment. The perception of the people on the current irrigation water management practice and problems identified was analysed by SPSS and ETo, CWR, and IR schedule. The effective rainfall of the main crop cultivated in the study area was calculated by the CROPWAT 8.0 model for the years 2000-2022.

1.8 Limitations of the Study

The study was constrained by a number of factors, which include: unwillingness to interview and to do focus group discussions. The survey questionnaires were collected from Andode wereda alone and rely on self-reported responses, which may be influenced by recall bias. Therefore, the readers need to consider that this may affect generalization. Furthermore, in this study, certain climatic parameters, specifically sunshine hours and relative humidity, were not available from local meteorological stations in Akaki to address this gap, the data were obtained from NASA’s global climate database. Although NASA datasets are widely used in hydrological and agricultural modeling, they may not fully capture microclimatic variations at the local scale. This limitation could introduce minor discrepancies in the estimation of reference evapotranspiration (ETo) and, consequently, crop water requirements generated by the CROPWAT 8.0 model.

1.9 Structure of the Thesis

This thesis is organized into six chapters. In chapter one, the background of the study was presented. Chapter 2 deals with a literature review related to the study. The material and methodology are explained in Chapter 3. In Chapter 4, the data were analysed. Chapter 5 Presents and Discusses the Results. Finally, Chapter 6 presents the conclusions and recommendations for further research.

2 LITERATURE REVIEW

2.1 Introduction

This review covers the concepts of irrigation water management practices, crop water requirement of specific crops, the challenge of mismanagement of irrigation, the relationship between water application and crop productivity, and the role of the community in environmental management are targeted issues in this literature.

The objective of the review is to assess irrigation water management practices, identify problems, crop water requirements, and how crop productivity is affected by water application and management practices.

2.2 Importance of Effective Irrigation Water Management

Effective irrigation water management remains a basis of agricultural productivity, particularly in water-intensive farming systems. In Ethiopia, the sustainable and efficient use of water resources has become increasingly important not only to support agricultural development but also to address the growing competition for water across various sectors (Ministry of Water Resources 2015). Accurately estimating Crop Water Requirement (CWR) is essential to effective irrigation management because it ensures that crops obtain adequate water without waste or misuse (Youssef et al. 2024).

As the availability of freshwater resources declines, especially high-quality water, optimizing water use for food production becomes increasingly critical (Fazal Hussain et al. 2023). One important part of this optimization process is irrigation scheduling, which must be improved to ensure the efficient distribution of water across crops (Ali et al. 2001). Crop evapotranspiration (ETc) is the main factor in determining water requirements.

The Penman-Monteith method is widely recognized as a reliable and standardized approach for estimating both reference evapotranspiration (ETo) and actual crop evapotranspiration (ETc), forming the basis for precise irrigation planning (Pereira et al. 2021). An efficient ET estimate is crucial for resolving water-related agricultural issues as well as for calculating CWR. Whether too little or too much, improper irrigation is frequently associated with crop stress and decreased yield.

A significant part of the agricultural water balance and the larger hydrological cycle is evapotranspiration (ET), which includes both soil and surface evaporation as well as plant transpiration (Youssef et al. 2024). Therefore, its precise evaluation is essential for managing irrigation water sustainably and reducing the detrimental effects of water shortage and incorrect utilization on agricultural yield and health (Papoutsa et al. 2020).

A lot of research in agricultural water management and irrigation over the past fifty years has focused on understanding how production responds to changes in evapotranspiration and water availability (González-Dugo and Mateos 2008). Sustainable development is essential to the smart and effective management of water resources, especially in the agricultural sector. Coordination of land and water management strategies is necessary to reach this objective. This combination has become increasingly recognized as being crucial in developing nations to advance environmental sustainability, enhance livelihoods, boost economic growth, and reduce poverty.

Crop water requirements and, consequently, agricultural output are greatly influenced by a number of biophysical and climatic parameters, such as soil fertility, irregular rainfall patterns, and evapotranspiration (Gabr and Fattouh 2021b). Crop coefficient (Kc)-based ETc calculation is becoming a common technique for small-scale irrigation water management. Crop coefficient and Penman-Monteith (PM) reference evapotranspiration (ETo) are multiplied to obtain actual evapotranspiration (Tongwane et al. 2017).

The Penman-Monteith approach was explicitly suggested by the Food and Agriculture Organization of the United Nations (FAO) in its Irrigation and Drainage Paper No. 56 (FAO–56) for determining ETo under standard conditions. Since then, this method has established itself as the norm worldwide since it is reliable and flexible in a variety of climatic and agro-ecological contexts (Tongwane et al., 2017). Consequently, accurate ETc estimation based on the FAO-56 methodology is now fundamental to informed irrigation planning and sustainable crop water management (Tongwane et al. 2017).

2.3 Management of Small-Scale Irrigation in Ethiopia

Better productivity in agriculture and improved food security are made possible by irrigation, especially in areas affected by drought and unpredictable rainfall. Around 70%

of all freshwater withdrawals worldwide are from irrigated agriculture, making it the single biggest user of water resources (Nazari et al. 2018). Small-scale irrigation is becoming more widely known in Ethiopia as a practical solution to rural poverty and food insecurity. Within this context, small-scale irrigation (SSI) has emerged as a vital strategy for improving agricultural output, stabilizing rural livelihoods, and enhancing resilience to climate variability. SSI provides revenue, meets household food requirements, and promotes local economic growth by facilitating more dependable and varied crop production. Additionally, it acts as a protective barrier against the negative consequences of rainfall unpredictability, which is still a significant problem in rain-fed agricultural systems (FAO 2018). Thus, increasing the durability and productivity of small-scale irrigation systems is essential to lowering vulnerability and boosting rural resilience.

Despite its potential, the management of small-scale irrigation schemes in Ethiopia faces significant institutional and operational challenges. One of the critical issues is the lack of clearly defined responsibilities between implementing agencies and beneficiary communities in managing completed irrigation schemes (Sileshi et al. 2006). Inadequate water management practices and insufficient drainage infrastructure have also led to waterlogging and soil salinity, which in turn contribute to health risks such as increased incidence of malaria (Sileshi et al. 2006). Poorly managed irrigation systems, therefore, pose environmental and public health concerns alongside productivity challenges.

Ethiopia continues to struggle with multiple structural problems, including widespread poverty, food insecurity, rapid population growth, land degradation, limited institutional support, and heavy reliance on rain-fed agriculture (Bacha et al., 2011). (Bacha et al. 2011). As a result, irrigation both commercial and smallholder, has become a more important factor in agricultural transformation, according to national policies and development plans (Mohammed 2019). Small-scale irrigation is currently heavily encouraged by government programs as a way to increase family food security, reduce dependence on food aid, and adoptive equitable economic growth (Tesfaw 2018).

2.4 Irrigation Water Management Practices

Understanding the water requirements of crops and the optimum timing of water application is fundamental for effective agricultural water management (Ewaid, Abed, and

Ansari 2019). Water management requires careful irrigation scheduling, which has a direct impact on agricultural output and water usage efficiency (Heeren 2021). The most serious environmental hazard caused by irrigation is caused by poorly managed irrigation systems, which can result in soil salinity, degradation, and loss of agricultural land (Kassie 2020, Heeren 2021).

Irrigation water management techniques aim to meet agricultural water needs while minimizing waste, water loss, and environmental impacts. These strategies have several benefits, including lowering poverty, saving money, reducing soil salinity and waterlogging, minimizing productivity losses, and minimizing environmental harm. Thus, efficient irrigation water management is essential for maintaining food security, conserving water, and advancing sustainable agriculture.

The goal of best practices in irrigation water management worldwide is to fulfill the growing demand for food production by boosting sustainability and efficiency while reducing negative ecological impacts. Inappropriate usage or mismanagement of irrigation systems may damage long-term sustainability, lower water production, and cause economic inefficiencies. (Levidow et al. 2014). Research has recently placed more emphasis on creating instruments and assessments to evaluate irrigation systems' effectiveness in terms of energy and water use. (Tarjuelo et al. 2015).

The goal of on-farm water management is to maximize plant water uptake and yield potential by implementing irrigation during crucial crop growth stages. (Eshete et al., 2020). In particular, irrigation scheduling is essential for deciding how much water to apply and when, which directly affects water usage efficiency. (Bwambale, Abagale, and Anornu 2022).

Enhancing irrigation systems is presented as a crucial strategy to increase agricultural productivity and promote economic expansion (Deksisa and Bayissa 2020).

2.5 Sustainability of Irrigation Water Management in Peri-Urban

Although urbanization is seen as a transition to a contemporary lifestyle, it can lead to several serious environmental problems, such as pollution, climate change, decline in agricultural production, and general ecological degradation (Yohannes 2020). Sustainability in agriculture focuses on developing environmentally friendly and safe methods (Velasco-Muñoz et al. 2018). A key element of sustainable development is sustainable water management (SWM), which addresses sustainability issues (Russo, Alfredo, and Fisher 2014). Since irrigated agriculture is essential to future food security, poverty alleviation, and economic expansion, efficient irrigation system management is a critical concern (Tewabe and Dessie 2020). Inadequate irrigation water management is the main cause of most of the current problems with waterlogging, salinity in irrigated areas, and poor water quality (Qadir et al. 2003).

Irrigation water management practices aim to promote sustainability and environmental health. A recent study shows that Poor irrigation water management can lead water waterlogging, which can lead to yield reduction (Berhe et al. 2022). According to, better irrigation water management techniques ultimately benefit irrigation water use.

Indirectly, urban agriculture can enhance city water management (Lupia and Pulighe 2015). Water availability and cost are major factors in irrigation practices. Water is frequently used carelessly when it is inexpensive and easily accessible, which can harm the ecosystem through leaching and soil compaction(Greenwood et al. 2010). Peri-urban agriculture refers to cultivating crops on a modest to large scale in urban neighborhoods. A recent study shows that due to rising food prices, the food situation in Ethiopia has become insecure in both rural and urban regions, especially since 2004 (Nigussie, Liu, and Yeshitela 2021). To solve this food insecurity, the cultivation of crops in urban neighborhoods is very important.

2.6 Crop Water Requirement

The water requirement of crops is the amount of water needed to compensate for the evapotranspiration loss on the cultivated field. However, the amount of water required for agricultural production, excluding precipitation, is called the irrigation water requirement. Increased development costs could also result from overestimating IR at times of peak demand. Inaccurate irrigation requirements may lead to the waste of valuable water resources, nutrient leaching, waterlogging, overestimation of cost, and lead to low water use efficiency (Timotewos and Barjenbruch 2024).

2.7 Irrigation Scheduling

The main objective of irrigation is to ensure that the crop root zone is always maintained at field capacity. To design any irrigation system, the first thing that we need to know is what amount of water required for the crop root zone to be maintained at field capacity. Irrigation scheduling indicates when to irrigate (day/time) and how much to apply (depth) to the soil. CROPWAT 8.0 is a decision support tool developed by FAO's Land and Water Development Division. According to Heeren (2021), Irrigation scheduling is the decision of when and how much water to apply to the field. To calculate irrigation scheduling by the software of CROPWAT 8.0, we need data on Climate/ETo (Tmin, Tmax, Relative Humidity, Sunshine hours), Rainfall, Crop, and Soil.

The amount of water a crop needs in a particular period to support normal growth in a specific set of environmental conditions is called crop water need.

According to (Gundekar et al. 2008). The crop water needs mainly depend on:

1. Climate: -Crops need more water to sustain growth and health in hot, sunny settings because plants tend to lose more moisture through transpiration and evaporation. On the other hand, evaporation is slower, and crops may require less water in colder and cloudy weather
2. Crop type: - Different crops need different amounts and different timing of water
3. Growth stage of crop: Fully developed crops need more water than crops that have just been planted

The CROPWAT 8.0 model is a well-known tool for calculating crop water requirements. The Food and Agriculture Organization (FAO) created the CROPWAT 8.0 model, which takes climate factors, soil properties, and crop-specific data into account to improve the accuracy of calculating evapotranspiration rates and crop water needs. The agricultural water requirement, or crop evapotranspiration, ETc (mm/day), is typically calculated using the following expression:

ETc Kc * ETo.

Where

Kc = crop coefficient

ETo = Reference Evapotranspiration (mm/day).

Estimation of Reference Evapotranspiration (ET_o).

The common method for calculating reference and crop evapotranspiration is the FAO-Penman-Monteith equation(Memon and Jamsa 2008). ET_o is the amount of water lost during evapotranspiration, and it is a vital parameter in plant water requirements, irrigation scheduling, planning, and management (Youssef et al. 2024). It is normally estimated using the Penman-Monteith method.

$$ET_0(mm/day) = \frac{0.408\Delta(Rn - G) + \gamma(\frac{900}{T + 273})(e_s - e_a)}{\Delta + \gamma[1 + 0.34u_2]}$$

Where,

ETo reference evapotranspiration [mm day-1],

Rn =net radiation at the crop surface [MJ m-2 day-1],

G soil heat flux density [MJ m-2 day-1],

T =mean daily air temperature at 2 m height [°C],

u2 wind speed at 2 m height [m s-1],

es saturation vapor pressure [kPa],

ea= actual vapor pressure [kPa],

es – ea= saturation vapour pressure deficit [kPa],(Allen 2006).

2.8 Growing Period of Plants

The growing period of plants can affect the water requirement of crops. At the development stage, crops need high water and are sensitive to water. The total growing period is divided into four distinct growth stages (Memon and Jamsa 2018).

Figure 1 illustrates the crop growing period.

1. Initial Stage: This stage begins with sowing or transplanting and continues until the crop covers approximately 10% of the ground.
2. Crop Development Stage: Following the initial stage, this phase lasts until the crop reaches full ground cover, typically around 70-80%. It is important to note that maximum height is not necessarily achieved during this stage.
3. Mid-Season Stage: This stage commences after the crop development phase and extends until the crop reaches maturity. It encompasses critical processes such as flowering and grain setting.

4. Late Season Stage: This final stage begins after the mid-season stage and continues until the harvest is complete. It includes the ripening of the crop.

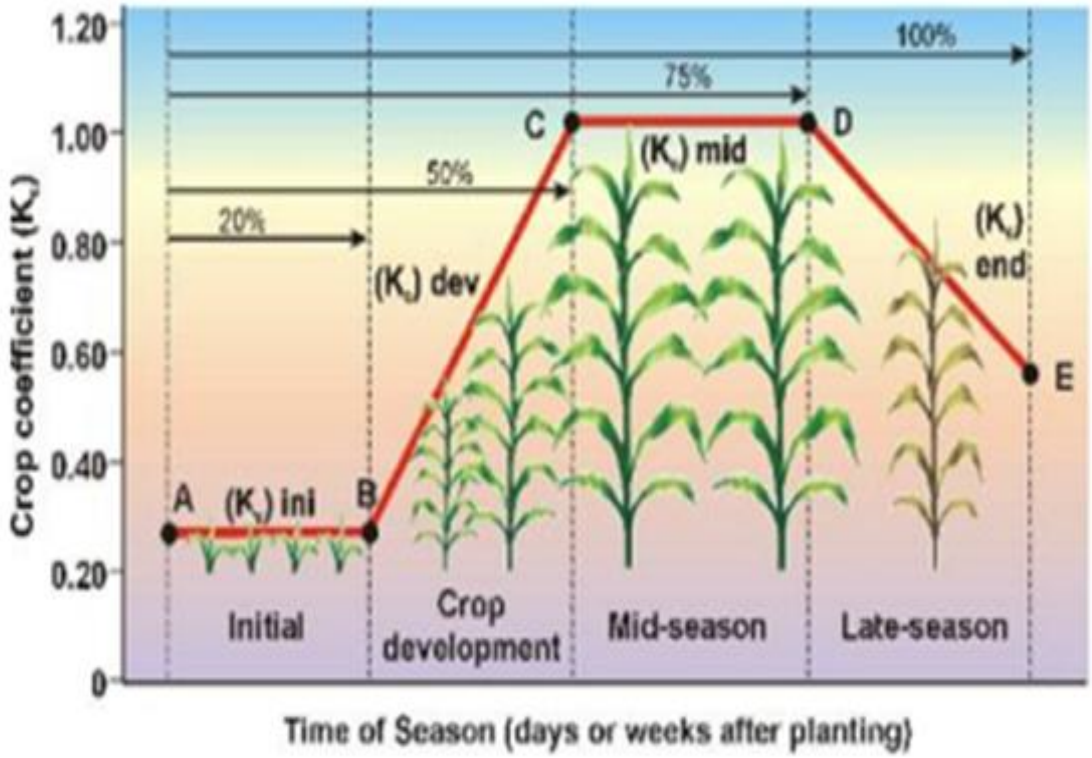


Figure 1: Growing Period of Plants

2.9 Conceptual Framework

The schematic diagram that explains the conceptual framework of the thesis is presented in Fig.2. It precisely describes the entire flow of the research work performed in the current study.

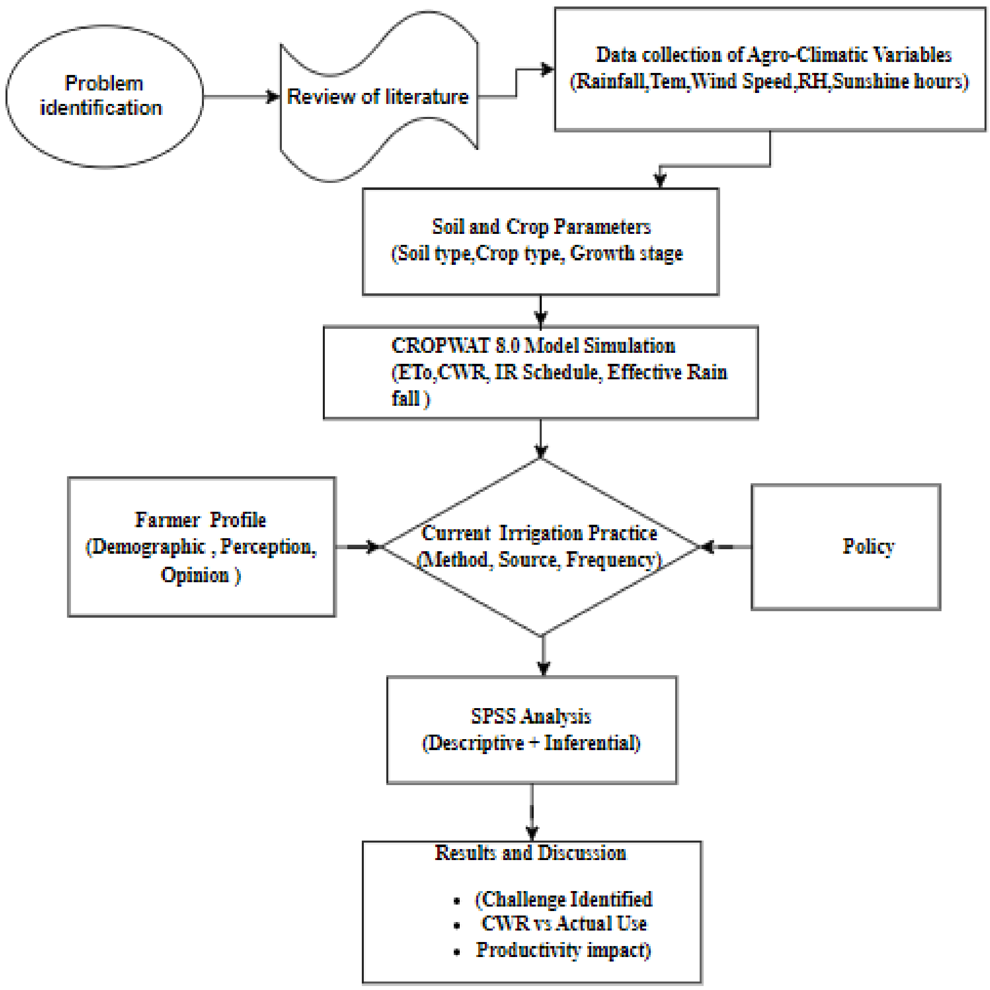


Figure 2: Conceptual Framework

3 MATERIALS AND METHODS

3.1 Introduction

Both analytical and field-based methods were used to achieve the study's goals. Primary data were collected through household surveys using structured questionnaires, while secondary data were obtained from national meteorology and literature. The descriptive statistics were used to analyze quantitative survey data, focusing on the challenge of irrigation water management, trends related to irrigation practices, water use efficiency, and farmers' perceptions. Additionally, the CROPWAT model, developed by FAO, was applied to estimate crop water requirements and irrigation scheduling based on local climatic, soil, rainfall, and crop data. The mixing of field data with model-based analysis is acceptable for a comprehensive assessment of irrigation water management and its effectiveness in the study area.

3.2 Geographical Location

This study was conducted in the Akaki catchment upper Awash Basin, Ethiopia. The catchment encompasses Addis Ababa city. It is with geographical coordinates between 8° 4' 0"N and 9° 2' 0" N latitude and 38° 20' 0"E and 39° 0' 0" E longitude. It has an area of 1444.06 km^2covering an estimated population of 181,202 people. The Akaki catchment is a tributary of the Awash River. Some of the perennial rivers in this catchment are Akaki, Hanku, Jemo, Kebena, Kotebe, Lafto, Roge, Tafo, and Tinishu Akaki, as illustrated in Figure 3.

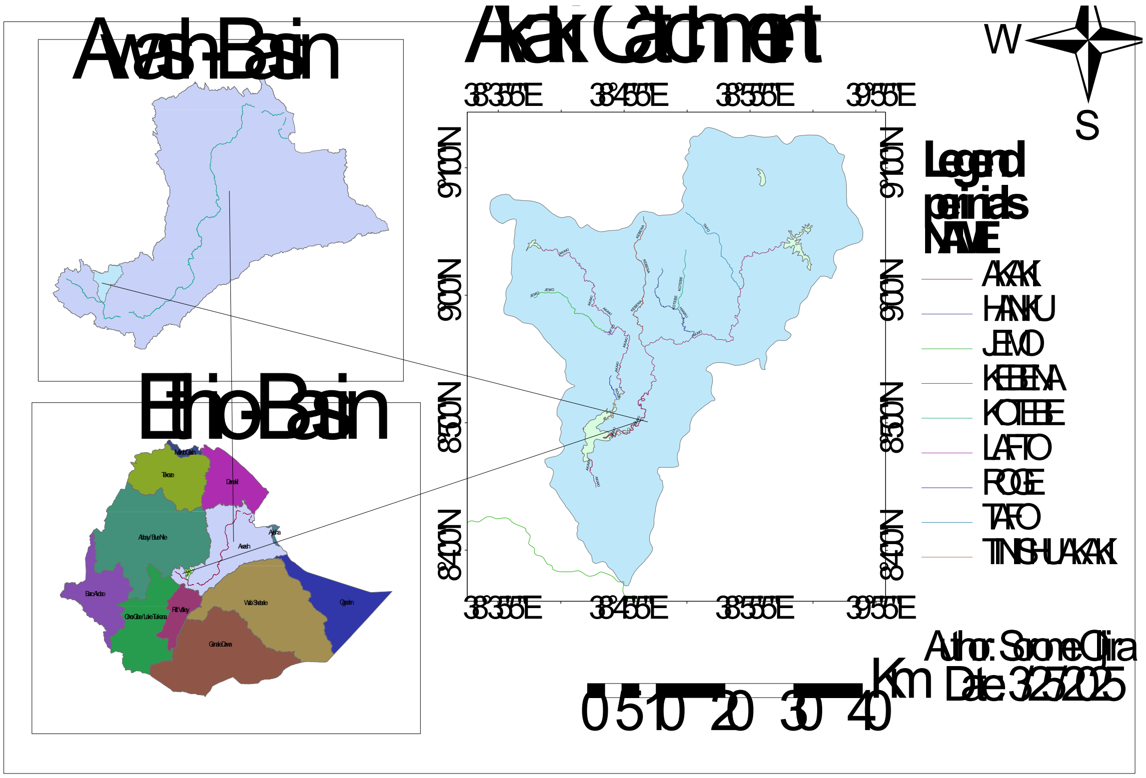


Figure 3: Study Area

3.2.1 Soil

Effective irrigation management in the Akaki catchment must consider the soil type, the water requirements of the plants, and the climatic conditions. For better irrigation management, it is important to know the soil characteristics of the area in question. Cambisols, leptosols, and xerosols characterize their soil type and are only present in small amounts, while the predominant soil types are vertisols (68 %), nitosols (11 %), and luvisols (9 %) (Argaw and Yohannes 2024). The current study area is dominated by clayey soils, as shown in Figure 4. The diversity of soil properties has a direct impact on the water requirements of plants, as each soil type has a different ability to store and release water. The soil type of the current study is the majority of Vertisols (68%) with a high clay content, which can store water for longer, but also hinders water infiltration.

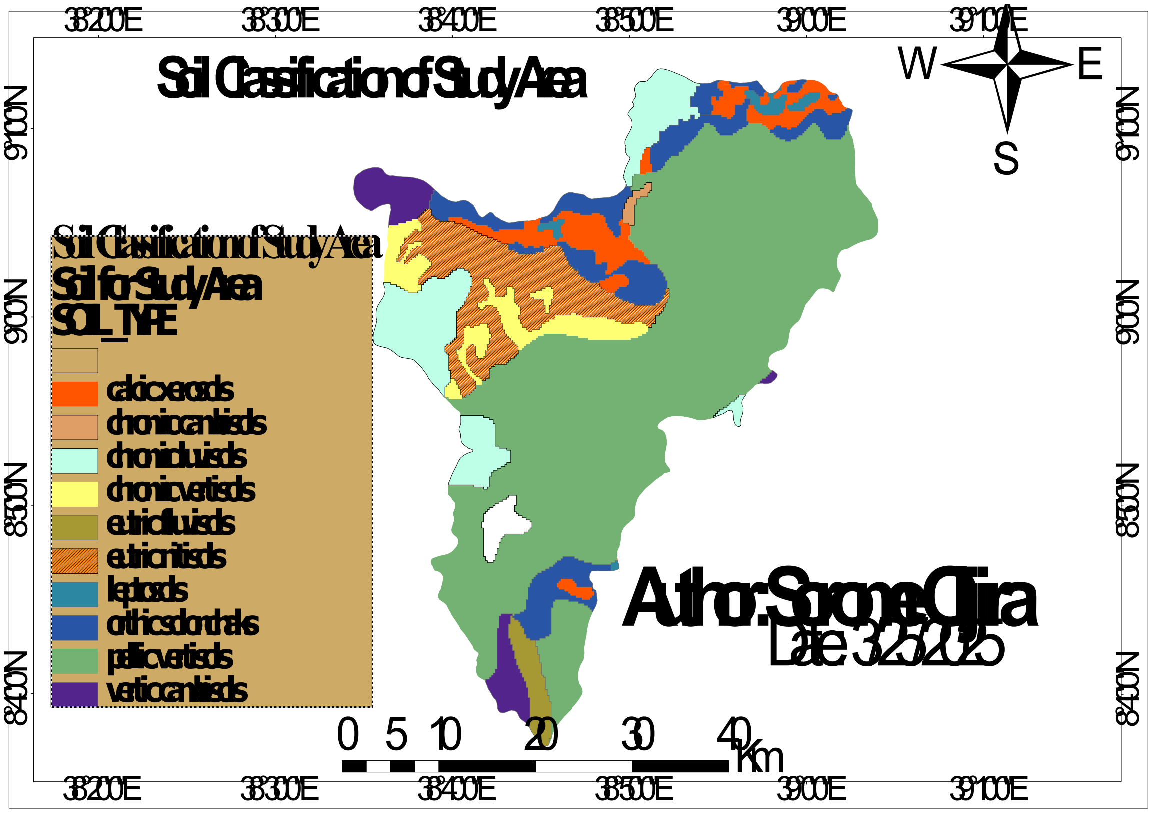


Figure 4:Soil Types of Akaki

3.2.2 Land Use Land Cover

The expansion of cities, especially around Addis Ababa, has severely changed the land use structure. The land use and land cover (LULC) includes urban and peri-urban areas, agricultural land, forested regions, water bodies, grasslands, and wastelands. The majority of land cover is plantation, as shown in Figure 5.

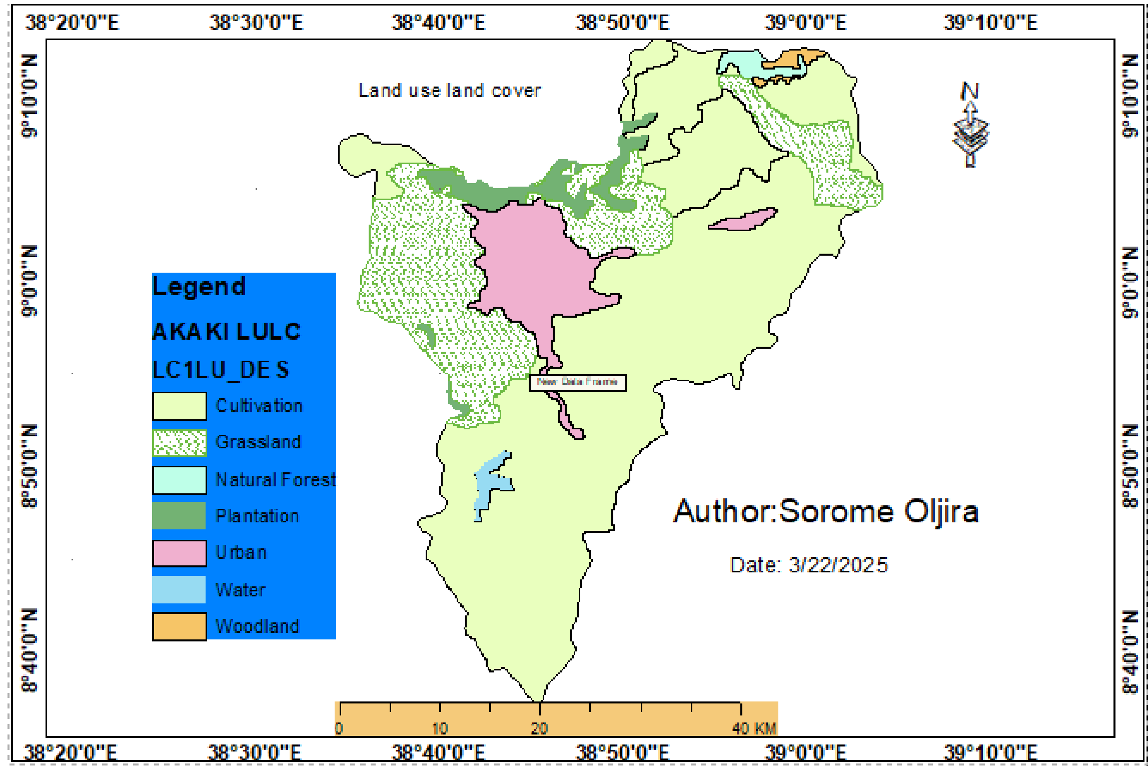


Figure 5: Land Cover

3.2.3 *Topography*

The study area's topography is diverse, characterized by plateaus and highlands, influenced by the Entoto Mountains and the Akaki River. The elevations range from 1804 m to 3388 m above sea level. The topography of the study region is illustrated in Figure 6. The region experiences various temperatures and climate patterns, including high-altitude areas around Addis Ababa. The daily average temperatures range between 3.4°C and 31.9°C. The rainy season, locally called (Gaanna, Kiremt), is from June to September, contributing approximately 73.1% of the total annual rainfall and and a minor rainy season (Arfasaa, (Belg)) from March to May. The highest yearly average catchment rainfall was reported in July 2010, at 236.4 mm, as illustrated in Figure 8.

The Akaki Catchment's current agricultural water supply system is comprised of a fragmented and mainly informal network of water sources and conveyance infrastructure. Irrigation is principally based on the Little Akaki and Big Akaki rivers, supplemented by shallow groundwater abstraction, both of which have high seasonal variability and deteriorating dependability. Water diversion is mostly accomplished via traditional clay canals, locally created furrows, and pump-based extraction systems that run with little oversight. These systems have high conveyance losses, limited flow control, and uneven distribution among users. The total effectiveness of the irrigation supply system is further limited by declining water quality caused by urban runoff, industrial effluents, and wastewater discharge, particularly in peri-urban areas.

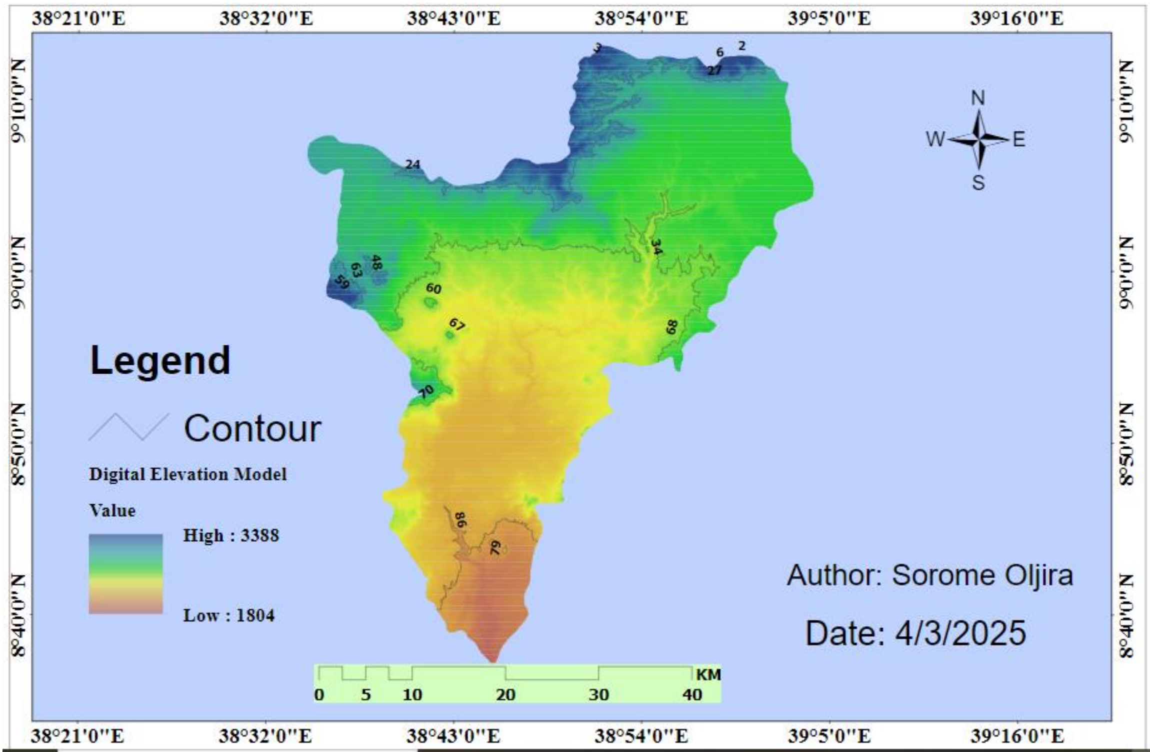


Figure 6:Topography of the Study Area

3.3 Data Availability

Both primary and secondary data were collected from the selected Akaki catchment and secondary data sources. The researcher obtained a 30*30m digital elevation model (DEM) from the Ministry of Water and Energy. The researcher acquired monthly meteorological data from the Ethiopian National Meteorological Agency, including rainfall, temperature, relative humidity, sunlight hours, and wind speed of Akaki, Bole, OBS, and Intoto stations from 2000 to 2022 were used for the study.

The Meteorological Stations, location, Elevation, and record period were illustrated in Table 1.

Table 1:Meteorological Gauge Station of the Study Area

No.	*Station Name*	*Location*		*Elevation*	*Record Period*
		Latitude	*Longitude*		
1	*Addis Ababa Bole*	*8.98101*	*38.79871*	*2354*	*2000-2022*
2	*Addis Ababa OBS*	*9.01891*	*38.7475*	*2386*	*2000-2022*
3	*Akaki*	*8.872*	*38.788*	*2057*	*2000-2022*
4	*Intoto*	*9.083667*	*38.725*	*2903*	*2000-2022*

To run the CROPWAT model, essential input data such as crop characteristics, soil properties, rainfall records, and meteorological data (maximum and minimum temperatures, relative humidity, sunshine duration, and wind speed) are needed.

Among the four stations, only the Addis Ababa Bole and Addis Ababa observation stations had data on soil, meteorology, rainfall, and crops. Since the study was conducted in Akaki, we used the closest station and filled in the missing data using regression analysis. The relative humidity, sunshine hours, and wind speed for Akaki were downloaded from NASA Power.

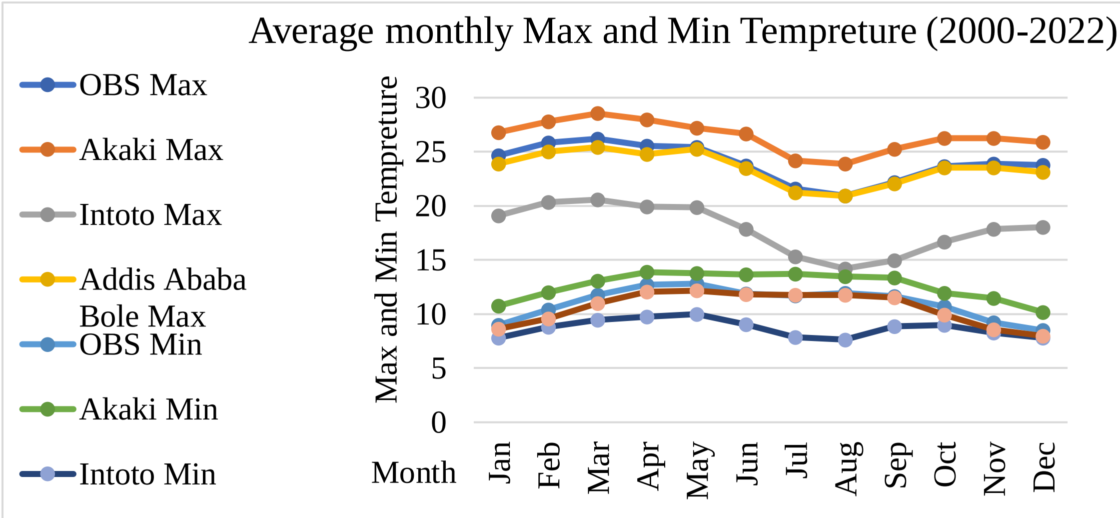


Figure 7:Average Monthly Max and Min Temperature Patterns of Four Station

Figure 7 shows that the maximum temperature was reached in March and gradually decreased until Jul. The minimum temperature was measured between June and August. In March, maximum temperatures of 28.5 degrees Celsius were measured at the Akaki station.

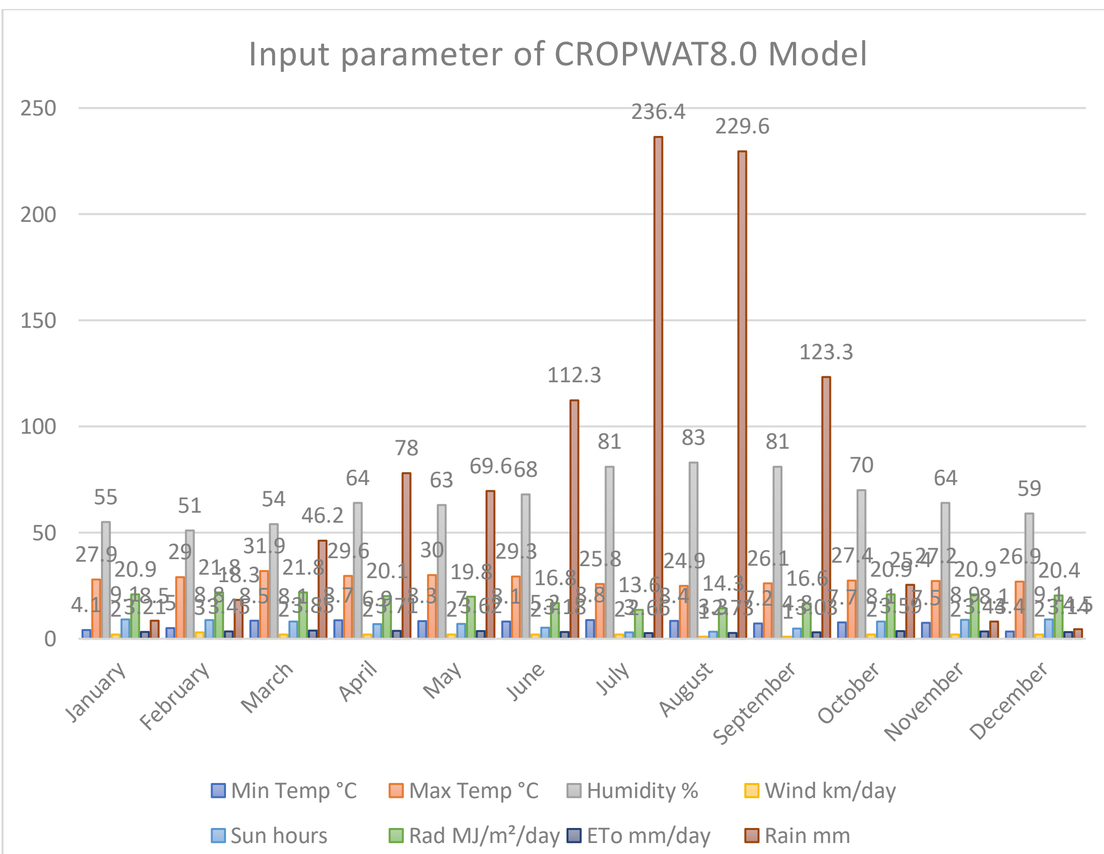


Figure 8:Climate/ETo of Akaki Catchment

The water requirement of plants depends on Tmax, Tmin, RH, WS, and sunshine hours. Figure 8 shows the climatic characteristics of the Akaki catchment. As indicated in the figure, the average rainfall and relative humidity are maxima between June to September. As illustrated in Figure 8, the highest irrigation demand is from December to April, when (high temp, sunny, low humidity, windy) and from June to September, when rainfall is high and it is cool, humid, and cloudy with little or no wind, no irrigation is needed.

3.1 Materials and Tools Used

A range of materials and analytical tools were employed to support the methodological processes of this thesis. Table 3 summarizes the primary tools utilized and their respective purposes. ArcGIS was used to delineate watersheds and provide spatial outputs such as study area maps, topography, land use/coverage, and soil properties. Regression analysis was used to estimate and fill in missing hydrological data, guaranteeing that the dataset is comprehensive and reliable. CROPWAT 8.0 and SPSS were used for data analysis, which included calculating crop water requirements (CWR), statistically evaluating survey results, and interpreting irrigation management indicators in the Akaki Catchment.

Table 2: Materials and Tools Used

Description of material	Purpose
ArcGIS	To delineate the watershed, Map Study area, Topography, LULC, and soil
Regression	To fill in missing data
CROPWAT 8.0 and SPSS	To analyze data, determine CWR, and interpret data

3.2 Data Collection Methods

Different methods were used to gather quantitative and qualitative information about current irrigation water management practices in the selected case study area. These methods include focus group discussions (FGDs), interviews, field observations, and literature analysis. Furthermore, monthly weather data such as maximum and minimum temperatures, relative humidity, wind speed, sunshine hours, rainfall, and soil type were gathered.

3.2.1 Validity and Reliability of Data

After creating the questionnaire, attempts were made to evaluate its validity and reliability to confirm its suitability for the research. The items in the questionnaire were developed through a thorough examination of pertinent literature and resources. To ensure content validity, experts in the relevant areas, such as course specialists and academic advisors, examined and approved the initial questionnaire. Drawing on insights gained from a pre-test with a group of respondents, essential adjustments were made to enhance both clarity and relevance. A pilot test with 30 farmers, who were excluded from the main study sample, was performed to evaluate reliability. The questionnaire's internal consistency was assessed with Cronbach's Alpha coefficient, resulting in a value of 0.76. This finding shows a satisfactory degree of reliability for the research tool.

3.2.2 Questionnear

The questionnaire was one of the main tools for data gathering in this study. Both open and closed-ended questions were prepared and used. It was translated from English to Afan Oromo, the native language of the households (HHs). The questionnaire covered a wide range of information, including irrigation water management practices, HHs' perception about soil and irrigation management, crop yield, soil management strategies, irrigation water use efficiency, and others. In total, 155 households were successfully interviewed during the data collection process.

3.2.3 I*nterview*

Individual interviews were a methodological approach for gaining insights into perceptions and attitudes of irrigation water management. Specifically, they help the investigation of existing problems, potential solutions, and suggested improvements. In this study, interviews were done in Andode Worede, because the majority of irrigation water users in the catchment are located in Andode, where farmers depend heavily on the Akaki River for irrigation. This area also reflects the interface between urban and rural pressures, industrial pollution, rapid urbanization, and increasing irrigation demand, making it an ideal site to study water management and irrigation practices. Semi-structured questionnaires with open-ended checklists were prepared for key informant interviews. In total, 40 participants were interviewed.

3.2.4 Focus Group Discussion

A focus group discussions (FGD)were held at Andode woreda (Figure 9). The participants were selected based on their experience in irrigation farming, Land management, involvement in irrigation water user committees, and acceptance of new agricultural technologies. During the discussion, the key problems were pointed out, and possible irrigation water management strategies were discussed.

3.2.5 Field Visit

Data collected through focus groups, interviews, and questionnaires were validated and supplemented by guided field visits. To promote contextual knowledge and guarantee data accuracy, casual conversations with farmers involved in their agricultural operations were conducted throughout each visit.

Figure 9: Picture taken during data collection

The data used and the data gathered were detailed in the tables below.

Table 4 illustrates the data used for this research and the sources of the data.

Table 4: Data Used and Sources

Data type	**Source**
Primary data	Field Observation, Interview, and FGD
Secondary data (Meteorological, Rainfall, windspeed, Sunshine hours, Relative humidity data).	National Meteorological Agency
DEM (30 by 30), LULC, MOWE soil	Ministry of Water and Energy

3.3 Study Design

This research used an embedded mixed-methods design, combining qualitative and quantitative methods to evaluate irrigation water management practices carefully. Quantitative data gathering included the assessment of meteorological factors, such as temperature, humidity, sunshine hours, and wind speed, along with crop information, which enabled accurate determinations of crop water requirements. The qualitative analysis applied SPSS software to evaluate survey data, identify patterns, and explore relationships between variables. Furthermore, the CROPWAT 8.0 model was used to calculate specific water requirements, with reference evapotranspiration (ET_0) using the Penman-Monteith method, to calculate crop water requirements. In addition to this, the qualitative component needed to gather opinions on farmers' perceptions, and a field visit was conducted to clarify several factors that affect water management practices. The combination of qualitative perceptions with quantitative results enabled understanding of current irrigation water management, where related viewpoints shaped the analysis of empirical data, thereby improving the preparation of modified and precise crop water management recommendations.

3.4 Sample Size and Sampling Procedure

In Akaki Kality Subcity, the Ethiopian Population Census Survey Commission reports a total population of approximately 181,202 residents according to Deribie. Within this demographic, an estimated 700 peri-urban farmers are engaged in irrigation farming (Mark and Deribie 2015). Among these farmers, all 700 households are considered to experience food insecurity, from both irrigator and non-irrigator producers. To facilitate a comprehensive analysis, households were stratified into two categories: "small-scale irrigation users" and "non-users." From a sampling frame comprising 355 small-scale irrigation households, a sample of 155 households was selected through random sampling procedures.

3.5 Method of Data Analysis

After collecting both qualitative and quantitative data, the study employed comprehensive analytical methods to achieve a thorough understanding of irrigation water management. Quantitative data, including climatic variables (Tmax, Tmin, RH, sunshine hours, rainfall, wind speed), soil characteristics, and crop parameters, were analyzed using the CROPWAT 8.0 model to compute key parameters such as reference evapotranspiration and irrigation requirements, and irrigation schedule.

The study adopted a descriptive survey approach to gather detailed insights into current practices and challenges, utilizing questionnaires, key informant interviews, and field observations, with qualitative data analyzed through thematic content analysis. Quantitative data were processed in Excel and analyzed with SPSS Version 27, while qualitative insights provided contextual understanding of farmers' perceptions and attitudes. Overall, the combined use of software tools and analytical techniques ensured a comprehensive evaluation of irrigation management in the study area.

4 RESULTS

4.1 Introduction

The study's results are presented in this section to address the research goals. The results are specifically categorized into three main types: challenges faced in irrigation water management, crop water requirements for the primary crops cultivated, and how water application affects agricultural yield.

4.2 Demographic Information of Respondents

This section presents data regarding the respondents' educational level, sex, and age. Figure 9 illustrates the distribution of respondents by sex and Educational level. The sample comprised 95 males (61.3%) and 60 females (38.7%), totaling 155 participants. The supplementary pie chart indicates that approximately 68% of respondents have no formal education, while those possessing a bachelor's degree or higher institute the smallest segment of the sample, represented in red.

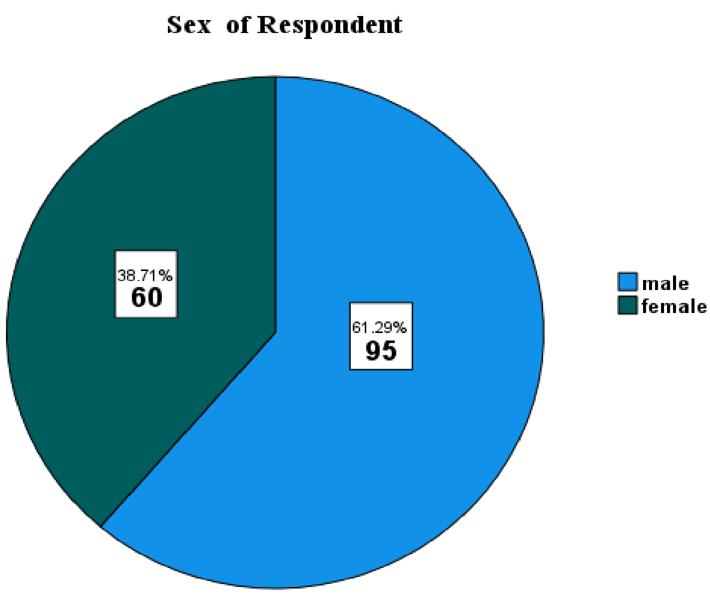


Figure 9: Sex of Respondents

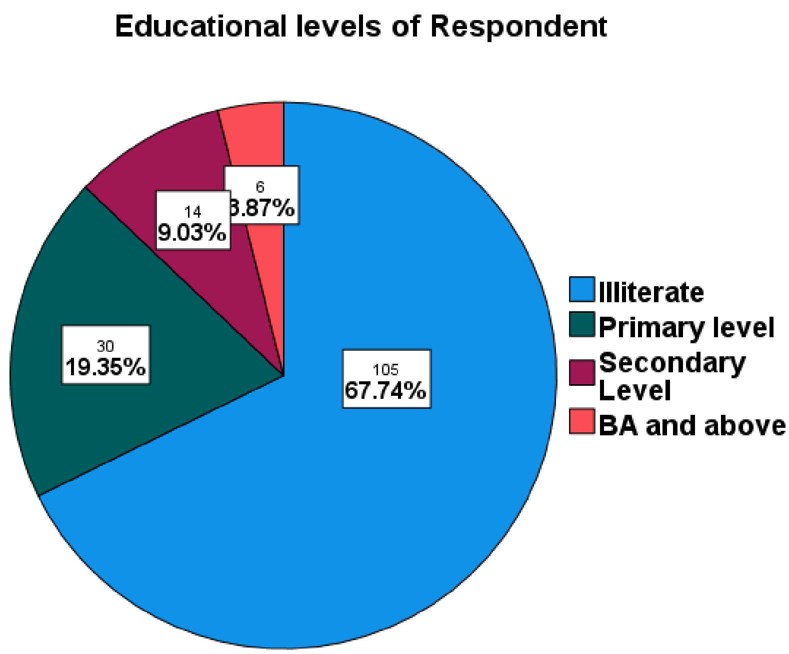


Figure 10: Education Level of Respondents

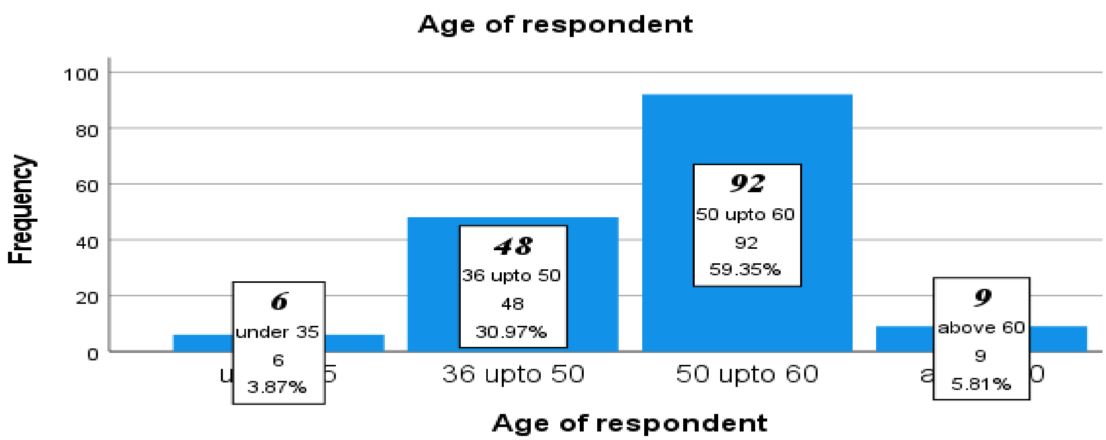


Figure 11: Age of Respondents

The age of respondents was displayed in Figure 11. As displayed, various age categories were engaging in irrigation farming. The majority of respondents, 92(59.35%), were between the ages range 51 to 60, and the least number of respondents, 6 (3.9) under the age of 35.

4.2.1 Irrigation Practices and Crop Water Use

Table 4 illustrates the analysis of the primary crop cultivated, water sources used, abstraction method, and frequency of irrigation and current water quality for irrigation purposes.

Table 3:Irrigation Practices and Crop Water Use

No			
1	**Types of Crops Cultivated**	**Frequency**	**Percent**
	✓ Vegetables	145	93.5
	✓ Cereals	10	6.5
	✓ Fruits	-	-
	Total	**155**	**100**
2	**Abstraction method**	Frequency	Percent
	✓ Pumping	100	100
	✓ Manual extraction	-	-
	✓ Gravity-fed system	-	-
	Total	**155**	**100**
3	**Source of water**	Frequency	Percent
	✓ Ground	-	-
	✓ Surface	155	100
	✓ Rain	-	-
	Total	**155**	**100**
4	**Irrigation Frequency**		
	✓ Daily	-	-
	✓ 2-3 per week	76	49
	✓ Weekly	79	51
	✓ When necessary	-	-
	Total	**155**	**100**
5	**Irrigation Quality**	Frequence	
	✓ Excellent	-	-
	✓ Good	-	-
	✓ Poor	112	72.3
	✓ Very poor	43	27.7
	Total	**155**	**100**

According to the study, only 10 (6.5%) percent of respondents planted Cereals, making vegetables the most common crop, cultivated by 145 (93.5%) percent of respondents. Crop preferences or resource limitations may prevent the cultivation of fruits. Soil conditions, market demand, and other environmental factors may influence the dominance of vegetable farming. During the focus group discussion, the respondents stated that they prefer planting vegetables as it allows them to cultivate twice a year.

Every respondent 100 (100%) uses just surface water for irrigation; neither groundwater nor rainwater collection is used. This total dependence could compromise the supply of water, especially during dry seasons. Also, all respondents 100% abstract water using the pumping method. This could increase fuel costs. There is no daily or as-needed irrigation; 51% of respondents do it weekly, and 49% do it two to three times a week.

Irrigation water quality is rated as poor by the majority of respondents (72.3%) and as very poor by 27.7%, with no ratings of good or exceptional. Concerns regarding the possible effects of this pervasive discontent with water quality on crop production and public health.

4.2.2 Challenges in Water Management and Irrigation

Table 4 deals with various challenges that water management and irrigation encounter in the study area. Accordingly, the types of challenges faced, the severity, the cause of the challenge, and the ease of the challenges are considered.

Table 4:Challenges in Irrigation Water Management

No			
1	**Nature of challenges**	**Frequency**	**Percent**
	✓ Over-flooding during heavy rains	46	29.7
	✓ Poor water quality due to industrial waste	57	36.8
	✓ Cost of pumping	52	33.5
	Total	**155**	**100**
2	**Severity of Challenges**	**Frequency**	**Percent**
	✓ Moderately severe	50	32.3
	✓ Very severe	54	34.8
	✓ Extremely severe	51	32.9
	Total	**155**	**100**
3	**Cause of challenges**	**Frequency**	**Percent**
	✓ Over extraction of water	40	25.8
	✓ Climate change	51	32.9
	✓ Poor water management	64	41.3
	Total	**155**	**100**
4	**Ease of the Challenges**	**Frequency**	**Percent**

	✓ Improvement from a technological point of view	61	38.9
	✓ Improvement from a governance point of view	56	35.7
	✓ Improvement from community awareness and action	38	24.5
	Total	**155**	**100**

Table 4 shows that 57 (36.8 %) of respondents stated that poor water quality due to industrial waste is the main irrigation management issue, whereas 52 (33.5 %) of respondents attributed high-cost fuel as the second irrigation management issue. However, according to 29.7 % of respondents (46 respondaents), over-flooding during heavy rains is 3rd problem. Over-flooding issues should also be addressed, even though poor water quality and high fuel costs are serious problems that call for focused remedies.

The results suggest that the main challenges are poor water quality and high fuel prices, which are urgent issues that need to be addressed now. These findings indicate a critical need for focused remedies to enhance irrigation management in the area.

The respondents' opinions on the severity of the problem are shown in the table above. These difficulties are rated as somewhat serious by 32.3% of respondents (50), which means that they are not among the most urgent problems. 34.8% of respondents (54) who classify the situation as very serious are seriously concerned about water management. In addition, 32.9% of respondents (51 in total) describe an extremely difficult situation, indicating that many people are facing serious water-related problems that could affect their general well-being and agricultural yields. The result shows that urgent water management strategies are needed.

4.2.3 Water Quality and Quantity

This analysis contains irrigation water quality, awareness of changes over time.

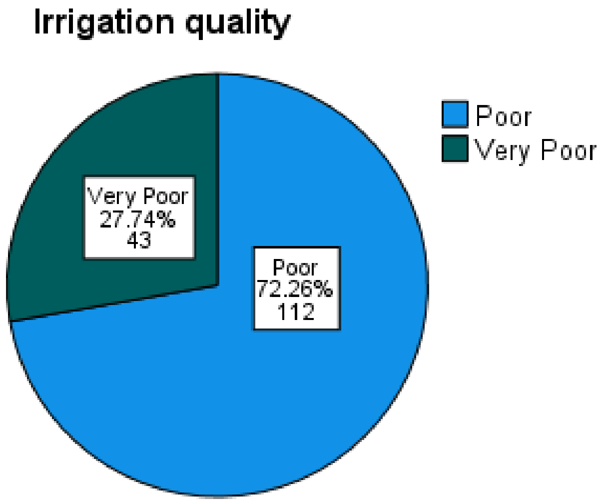


Figure 12: Irrigation Quality

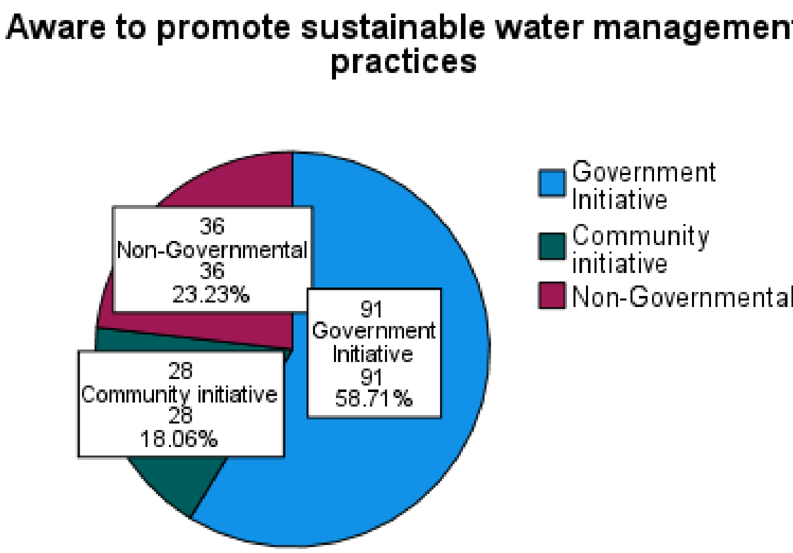


Figure 13: Awareness to Promote Sustainability

The assessment of irrigation water quality reveals a substantial perception among farmers that the water used for irrigation is degraded. Specifically, 72.26% (n = 112) of respondents rated the water quality as poor, while 27.74% (n = 43) rated it as very poor as illustrated in Figure 12. The absence of any positive ratings highlights a widespread wave of declining water quality within the Akaki Catchment, likely attributable to contamination from domestic, industrial, and urban runoff sources.

Regarding awareness of initiatives aimed at promoting sustainable water management, the findings demonstrate that a majority of respondents (58.71%, n = 91) are aware of government-led interventions, indicating that formal institutional actors are the primary agents in outreach and awareness creation. In contrast, community-based initiatives and non-governmental organizations represent smaller proportions, accounting for 18.06% (n = 28) and 23.23% (n = 36), respectively as shown in figure 13. This distribution suggests a relatively limited but meaningful involvement of community groups and NGOs in advocating sustainable water management practices.

Overall, the results highlight both the pressing water quality challenges perceived by farmers and the varying visibility of institutional actors engaged in awareness efforts. These findings emphasize the importance of encouragement, coordinated collaboration among government bodies, community organizations, and non-governmental stakeholders to effectively address water quality deterioration and enhance the reach and impact of sustainable water management programs.

4.2.4 Capacity Building and Technological Support

This analysis contains the training received on water-efficient techniques, the provider of training and support, and the technological and educational support needed.

Table 5: Training Received and Support Needed

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	91.554[a]	1	<.001		
Continuity Correction[b]	85.452	1	<.001		
Likelihood Ratio	67.388	1	<.001		
Fisher's Exact Test				<.001	<.001
Linear-by-Linear Association	90.963	1	<.001		
N of Valid Cases	155				

a. 1 cells (25.0%) have expected count less than 5. The minimum expected count is 3.25.

b. Computed only for a 2x2 table

The Pearson Chi-Square value is 91.554 with 1 degree of freedom and a p-value of .000, indicating a highly statistically significant association between the two variables being tested. The Continuity Correction (used for 2x2 tables to adjust for small sample size) also yields a significant result ($\chi^2 = 85.452$, $p = .000$), confirming this finding. The Likelihood Ratio and Fisher's Exact Test both reinforce the significance of the association with p-values of .000.

Although 1 cell (25%) has an expected count less than 5 (minimum expected count = 3.25), which slightly violates the assumption of the Chi-square test, the effect is limited. Given that Fisher's Exact Test also confirms significance, we can still rely on the result with caution.

The Linear-by-Linear Association statistic ($\chi^2 = 90.963$, $p = .000$) indicates a significant linear trend or ordinal relationship between the variables.

4.2.5 Irrigation and Perception of Water Management Effectiveness

A Chi-square test was used to determine if irrigation frequency relates to household opinions of the success of present water management practices in the Akaki Catchment. The findings indicate a statistically significant relationship between the two variables.

Table 6: Chi-Square Test for Irrigation Frequency with Farmer Opinions

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	68.513[a]	6	<.001
Likelihood Ratio	65.594	6	<.001
Linear-by-Linear Association	3.363	1	.067
N of Valid Cases	155		

a. 7 cells (58.3%) have expected count less than 5. The minimum expected count is 2.45.

A Chi-square test of independence was conducted to assess the relationship between the frequency of irrigation and the perceived effectiveness of water management among respondents (N = 155).

The Pearson Chi-Square value was $\chi^2(6) = 68.513$, with a p-value $< .001$, indicating a statistically significant association between the two variables

4.2.6 Perceptions and Effectiveness of Current Practices

Table 7: Perceptions and Effectiveness of Current Practices

NO			
1	**Effectiveness of irrigation water management**	**Frequency**	**Percent**
	✓ Some effective	12	7.7
	✓ Very ineffective	120	76.4
	✓ Not sure	13	8.4
	✓ Neutral	10	6.4
	Total	**155**	**100**
2	**Sustainability perceptions of current irrigation**	**Frequency**	**Percent**
	✓ Highly Sustainable	-	-
	✓ Moderately Sustainable	68	44.6
	✓ Not Sustainable	87	55.4
	✓ No Opinion/Not Informed	-	-
	Total	**155**	**100**

4.2.7 Policy, Government, and Community Participation

This part analysis contains how the police, the government, and the community improve irrigation water management practices.

Table 8: Ways of Irrigation Water Management Improvement

NO			
1	**How the Police solve the irrigation water management challenge**	**Frequency**	**Percent**
	✓ No intervention needed	28	17.8
	✓ Minor intervention	17	10.8
	✓ Major intervention	40	25.5
	✓ Urgent and Comparative intervention	70	44.6
	Total	**155**	**100**

2	**How does the government solve the irrigation challenge**	**Frequency**	**Percent**
	✓ Increased funding for water conservation projects	38	24.5
	✓ Training programs for farmers on sustainable water management	51	32.9
	✓ Public awareness engagements about water conservation	55	35.5
	✓ Improved water infrastructure and maintenance	11	7.1
	Total	**155**	**100**
3	**Community Participation**	**Frequency**	**Percent**
	✓ Community engagement and participatory management	**80**	**51.6**
	✓ Training programs for farmers on sustainable water management	**75**	**48.4**
	✓ Raising awareness	**79**	**50**
	✓ Participating in water conservation efforts	**64**	**41.3**
	✓ Total	**155**	**100**

The analysis of community participation revealed moderate involvement across all four measured components. More than half of respondents reported engaging in community engagement and participatory management (51.6%) and being aware of water-related issues (51.0%). Participation in training programs for farmers on sustainable water management was slightly lower at 48.4%, suggesting that training opportunities may not have reached all farmers or that some farmers might have faced barriers to attendance.

The lowest participation rate (41.3%) was observed in water conservation efforts such as tree planting, soil conservation, and maintenance of irrigation structures. This indicates an area that requires further mobilization and support to encourage active involvement in practical conservation initiatives.

Overall, while more than half of respondents are engaged and aware, there are clear gaps in training coverage and hands-on conservation activities, which may limit the overall impact of community participation on sustainable water management practices.

4.3 Water Abstraction and Irrigation Management Issues in Akaki

The study and field observations conducted in the Akaki catchment found that all farmers irrigate their fields using individual water pumps from the Akaki River. Each farmer uses a separate fuel-powered pump, which greatly raises irrigation expenses. Furthermore, due to the lack of a coordinated irrigation schedule, farmers often use excessive quantities of water, resulting in over-irrigation. This method has led to inadequate irrigation management, inefficient water consumption, and higher production costs.

4.4 Water Requirements of the Major Crops Cultivated

The FAO Penman calculates the reference evapotranspiration ETo- Monteith method, using decision support software CROPWAT 8.0 developed by FAO, based on FAO Irrigation and Drainage Paper 56 (Allen et al. 2011). Climate, crop, soil, and rainfall data are the four primary categories of information needed by the CROPWAT 8.0 program. Long-term climatic data, including maximum and minimum temperatures, daily relative humidity, sunshine hours, wind speed, and monthly rainfall, covering 22 years (2000–2022), were acquired from the National Meteorological Agency for this study. Although excessive watering can damage crops by saturating the soil and reducing air availability, irrigation is essential for crop growth. The overall amount of irrigation water needed is the crop's water requirements for transpiration and evaporation. Water needs are approximately half of those during the midseason when transpiration peaks and crops are fully formed, whereas evaporation predominates during the early growth stages. Depending on the stage of crop growth, irrigation schedules should change.

4.4.1 Calculating Crop Water Requirements Using CROPWAT 8.0 Model

The data that were entered into the CROPWAT8.0 software included the country (Ethiopia), climatic station (Akaki), type of crop, date of cultivation, and soil type (clay soil). Once all the data were entered into the software, it calculated the climatic parameters, ETo, effective rainfall, and total irrigation requirements for the studied crop. Other outputs of the CROPWAT program are presented in tables and charts in the next paragraphs. Table

9 contains data about the four crops in this study. Table 10 contains the climate characteristics of the Akaki area.

Table 9: Input Data for CROPWAT 8.0 Model

Location	**Akaki, Oromia**	**Station**	**Crop-type Coverage area**	**Area %**
County	Ethiopia		Cabbage	30%
Latitude	8.872 N	Akaki	Vegetabe	40%
Longitude	38.78 E	Akaki	Tomato	20%
Elevation	2057	Akaki	Potato	10%
			Total	100%

Table 10:Climatic Characteristics of Study Area

Month	**Min temp (oC)**	**Max temp (oC)**	**Humidity (%)**	**Wind (Km/day)**	**Sunshine (hr)**	**RF (mm)**
January	4.1	27.9	55.0	2.2	9.1	8.5
February	5	29	51.0	2.5	8.8	18.3
March	8.5	31.9	53.6	2.4	8.1	46.2
April	8.7	29.6	63.7	2.2	6.9	78.0
May	8.3	30	62.6	2.1	7.0	69.6
June	8.1	29.3	68.2	1.6	5.2	112.3
July	8.8	25.8	80.7	1.6	3.0	236.4
August	8.4	24.9	83.4	1.4	3.3	229.6
September	7.2	26.1	80.8	1.4	4.8	123.3
October	7.7	27.4	70.3	2.2	8.1	25.4
November	7.5	27.2	63.7	2.2	8.9	8.1
December	3.4	26.9	59.4	2.2	9.1	4.5

4.4.2 Filling Missing Meteorological Data

Missing Meteorological data can pose significant challenges in hydrological analysis. Common reasons for missing data include the failure of the instrument or the absence of observers responsible for periodic gauge readings, damage to recording instruments, and mechanical or electrical failures. To address this issue, a multiple regression filling method was employed to estimate missing data for rainfall and climatic analysis in the Akaki catchment. Initially, the station that best correlates with the records of the station in question was identified using a method that accounts for the percentage of missing data. Then, after, a multiple regression analysis was performed to obtain an equation that estimates missing values for the corresponding periods.

4.4.3 Homogeneity Test

The homogeneity of rainfall data for the Akaki Catchment, including stations at Akaki, OBS, Bole, and Entoto, was evaluated through graphical methods. These methods provide a visual assessment of the temporal consistency of rainfall records, facilitating the detection of shifts attributable to nonclimatic factors such as station relocations and environmental changes. By plotting cumulative rainfall deviations and comparing trends among the various stations, this analysis identifies inconsistencies within the dataset, thereby ensuring its reliability for ensuing hydrological studies and irrigation planning. The results confirm the strength of the data, enabling a precise evaluation of rainfall trends and their implications for water management in the catchment area is important.

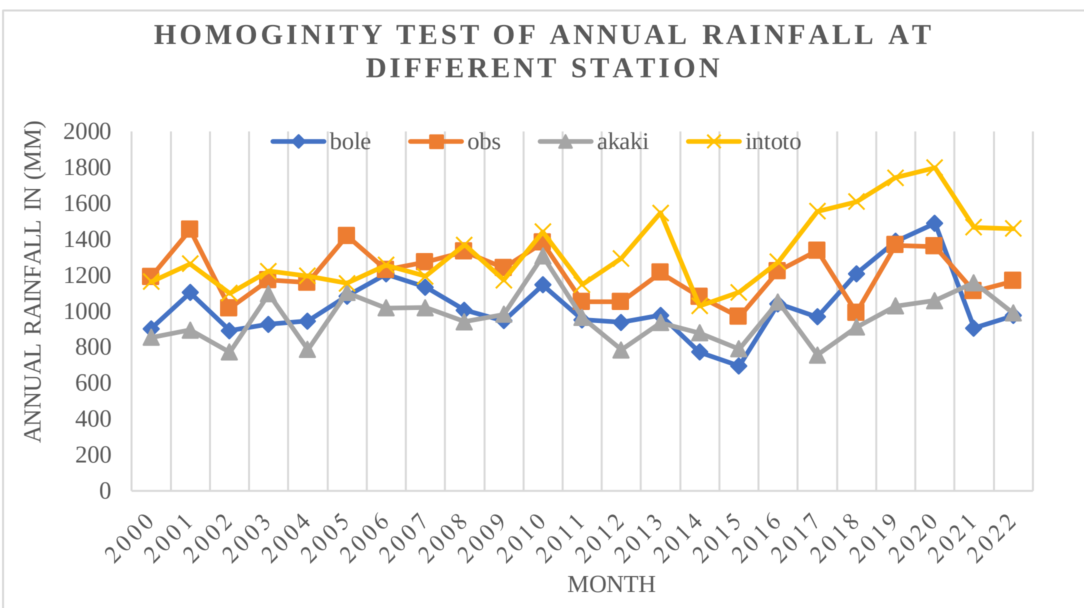


Figure 14:Annual Rainfall Graph of Different Stations

4.4.4 *Reference Crop Evapotranspiration*

The model calculated the Akaki catchment's mean monthly reference evapotranspiration to be 3.3 mm/day. The monthly evapotranspiration was lowest in July (2.66 mm/day) and at its peak in March (3.85 mm/day), which was above average. The observed ETo between February and May exceeded the average ETo (Table 4). Increased evapotranspiration was caused by low humidity and the highest temperatures between February and April. Because there were fewer hours of sunshine and lower temperatures from July to September, the ETo value was lower.

Table 4: Reference Crop Evapotranspiration (ETo) for Akaki Station

Country: Ethiopia **Station: Akaki**
Altitude 2057m **Latitude 8.87 N** **Longitude 38.78 E**

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun Hours	Rad MJ/m²/day	Rain mm	Eff. Rain	ETo mm/day
January	4.1	27.9	55	2	9.1	20.9	8.5	0	3.21
February	5	29	51	3	8.8	21.8	18.3	1	3.45
March	8.5	31.9	54	2	8.1	21.8	46.2	17.7	3.85
April	8.7	29.6	64	2	6.9	20.1	78	38.4	3.71
May	8.3	30	63	2	7	19.8	69.6	31.8	3.62
June	8.1	29.3	68	2	5.2	16.8	112.3	65.8	3.18
July	8.8	25.8	81	2	3	13.6	236.4	165.1	2.66
August	8.4	24.9	83	1	3.3	14.3	229.6	159.7	2.73
September	7.2	26.1	81	1	4.8	16.6	123.3	74.6	3.03
October	7.7	27.4	70	2	8.1	20.9	25.4	5.2	3.59
November	7.5	27.2	64	2	8.9	20.9	8.1	0	3.44
December	3.4	26.9	59	2	9.1	20.4	4.5	0	3.14
Average	**7.1**	**28**	**66**	**2**	**6.9**	**19**	**960.2**	**559.4**	**3.3**

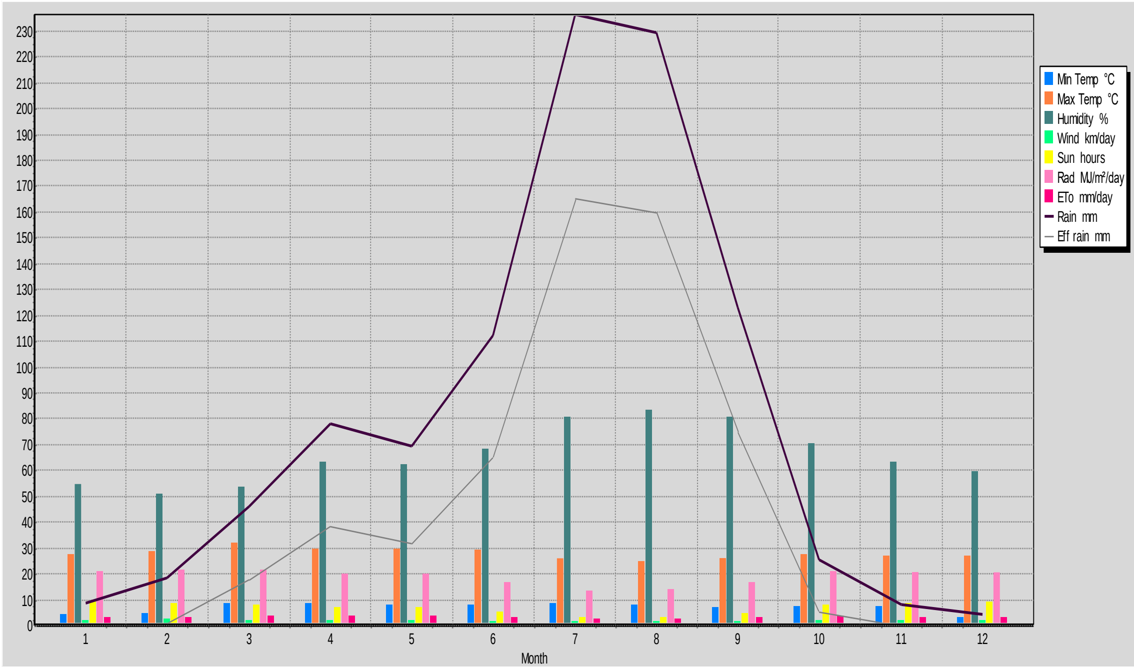


Figure 15:Climate/Eto/Rain Chart

The chart above shows that the maximum rainfall recorded in July was 236.4 mm, with an effective rainfall of 165.1 mm, and the minimum rainfall in December was 4.5 mm, with an effective rainfall of 0 mm. The findings highlight that irrigation is necessary in December. Most agricultural irrigation operations in Ethiopia start their work after this month (Gebeyhu, Dagalo, and Muluneh 2024).

4.4.5 Effective Rainfall

Part of the rainfall that is useful to plants for agricultural production is referred to as effective rainfall. Because some water is lost through runoff (RO) and deep percolation (DP), the crops cannot use all the rainfall. CROPWAT 8.0 offers the possibility to use several methods to calculate the effective rainfall, such as Fixed percentage of rainfall, Dependable Rain, Empirical formula and USDA Soil Conservation Service Method. In this this the effective rainfall was calculated by dependaple rainfall (FAO). The Akaki weather station provided average monthly rainfall data for each month. To calculate crop water requirements, we need long-term data, at least 10 Years up to 30 Years later. For this study, 22 years of monthly data were gathered to determine the effective rainfall of the catchment.

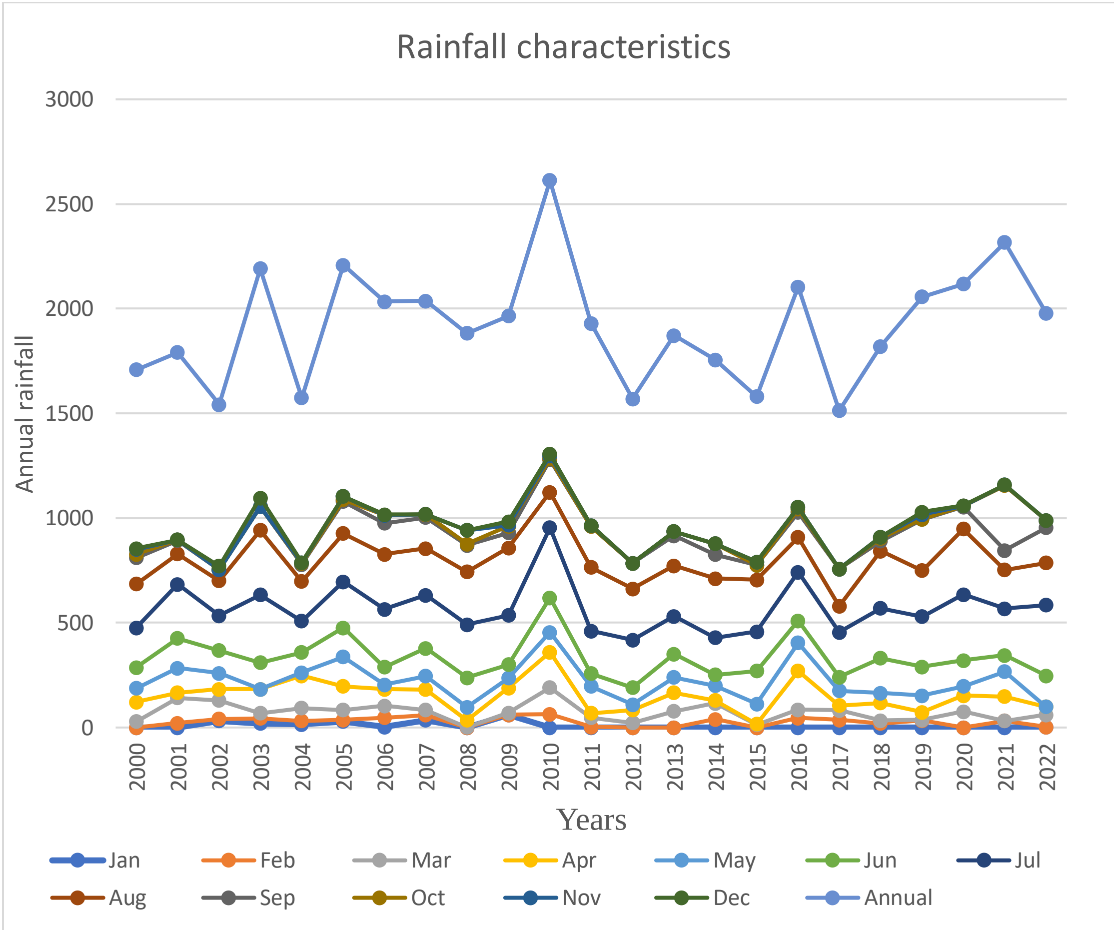


Figure 16:Akaki Monthly Rainfall

The above chart shows that the maximum rainfall was recorded in July 2010 as 1306.1 mm annually and the average annual of 236.44mm. The annual minimum rainfall was recorded in December 2017 as 756.6 mm, with an average annual rainfall of 4.5 mm.

4.4.6 Rainfall Characteristics

559.4 mm of rainfall was effective for plant growth, out of an average of 960.2 mm of rainfall per year (Table 5). July experienced the highest precipitation at 236.4 mm, with 165.1 mm being effective for plant growth (Table 5). Conversely, December recorded the lowest rainfall at 4.5 mm, with no effective rainfall for plant growth (Table 5). The period from June to September received the most rainfall, accounting for nearly 73% of the total.

Effective rainfall varied between 0 and 17.7 mm from November to March (Table 5), indicating a need for supplemental irrigation during this period.

Table 5: Climate/Eto/Rain Akaki Catchment

Month	**Rain (mm)**	**Eff rain (mm)**
January	8.5	0
February	18.3	1
March	46.2	17.7
April	78	38.4
May	69.6	31.8
June	112.3	65.8
July	236.4	165.1
August	229.6	159.7
September	123.3	74.6
October	25.4	5.2
November	8.1	0
December	4.5	0
Totkal	**960.2**	**559.4**

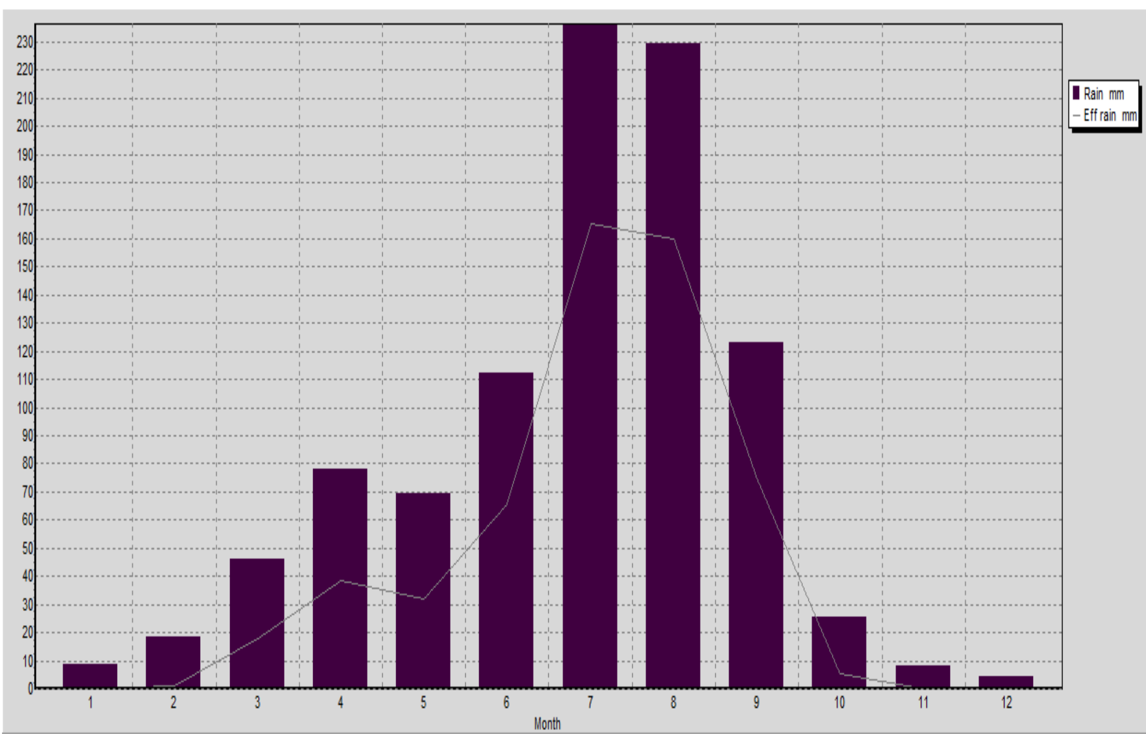


Figure 3: Climate/Eto/Rain Akaki Catchment Graph

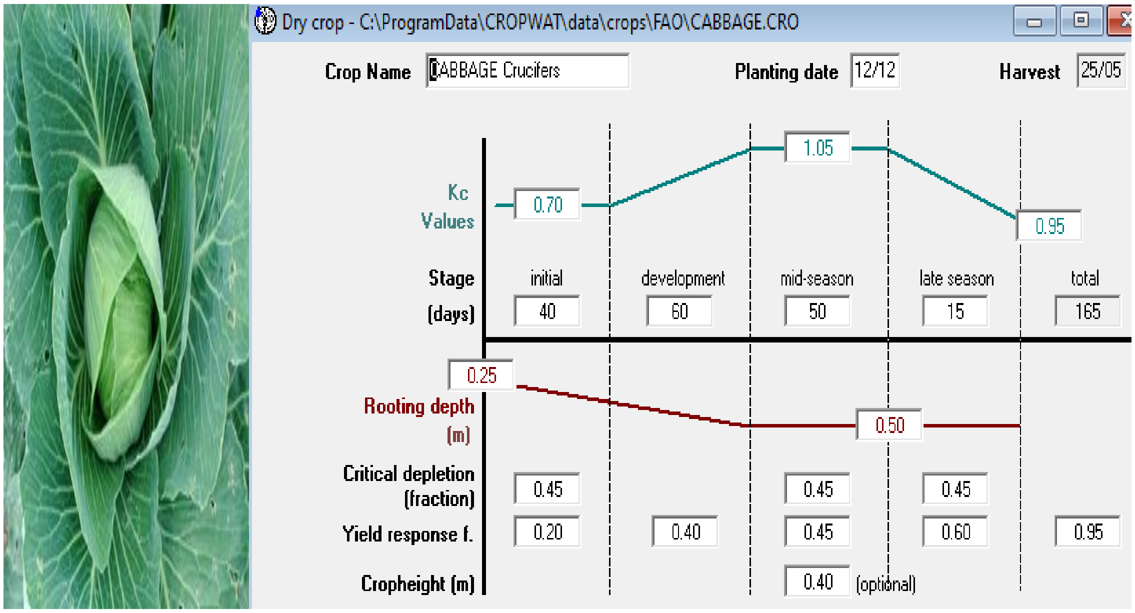


Figure 4: Crop type (Cabbage)

Table 11Crop evapotranspiration and irrigation water requirement at different growth stages of cabbage at Akaki catchment.

Table 11: CWR and IR of Cabbage

Crop Water Requirements

ETo station: Akaki Crop: CABBAGE Crucifers
Rain station: Akaki Planting date: 12/12

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	2	Init	0.70	2.20	19.8	0.0	19.8
Dec	3	Init	0.70	2.22	24.4	0.0	24.4
Jan	1	Init	0.70	2.23	22.3	0.0	22.3
Jan	2	Init	0.70	2.25	22.5	0.0	22.5
Jan	3	Deve	0.73	2.42	26.6	0.1	26.5
Feb	1	Deve	0.80	2.68	26.8	0.0	26.8
Feb	2	Deve	0.85	2.95	29.5	0.0	29.5
Feb	3	Deve	0.91	3.25	26.0	1.1	24.9
Mar	1	Deve	0.96	3.56	35.6	3.9	31.7
Mar	2	Deve	1.02	3.91	39.1	5.8	33.3
Mar	3	Mid	1.05	3.98	43.8	8.1	35.7
Apr	1	Mid	1.05	3.93	39.3	11.3	28.0
Apr	2	Mid	1.05	3.88	38.8	14.1	24.8
Apr	3	Mid	1.05	3.86	38.6	12.9	25.7
May	1	Mid	1.05	3.83	38.3	10.1	28.2
May	2	Late	1.01	3.66	36.6	8.7	28.0
May	3	Late	0.96	3.34	16.7	6.0	10.2
					524.7	**82.0**	**442.1**

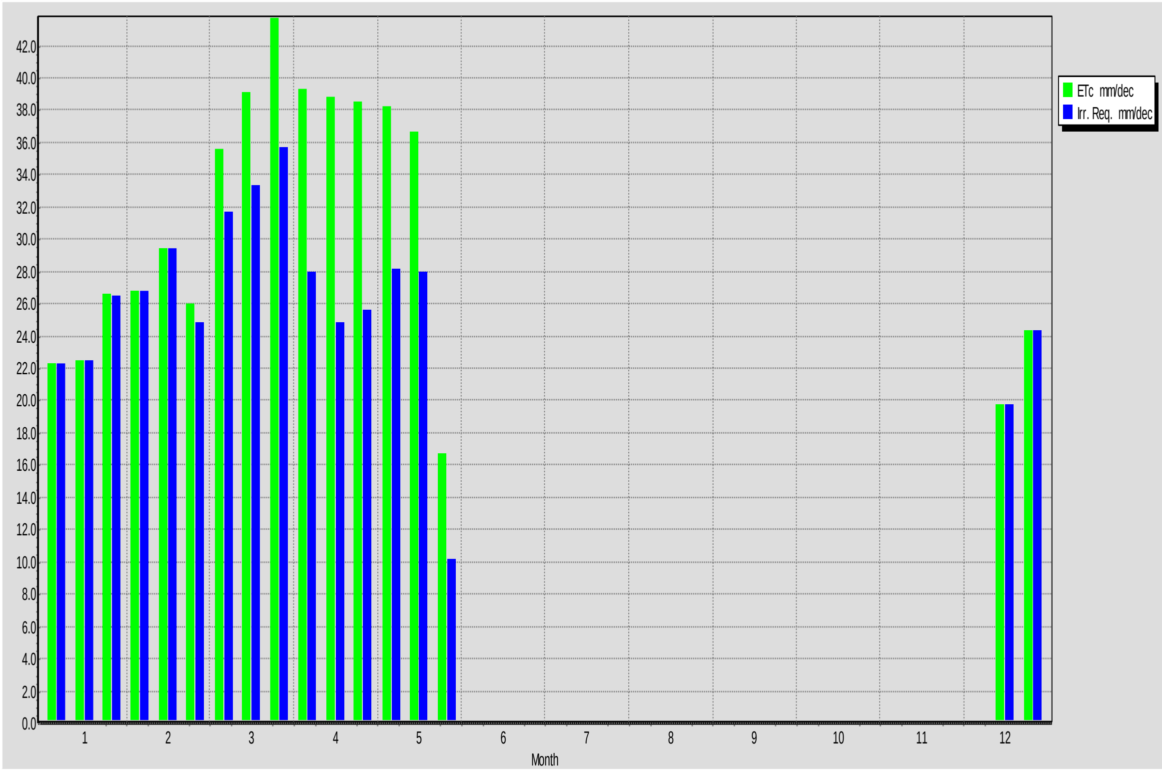


Figure 8: Crop Water Requirement Graph of Cabbage

Table 12: Irrigation Scheduling of Cabbage

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
12-Dec	1	Init	0	0.91	91	54	27.3	0	0	68.1	7.89
23-Dec	12	Init	0.9	1	100	45	25.5	0	0	63.7	0.67
5-Jan	25	Init	0	1	100	48	30.1	0	0	75.3	0.67
20-Jan	40	Init	0	1	100	48	33.7	0	0	84.2	0.65
4-Feb	55	Dev	0	1	100	45	35.1	0	0	87.6	0.68
19-Feb	70	Dev	0	1	100	46	38.8	0	0	97	0.75
9-Mar	88	Dev	0	1	100	47	44.5	0	0	111.3	0.72
29-Mar	108	Mid	0	1	100	47	47.1	0	0	117.8	0.68
30-Apr	140	Mid	0	1	100	47	46.9	0	0	117.1	0.42
25-May	End	End	0	1	0	35					

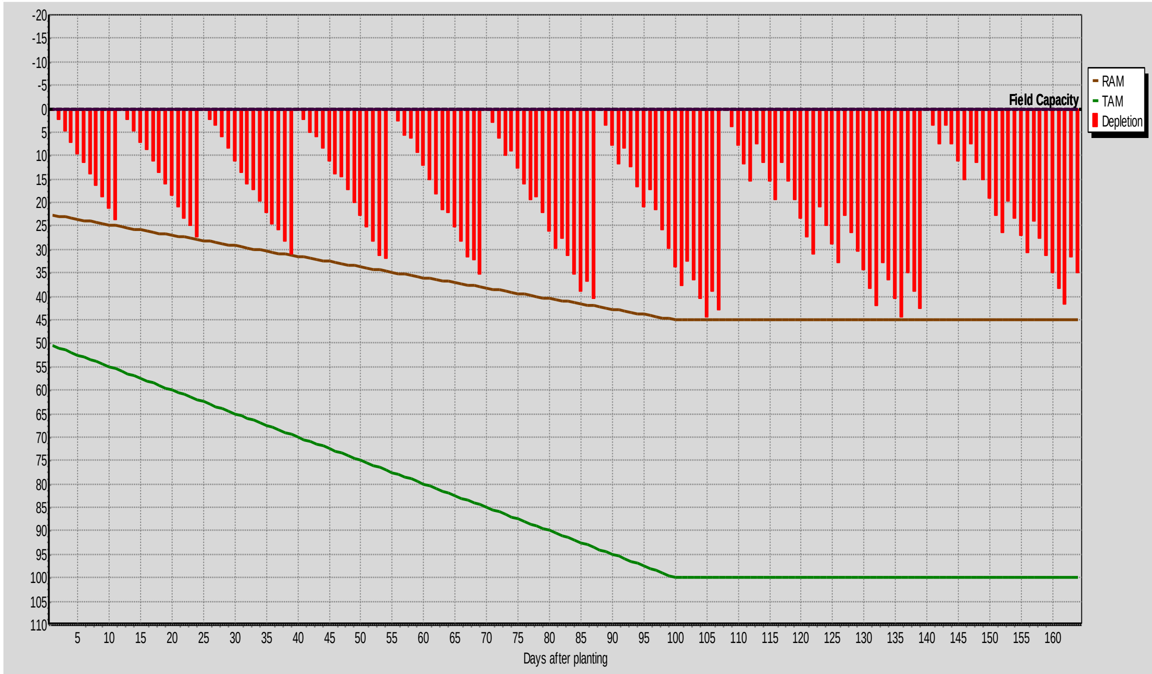
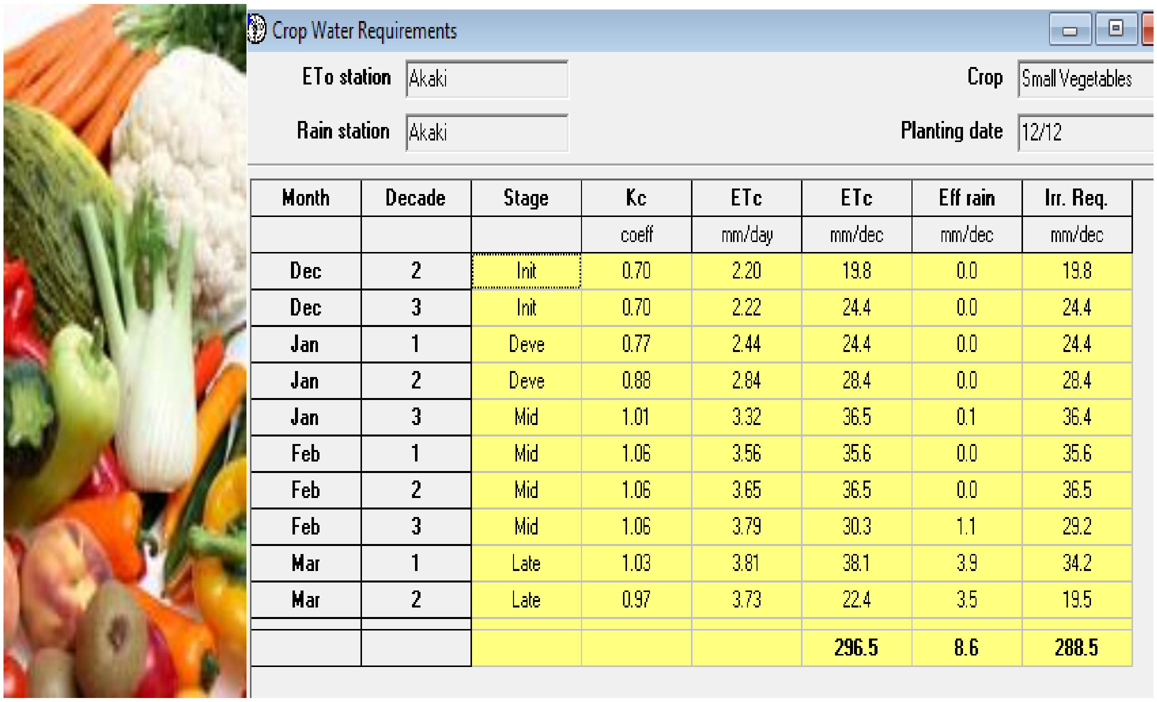


Figure 8: Irrigation Scheduling Graph of Cabbage

The CROPWAT8.0 model calculates the irrigation water requirement for cabbage in nine irrigation schedules as illustrated in Figure 8 and Table 8. The first schedule is December 12. The second, third, fourth, fifth, and sixth irrigations are after 11,13,15,15, and 15days respectively. This means after about two weeks in the initial and development phases. The seventh, eighth, and ninth irrigation is scheduled after 18, 20,32 days, respectively, after the sixth irrigation. It indicates that the seventh and eighth irrigation takes place approximately three weeks after the sixth irrigation, and the last irrigation one month after the eighth irrigation. According to the model, the total gross water requirement of cabbage is 822.1 mm with a net irrigation requirement of 328.8mm. Irrigation is 100% efficient with 98.3% of rainfall efficiency. Furthermore, the water requirement of cabbage is 524.7 mm/dec and the irrigation requirement is 442.1 mm/dec (Table 6).

Table 13:CWR and IR Vegetable (Onions and Carrots)


Crop Water Requirements

ETo station Akaki
Crop Small Vegetables

Rain station Akaki
Planting date 12/12

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	2	Init	0.70	2.20	19.8	0.0	19.8
Dec	3	Init	0.70	2.22	24.4	0.0	24.4
Jan	1	Deve	0.77	2.44	24.4	0.0	24.4
Jan	2	Deve	0.88	2.84	28.4	0.0	28.4
Jan	3	Mid	1.01	3.32	36.5	0.1	36.4
Feb	1	Mid	1.06	3.56	35.6	0.0	35.6
Feb	2	Mid	1.06	3.65	36.5	0.0	36.5
Feb	3	Mid	1.06	3.79	30.3	1.1	29.2
Mar	1	Late	1.03	3.81	38.1	3.9	34.2
Mar	2	Late	0.97	3.73	22.4	3.5	19.5
					296.5	8.6	288.5

Table 14:Irrigation Scheduling of small vegetables

Date	Day	Stage	Rain Mm	Ks fract.	Eta (%)	Depl (%)	Net Irr (mm)	Deficit (mm)	Loss (mm)	Gr. Irr (mm)	Flow (l/s/ha)
12-Dec	1	Init	0	0.71	71	53	27.3	0	0	68.2	7.89
19-Dec	8	Init	0	1	100	32	19.7	0	0	49.3	0.81
28-Dec	17	Init	0	1	100	33	24.5	0	0	61.2	0.79
8-Jan	28	Dev	0	1	100	36	31.7	0	0	79.2	0.83
22-Jan	42	Dev	0	1	100	43	47.2	0	0	118	0.98
8-Feb	59	Mid	0	1	100	46	55.1	0	0	137.7	0.94
26-Feb	77	Mid	0	1	100	47	56.7	0	0	141.8	0.91
16-Mar	End	End	0	1	100	37					

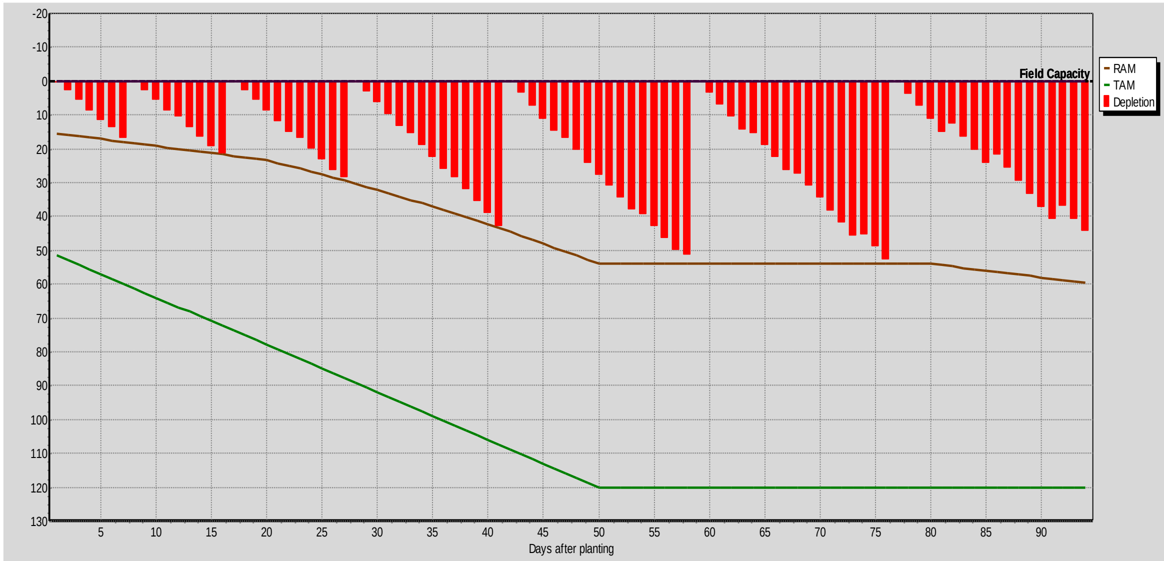


Figure 17: Irrigation Scheduling of small Vegetables

The CROPWAT 8.0 model calculates the irrigation water requirement for small vegetables in seven irrigation schedules (Table 14 and Figure 17). The first irrigation is on December 12. The second irrigation schedule is one week after the first irrigation. The third, fourth, and fifth irrigations are after 9, 11, and 14 days, respectively, which implies approximately the third irrigation is after one week of the second irrigation, and the fourth and fifth irrigations are after two weeks of the fourth and fifth irrigations, respectively. The sixth and seventh irrigation scheduling is after 17 and 18 after the sixth irrigation scheduling. According to the model, the total gross irrigation of small vegetables is 655.4mm with a total net irrigation is 262.1 mm. Furthermore, the water requirement for small vegetables is 296.5 mm/dec and the irrigation requirement is 288.5 mm/dec (Table 13).

Table 15:CWR and Irrigation Scheduling of Potatoes

Crop Water Requirements

ETo station: Akaki Crop: Potato

Rain station: Akaki Planting date: 12/12

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	2	Init	0.50	1.57	14.1	0.0	14.1
Dec	3	Init	0.50	1.58	17.4	0.0	17.4
Jan	1	Deve	0.53	1.70	17.0	0.0	17.0
Jan	2	Deve	0.73	2.35	23.5	0.0	23.5
Jan	3	Deve	0.96	3.16	34.8	0.1	34.7
Feb	1	Mid	1.14	3.86	38.6	0.0	38.6
Feb	2	Mid	1.16	3.99	39.9	0.0	39.9
Feb	3	Mid	1.16	4.15	33.2	1.1	32.1
Mar	1	Mid	1.16	4.30	43.0	3.9	39.0
Mar	2	Mid	1.16	4.45	44.5	5.8	38.7
Mar	3	Late	1.09	4.14	45.5	8.1	37.4
Apr	1	Late	0.95	3.55	35.5	11.3	24.2
Apr	2	Late	0.81	3.00	30.0	14.1	16.0
					416.9	44.4	372.5

Table 16:Irrigation Scheduling of Potatoes

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	Mm	mm	mm	l/s/ha
12-Dec	1	Init	0	0.67	67	52	31.6	0	0	79	9.14
21-Dec	10	Init	0	1	100	26	18.4	0	0	46.1	0.59
1-Jan	21	Init	0	1	100	26	21.8	0	0	54.4	0.57
13-Jan	33	Dev	1.3	1	100	26	25.4	0	0	63.4	0.61
24-Jan	44	Dev	0	1	100	30	31.9	0	0	79.7	0.84
4-Feb	55	Dev	0	1	100	32	38.9	0	0	97.2	1.02
15-Feb	66	Mid	0	1	100	32	38.2	0	0	95.5	1.01
26-Feb	77	Mid	0	1	100	32	37.9	0	0	94.6	1
10-Mar	89	Mid	0	1	100	33	39.1	0	0	97.7	0.94
22-Mar	101	End	0	1	100	31	37.5	0	0	93.8	0.9
20-Apr	End	End	0	1	100	32					

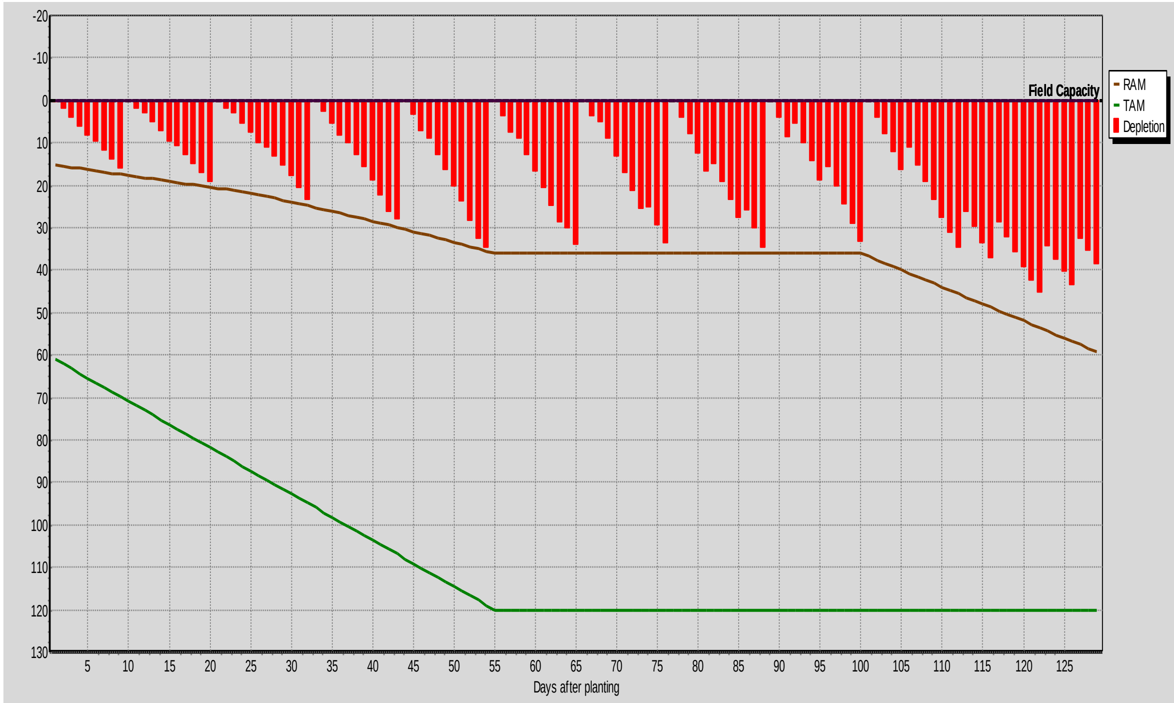


Figure 18:Irrigation Scheduling Graph of Potatoes

The CROPWAT 8.0 model calculates the irrigation water requirement for potatoes in ten irrigation schedules (Table 16 and Figure 18). The first irrigation was scheduled for December 12, with the following irrigation events occurring at intervals of 9,11,11,11,11, 11,12, 11, and 12 days, respectively. The total gross irrigation requirement for the potato crop was calculated to be 801.5 mm, while the total net irrigation is 320.6 mm. Furthermore, the total crop water requirement is 416.9mm/dec and the corresponding irrigation water requirement is 372.5mm/dec. These results provide a baseline for evaluating the best irrigation scheduling and improving water use efficiency for the potato crop in the study area.

Table 17:Irrigation Scheduling of Tomato

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	Mm	mm	mm	l/s/ha
12-Dec	1	Init	0	0.71	71	53	27.4	0	0	68.6	7.94
20-Dec	9	Init	0	0.99	100	33	23.1	0	0	57.7	0.83

30-Dec	19	Init	0	1	100	31	28	0	0	70.1	0.81
12-Jan	32	Dev	0	1	100	31	37.2	0	0	92.9	0.83
29-Jan	49	Dev	0	1	100	35	54.4	0	0	136.1	0.93
18-Feb	69	Dev	0	1	100	40	79.6	0	0	199.1	1.15
16-Mar	95	Mid	0	1	100	41	81.8	0	0	204.4	0.91
5-May	End	End	0	1	100	42					

Table 18: Crop Evapotranspiration and CWR of Tomatoes

Crop Water Requirements

ETo station: Akaki | Crop: Tomato

Rain station: Akaki | Planting date: 12/12

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	2	Init	0.60	1.88	17.0	0.0	17.0
Dec	3	Init	0.60	1.90	20.9	0.0	20.9
Jan	1	Init	0.60	1.91	19.1	0.0	19.1
Jan	2	Deve	0.68	2.17	21.7	0.0	21.7
Jan	3	Deve	0.82	2.71	29.8	0.1	29.7
Feb	1	Deve	0.97	3.26	32.6	0.0	32.6
Feb	2	Mid	1.10	3.81	38.1	0.0	38.1
Feb	3	Mid	1.15	4.14	33.1	1.1	32.0
Mar	1	Mid	1.15	4.29	42.9	3.9	38.9
Mar	2	Mid	1.15	4.44	44.4	5.8	38.6
Mar	3	Mid	1.15	4.39	48.3	8.1	40.1
Apr	1	Late	1.14	4.27	42.7	11.3	31.3
Apr	2	Late	1.03	3.81	38.1	14.1	24.1
Apr	3	Late	0.91	3.34	33.4	12.9	20.6
May	1	Late	0.82	2.99	15.0	5.0	9.9
					477.1	**62.3**	**414.7**

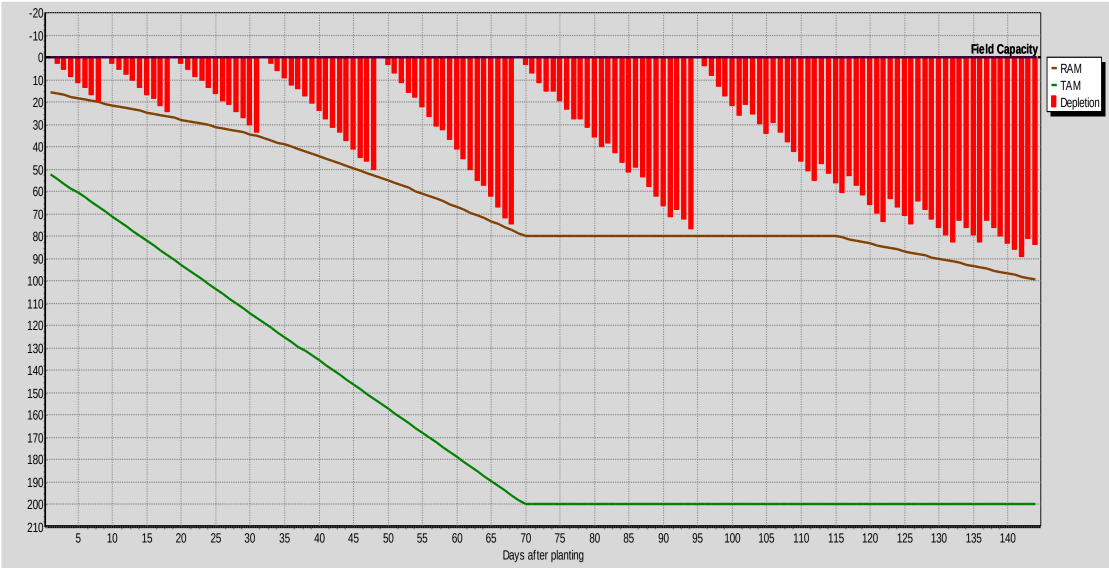


Figure 19: Irrigation Scheduling Graph of Tomatoes

CROPWAT 8.0 model calculates the irrigation water requirement for tomatoes in seven irrigation timetables (Table 18). The first irrigation was scheduled for December 12, with subsequent irrigation events occurring at intervals of 8, 10, 13, 17, 20, and 26 days, respectively. The total gross irrigation requirement for the tomato crop was calculated to be 828.8 mm, while the total net irrigation requirement was 331.5 mm. Additionally, the total crop water requirement was estimated at 477.7 mm/dec, and the corresponding irrigation water requirement was 414.7 mm/dec. These results provide a baseline for evaluating optimal irrigation scheduling and improving water use efficiency for tomato production in the study area.

No.	Crop file	Crop name	Planting date	Harvest date	Area %
1.	...\CROPWAT\data\crops\FAO\CABBAGE.CRO	CABBAGE Crucifers	12/12	25/05	30
2.	...CROPWAT\data\crops\FAO\VEGETABL.CRO	Small Vegetables	12/12	16/03	40
3.	...\CROPWAT\data\crops\FAO\POTATO.CRO	Potato	12/12	20/04	10
4.	...\CROPWAT\data\crops\FAO\TOMATO.CRO	Tomato	12/12	05/05	20

Figure 20:Crop Pattern in the Study Area

Figure 20 shows the cropping pattern in the study area, which includes cabbage, vegetables, potatoes, and tomatoes. The planting date for all four crops is the same day, December 12. However, the water requirement for irrigation and the harvest days are different for all four crops.

Table 19: Crop Pattern in the Study Area

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. CABBAGE Crucifers	71.3	81.2	100.7	78.5	66.3	0	0	0	0	0	0	44.2
2. Small Vegetables	89.3	101.3	53.7	0	0	0	0	0	0	0	0	44.2
3. Potato	75.1	110.6	115.2	40.1	0	0	0	0	0	0	0	31.5
4. Tomato	70.5	102.7	117.7	76	9.9	0	0	0	0	0	0	37.9
Net scheme irr.req.												
in mm/day	2.5	3.4	2.8	1.4	0.7	0	0	0	0	0	0	1.3
in mm/month	78.7	96.5	86.8	42.7	21.9	0	0	0	0	0	0	41.6
in l/s/h	0.29	0.4	0.32	0.16	0.08	0	0	0	0	0	0	0.16
Irrigated area	100	100	100	60	50	0	0	0	0	0	0	100
(% of total area)												
Irr.req. for actual area	0.29	0.4	0.32	0.27	0.16	0	0	0	0	0	0	0.16
(l/s/h)												

All crops are grown on the same day, December 12 but have different harvesting days (Figure 20 and Table 20). From December to March, all crops need to be irrigated, and 100% of the area is irrigated. As shown in Table 20 shows the crops grown in the catchment area (cabbage, vegetables, potatoes, and tomatoes). The irrigation requirement of cabbage is 44.2 mm, 71.3 mm, 80.2 mm, 100.7 mm, 78.5 mm, and 66.3 mm, respectively, from December to May and may 25 is the harvesting days of cabbage. The irrigation requirement of small vegetables is 44.2 mm, 89.3 mm, 101.3 mm, and 53.7 mm from December to March, with March 16 being the harvest day for vegetables. The irrigation requirement of potatoes is 31.5 mm, 75.1 mm, 110.6 mm, 115.2 mm, and 40.1 mm from December to April, and the harvest day for potatoes is April 20. The irrigation requirement of tomatoes is 37.9 mm, 70.5 mm, 102.7 mm, 117.7 mm, 76 mm and 9.9 mm respectively from December to may and the harvest day of tomatoes is May 5.

4.5 Water Application and Crop Productivity

In the current study area, crop productivity is highly affected by the amount, timing, and method of irrigation water application. Field observations and farmers' responses indicated that inappropriate irrigation practices particularly over-irrigation are among the main factors causal to yield reduction. Many farmers apply water frequently without considering the specific water requirements of each crop. During focus group discussions, one participant remarked, "We don't have a problem of water availability, so we frequently irrigate our crops," illustrating a common perception that more water always leads to better yields. However, this method has the opposite effect, as excessive irrigation causes waterlogging, nutrient leaching, and root zone oxygen deficiency, all of which reduce crop performance.

The results also indicated that farmers hardly use scientific irrigation scheduling or water measurement tools. Most rely on visual observation or personal experience to decide when and how much to irrigate. This practice leads to both under- and over-irrigation at different stages of crop growth. Such conditions cause uneven plant growth and reduce water-use efficiency. These findings are constant with studies by Tesfaye et al., 2019 which reported that improper irrigation scheduling and over-application of water are major causes of low productivity in smallholder irrigation schemes in Ethiopia.Moreover, several respondents reported that over-flooding during heavy rainfall events further aggravates the problem by washing away topsoil and nutrients, resulting in crop damage and yield loss. This situation is particularly common in poorly leveled fields or areas lacking proper drainage infrastructure. Hence, even though water resources are available, inefficient water management practices harm both water productivity and crop yield. Overall, the findings highlight the need for improved water management practices, including the adoption of irrigation scheduling based on crop water requirement (CWR) estimated through tools like CROPWAT 8.0, as well as farmer training on efficient water application methods. Implementing these measures would help optimize irrigation efficiency, reduce wastage, and enhance crop productivity in the study area.

5 DISCUSSION

5.1 Introduction

This chapter discusses the findings regarding irrigation water management, the problems faced, and suggests alternatives for improvement.

5.2 Existing Irrigation Development Patterns and Management Practices

The study shows that irrigation development in the area is dominated by traditional surface irrigation methods. Key challenges identified include water quality issues, flooding during heavy rain, and the high cost of fuel for pumping water. According to the frequency analysis, 36.8% of respondents (n=57) stated poor water quality caused by municipal or industrial waste as their top irrigation management problem. High fuel costs were identified as the second biggest concern by 33.5% of respondents (n=52), with 29.7% (n=46) referring to over-flooding after heavy rains as the third major challenge. Although poor water quality and high fuel prices emerged as the most pressing constraints, over-flooding must also be addressed because it poses a significant threat to irrigation systems and agricultural productivity. These findings highlight the immediate need for focused interventions to address water pollution and growing irrigation fuel costs, as well as the implementation of flood-risk management techniques.

5.2.1 Water Management Strategies for the Study Area

Effective irrigation management must consider the soil type, the water requirements of the plants, and the climatic conditions of the area. For better irrigation management, it is important to know the soil characteristics of the area in question. The soil type of the current study is the majority of Vertisols (68%) with a high clay content, which can store water for longer, but also hinders water infiltration. The findings highlight that careful irrigation management is required to avoid waterlogging.

- **Chronic Vertisols**: This soil is known as a vertisol and has a high clay content with good moisture retention. Irrigation should be well controlled to avoid runoff and waterlogging. Although Vertisols are naturally fertile, they have limited nutrient availability due to their difficult workability and poor drainage conditions.

According to an earlier study (Wubetu 2017), vertisols have deep profiles and high clay content, which contributes to their exceptional 60-70% water-holding ability.

- **Calcic Xerosols**: This type of soil is often dry. A drip irrigation system may be important for this type of soil to reduce water loss and improve soil moisture.

Chronic Cambisols and Luvisols: These soils benefit from moderate irrigation techniques that avoid over-saturation, promoting healthy crop growth

5.2.2 *Water Quality Impacts*

The research results show that the major challenge is the water quality issue. Pollution from industrial discharges, urban runoff, and agricultural chemicals leads to contamination, resulting in heavy metals, high nutrient levels, and microbial contaminants in irrigation water. According to these contaminants, not only harm soil health but also reduce crop yields and pose a risk to the health of farmers and consumers. Furthermore, (Gudeta et al. 2024) and (Qadir 2010) support these conclusions and show that the continuous use of polluted water for irrigation harms agricultural productivity and environmental sustainability. To address the issue, several pollution control strategies need to be implemented, wastewater treatment processes need to be improved, and water quality monitoring systems need to be strengthened.

5.2.3 Flooding During Heavy Rainfall

All the problems of waterlogging, soil erosion, crop damage, and yield reduction are due to the mismanagement of irrigation water and the problem of over-flooding during heavy rainfall in the current study area. This is due to the lack of well irrigation water management practice, which is the cause of reduced yield and environmental damage. These findings align with prior research (Deribie 2015), which concluded the impact of inadequate flood management on agricultural productivity. To control these challenges, appropriate management of water resources, such as flood control, effective drainage systems, and well irrigation practices, should be prioritized.

5.2.4 High Fuel Costs for Irrigation Pumping Systems

Farmers in the region face increasing operational costs due to the high fuel prices required for irrigation pumping systems. The dependence on fuel-powered pumps limits the affordability and sustainability of irrigation, particularly for smallholder farmers. This challenge contributes to inefficient water use, as financial constraints often prevent farmers from optimizing irrigation schedules or accessing more efficient knowledge. Implementing alternative energy sources, such as solar-powered irrigation systems, could significantly reduce fuel dependency and improve irrigation affordability.

5.2.5 Capacity Building and Technological Support

The Pearson Chi-Square value is 91.554 with 1 degree of freedom and a p-value of .000, indicating a highly statistically significant association between the two variables.

The results demonstrate a strong and statistically significant association between the two variables analyzed (training received on water-efficient techniques and provider type). With a very high Chi-square value and a p-value well below the 0.05 threshold, the relationship is not due to chance. This suggests that farmers' access to training is meaningfully related to their access to support systems or provider types.

There is a clear and reliable association between training access and the corresponding variable. This finding highlights the need for targeted capacity-building programs, especially for those who have not yet received training. Strengthening the role of support providers and ensuring that untrained farmers are identified and supported could help close the knowledge and technology gap in water-efficient irrigation practices. This finding is in line with (Timotewos and Barjenbruch 2024), which shows that community engagement is important for efficient water management.

5.3 Water Abstraction and Irrigation Management Issues in Akaki

The findings show that irrigation water abstraction in the Akaki catchment is severely fragmented, with farmers working independently rather than in a coordinated program. Individual abstraction procedures are frequently connected with increased operational expenses, particularly when irrigation relies on fuel-powered pumps. The lack of a coordinated irrigation system in Akaki is both an institutional and technological shortcoming. The previous finding by Alemayehu and Tadele (2020) supports my finding, which states that 'collaborative irrigation management methods improve the economic feasibility and sustainability of smallholder farming (Alemayehu and Tadele, 2020).

5.4 Crop Water Requirements (CWR) and Irrigation Scheduling

Crop water requirements (CWR) vary considerably depending on crop type, soil type, climate, and rainfall. In the study area, the primary cultivated crops are cabbage, potato, small vegetables, and tomato, which require different water demands. Among these, tomato demonstrated the highest water requirement, approximately 828.8 mm, highlighting its sensitivity to water stress. Moreover, CWR fluctuates across different crop growth stages, necessitating stage-specific irrigation planning(Ewaid, Abed, and Al-ansari 2019).

The calculated CWRs show that current irrigation schedules often do not align with crop needs, resulting in over-application, which causes wastage of water in the study area. Effective irrigation scheduling, therefore, requires an integrated understanding of water availability, soil conditions, crop sensitivity to water deficit, and rooting depth (Asmamaw et al. 2021). A well-irrigated water management system should use CWR. This may be accomplished by designing irrigation schedules matched to crop development phases and improving canal infrastructure to reduce conveyance losses. The study suggests that CWR-based Scheduling and farmer training could enhance the precision of water distribution. This is consistent with the work (Tefera, Kebede, and Mola 2021), who confirmed that training farmers to irrigate based on crop water requirements rather than fixed schedules can improve use. Over-irrigation beyond crop demands is common even for pump irrigated schemes that require extra cost for fuel and /or electricity. The previous research by (Teklay et al. 2022) and (Zande 2023) supports this finding.

5.4.1 Irrigation Frequency and Perception of Effectiveness

A Chi-square test was used to determine if irrigation frequency relates to household opinions of the success of present water management practices in the Akaki Catchment. The findings indicate a statistically significant relationship between the two variables.

The analysis demonstrated a statistically significant association between farmers' irrigation frequency and their perception of water management effectiveness (χ^2 (6) = 68.513, $p < .001$). Furthermore, the absence of a significant linear trend ($p = 0.067$) suggests a more complex, nonlinear relationship. These findings highlight the importance of enhancing water governance responsiveness and effective communication with farmers to improve perceptions and management effectiveness. The finding is in line with (Timotewos and Barjenbruch 2024), which found that the limited knowledge and understanding of the community on irrigation water management.

5.4.2 Current Practices Versus Actual Crop Irrigation Requirement

The study also shows that water wastage and yield reduction are due to inefficient irrigation practices. Traditional irrigation methods with limited knowledge of crop-specific water requirements lead to excessive or insufficient water application. In the current study, the common problem is that farmers use over-irrigation, which leads to nutrient leaching and reduced soil fertility. This mismatch negatively impacts crop productivity and water conservation efforts. This finding is the same as the previous research by (G. G. Haile 2015), which shows inadequate awareness of irrigation water management, as in irrigation scheduling techniques. Educational programs for farmers' understanding of irrigation scheduling and crop water requirements are essential for increasing efficiency and sustainability. The present study was irrigation timing irrigated at critical depletion (when the Readily Available Water (RAW) is depleted).

5.5 Water Application and Crop Productivity

As the findings of the study revealed, there is over-irrigation that resulted in yield reduction, waterlogging, and salinity problems. Problems related to crop health and yield reduction are more frequently associated with excessive water irrigation. This happens as a result of not having appropriate knowledge about crop water requirements. As stated by Mebrahtu, knowledge regarding crop irrigation water requirements and the time planning for irrigation improves irrigation skill management in the field (Mebrahtu 2021). By applying irrigation scheduling, based on CWR, maximum yields can be obtained.

Crop productivity is heavily impacted by the amount and time of water application. Proper irrigation management ensures that crops receive the necessary amount of water at the appropriate time, allowing them to reach their full potential yield while conserving valuable water resources. In contrast, poor irrigation techniques can significantly reduce agricultural output, leading to waterlogging, soil salinity, nutrient leaching, and damage to soil structure. These concerns not only hinder plant development and production but also threaten long-term soil health and agricultural sustainability. In line with this (Alotaibi et al., 2023), it is stated that productivity is increased by effective irrigation management. The current irrigation practice does not meet the CWR, often resulting in over-irrigation, which leads to waterlogging. This mismatch affects crop health and yield. Additionally, the results show that crop productivity is highly affected by irrigation water management. This gap is similar to findings by (Teklay et al. 2022) and (Asmamaw et al. 2021) who noted that many Ethiopian irrigation schemes apply water based on availability rather than crop needs, leading to yield reduction.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study assesses irrigation development patterns and management practices in the Akaki catchment, focusing on the challenges to efficient water management, the water requirements of major crops, and the impact of improper water use on crop productivity. Irrigation water management in the Akaki catchment faces multiple challenges, including the improper timing, quantity, and quality of irrigation, leading to water losses, excessive water abstraction, soil salinization, waterlogging, flooding during heavy rains, and a reduction in agricultural yields. Efficient irrigation management practices are important for sustainable agriculture and optimal water usage for several reasons, such as increased crop yield, soil health and nutrient management, environmental benefits, and economic viability. The results of the study indicate that the existing irrigation systems in the catchment are inefficient due to traditional practices with inappropriate use of irrigation water, leading to environmental damage and crop yield reduction. Major challenges include low water quality, flooding during heavy rains, waterlogging, soil salinity, over-extraction of water from the Akaki lake, and high fuel costs for irrigation pumping systems. Previous research has shown that the problems with lakes and the salinization of extensive agricultural areas due to excessive irrigation(Ayenew, 2007)

Additionally, the study shows that farmers use inadequate irrigation practices and insufficient knowledge of crop-specific water requirements, resulting negative impact on agricultural productivity. The current study also presents the crop water requirements of cabbage, small vegetables, potatoes, and tomatoes that were cultivated in December using the Cropwat8.0 model. The result reveals that the cabbage needs about 165 days, the small vegetable needs 95 days, the potato needs 130 days, and the tomato needs 145 days of growing season, respectively. Regarding the irrigation schedule, cabbage requires about nine, small vegetables seven, potatoes ten, and tomatoes seven, respectively. It can be concluded that the potatoes need to be irrigated more frequently than all other crops grown in this area.

6.2 Recommendation

The following strategies will address the identified challenges in the study area.

- **Modernizing Irrigation Infrastructure:** The use of technology such as sprinklers and drip irrigation will increase irrigation efficiency, reduce loss of water, soil, and environmental damage, and enhance crop productivity.
- **Promoting Water Saving Technologies:** Encouraging the adoption of water-efficient irrigation methods and alternative energy sources, such as solar energy, can improve environmental sustainability and cost reduction, especially in the problem of high fuel costs.
- **Enhancing Farmer Education and Training:** Capacity-building programs should focus on proper irrigation scheduling, crop water requirements, soil and water conservation, and sustainable water management practices.
- **Strengthening Water Quality Monitoring and Pollution Control:** Implementing severe regulations and effective wastewater treatment solutions is crucial to improving water quality.
- **Integrating Water Resource Management Approaches:** Adopting an Integrated Water Resource Management (IWRM) framework can enhance coordination among stakeholders, optimize water use, and ensure long-term water security in the subbasin.

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APPENDIX

Dear respondents,

The purpose of this questionnaire is to gather data regarding water management strategies and irrigation practices. It helps to gather data on the current water management strategies and irrigation practices and what farmers are actually practicing in their agricultural practices. The objectives of this questionnaire are to assess the current water management strategies and irrigation practices. Understand the impact of these practices on the sustainability of water resources in the peri-urban regions of the Upper Awash sub-basin. Identify challenges and opportunities for improving water management and irrigation efficiency in the context of urban expansion and climate variability. In this questionnaire, you are kindly requested to complete a survey. Some questions will be about the challenges of irrigation water management practice and how sustainability can be possible. Some others will be about activities you engaged in irrigation water management practices.

Your participation in this survey is entirely voluntary, and all responses will be kept confidential. You are free to stop the survey any time you wish. However, I do appreciate any help you are able to provide.

Your participation is greatly appreciated!

Thank you.

Farmers:

Part one: Demographic Information:

1. Gender: a. Male ☐ b. Female
2. Age: a. Under 35 ☐ b. 36 – 50 ☐ c. 50-60 ☐ d. Above 60
3. Education Level: A) Illiterate☐ B) Primary level ☐ C) Secondary Level ☐ D) BA

Part Two: Main Questions

Direction: The following statements ________________________. After reading each statement, indicate your responses by putting a checkmark (✔) under the alternative that represents your level of response.

1. **What crops do you primarily cultivate by irrigation in the areas of the Akaki Catchment?**
   a. ☐Vegetables
   b. ☐ Fruits
   c. ☐Cereal
   d. ☐ Other (Please specify): __________
2. **How do you currently access water for irrigation purposes? What are the sources of water? What are the abstraction methods?**
   ❖ **Sources of Water**
   a. ☐ Groundwater (wells, boreholes)
   b. ☐ Surface water (rivers, lakes, ponds)
   c. ☐ Rainwater harvesting
   d. ☐ Other (please specify): __________
   ❖ **Abstraction Methods:**
   a. ☐ Pumping
   b. ☐Manual extraction (buckets, hand pumps)
   c. ☐ Gravity-fed systems
   d. ☐Other (please specify): ________

3. **Can you identify any challenges faced in the management of irrigation schemes in the Akaki sub-basin**?
   a. ☐ High cost of fuel
   b. ☐ Over-flooding during heavy rains
   c. ☐ Poor water quality due to municipal or industrial waste
   d. ☐ Other (Please specify): __________
4. **Have you received any training or support on water-efficient irrigation techniques?**

a) Yes, I have received training.

If yes, please specify who provided the training and on what aspects:

Provider:

a. ☐ Government Agency
b. ☐ Non-Governmental Organization (NGO)
c. ☐ Private Sector Company
d. ☐ Agricultural Extension Services
e. ☐ No, I have not received any training

Aspects:

a. ☐ Drip Irrigation System
b. ☐ Rainwater Harvesting
c. ☐ Water Management Planning
d. ☐ Fertilizer application
e. ☐ No, I have not received any training

b) No, I have not received any training

5. How frequently do you irrigate your crop?

Frequency:

a. ☐ Daily
b. ☐ 2-3 times a week
c. ☐ Weekly
d. ☐ Only when necessary

❖ **Perceptions and Attitudes**

6. **How effective do you find the current water management strategies in the Akaki in general?**
    b. ☐ Very effective
    c. ☐ Somewhat effective
    d. ☐ Neutral
    e. ☐ Very ineffective
    f. ☐ Not sure/No knowledge

1. **What are your views on the sustainability of irrigation practices in peri-urban areas, considering environmental and socio-economic factors?**
    a. ☐ Highly Sustainable
    b. ☐ Moderately Sustainable
    c. ☐ Not Sustainable
    d. ☐ No Opinion/Not Informed
2. **Are you aware of any government programs or initiatives aimed at improving water management and irrigation practices in your community?**
    a. ☐ Yes, I am aware of the programs and actively participate in them.
    b. ☐ Yes, I am aware of the programs but do not participate in them.
    c. ☐ I have heard of some programs but lack detailed information.
    d. ☐ No, I am not aware of any such programs or initiatives

❖ **Suggestions for Improvement:**

3. **What technological support or resources do you think would help improve water management and irrigation practices in the area?**
    1. ☐ Advanced irrigation systems (e.g., drip irrigation, sprinkler systems)
    2. ☐ Renewable energy sources for pumping and filtration (e.g., solar, wind power)
    3. ☐ Training and educational programs on water conservation
    4. ☐ Community-based water management initiatives
4. **What policy and governance support or resources do you believe would most effectively improve water management and irrigation practices in the area?"**
    a. ☐ Increased funding for water conservation projects
    b. ☐ Training programs for farmers on sustainable water management

c. ☐ Public awareness engagements about water conservation

d. ☐ Improved water infrastructure and maintenance

5. **Identify the primary water-related challenge faced by farmers in your catchment area:**
   1. ☐ High costs
   2. ☐ Over flooding during heavy rain
   3. ☐ Poor water quality due to municipal or industrial waste
   4. ☐ Other (Please specify): ___________
6. **How would you rate the severity of water-related challenges in your area?**
   1. ☐ Not severe
   2. ☐ Moderately severe
   3. ☐ Very severe
   4. ☐ Extremely severe
7. **What are the main causes of these water-related challenges?**
   1. ☐ Climate change
   2. ☐ Over-extraction of water resources
   3. ☐ Poor water management practices
   4. ☐ Lack of investment in water infrastructure
8. **To what extent do you think policy intervention is required to solve these challenges? In which areas?**
   1. ☐ No intervention needed
   2. ☐ Minor intervention
   3. ☐ Major intervention
   4. ☐ Urgent and comprehensive intervention
9. **What role can local communities play in addressing these challenges?**
   1. ☐ Raising awareness
   2. ☐ Participating in water conservation efforts
   3. ☐ Supporting policy changes
   4. ☐ Engaging in community-based water management
   5. ☐ Other (Please specify): ___________

10. **In your opinion, how effective has been the government's response to water-related challenges so far?**
    1. ☐Very ineffective
    2. ☐Ineffective
    3. ☐Effective
    4. ☐Very effective
    5. **Local Authorities:**
11. **What initiatives are you aware of that are being undertaken to promote sustainable water management practices? (Please select all that apply)**
    a. ☐Government Initiative
    b. ☐Community-Based Organizations
    c. ☐Non-Governmental
12. **What are the main obstacles you encounter in implementing effective water management strategies? (Select all that apply)**
    a. ☐ Lack of funding and financial resources
    b. ☐ Limited public awareness and engagement
    c. ☐ Climate change and environmental factors
    d. ☐ Other (please specify): __________

Community

13. **What improvements would you like to see in water management within the community?** (Please select all that apply.)
    a. ☐ Improvement from a technological point of view
    b. ☐ Improvement from a governance point of view
    c. ☐ Improvement from community awareness and action

Water Resource Experts: Survey on Water Quality and Quantity Assessment in the Akaki Catchment for Irrigation

1. **How would you rate the overall water quality in the Akaki Catchment for irrigation purposes?**
    a. ☐ Excellent
    b. ☐ Good

c. ☐ Fair
d. ☐ Poor
e. ☐ Very Poor

2. **What are the primary challenges you face regarding water quality and quantity for irrigation? (Select all that apply)**
    a. ☐ Insufficient water supply
    b. ☐ Pollution from industrial/agricultural runoff
    c. ☐ Lack of water quality monitoring
    d. ☐ Climate change impacts
3. **What opportunities do you see for future interventions to improve water quality and quantity for irrigation? (Select all that apply)**
    a. ☐ Implementation of advanced irrigation technologies
    b. ☐ Strengthening policies and regulations
    c. ☐ Enhancing community engagement and education
    d. ☐ Other (please specify): _______________

Improving Water Management in Peri-Urban Areas

1. **Which of the following recommendations do you think would most effectively improve water management?**
    a. ☐ Establishing community-based water purification systems
    b. ☐ Enhancing irrigation efficiency in agriculture
    c. ☐Upgrading water distribution networks to reduce losses
    d. ☐Other (please specify): __________
2. **In terms of priority, which area should be addressed first for a significant impact?**
    a. ☐ Public awareness and education on water conservation
    b. ☐ Government policies and regulations
    c. ☐ Technological innovations for water management
    d. ☐ Other (please specify): __________
3. **What solution pathways do you suggest for sustainable water management in peri-urban areas?**
    a. ☐ Community engagement and participatory management
    b. ☐ Public-private partnerships for water projects

c. ☐ Investment in research and development for new water technologies

d. ☐ Strengthening legal frameworks to support water rights and access

Part three

Open Ended Questionary

Answer the following questioner.

1. Are you involved in any community-based water conservation or irrigation projects? If yes, please mention your engagements.

____

____

2. What role do you think community members should play in sustainable water management practices?

____

_____

3. To what extent you are willing to pay/put an effort to enhancing water use efficiency and contributing to sustainable water management?

____

____

4.How do you make decision about when to irrigate? On what basis Weather Conditions, Crop Growth Stage, Water Availability

____

____

5. What do you think is the role/responsibilities of communities/water users in ensuring sustainable water resources management for lasting development? Conservation, Efficient Water Use, Stakeholder Engagement:

____

____

Part four

Focus Group Discussion Outline: Water Management Strategies

Objective: To gather insights from farmers on current water management strategies, challenges, and peri-urban irrigation practices in the Akaki Catchment.

Part 1: Introduction

- Welcome and introductions
- Explanation of the FGD purpose and process
- Assurance of confidentiality and importance of honest, individual opinions

Part 2: Background Information

- ✓ Participant names
- ✓ Duration of farming in the area
- ✓ Types of crops grown
- ✓ Previous experience with water management and irrigation

Part 3: Current Water Management Practices

- ✓ Challenges faced in water management
- ✓ Impact of water management on crop yield and quality

Part 4: Future Perspectives

- ✓ Desired improvements in water management and irrigation
- ✓ Farmers' willingness to try new strategies or technologies
- ✓ Discussion on potential solutions and support needed prioritize possible interventions in terms of feasibility, effectiveness, relative costs and benefits ….
- ✓ Who is responsible for what?

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