COLLEGE OF DEVELOPMENT STUDIES

CENTER FOR ENVIRONMENT AND DEVELOPMENT

SUSTAINABLE DEVELOPMENT AND WATER MANAGEMENT IN KOGA SCHEME, ETHIOPIA: A TRIPLE BOTTOM LINE AND WEDDING CAKE FRAMEWORK

Ph.D DISSERTATION

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ADDIS ABABA, ETHIOPIA

JUNE, 2024

SUSTAINABLE DEVELOPMENT AND WATER MANAGEMENT IN KOGA SCHEME, ETHIOPIA: A TRIPLE BOTTOM LINE AND WEDDING CAKE FRAMEWORK

By

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A dissertation submitted to the center for environment and development of college of development studies, Addis Ababa University, Ehiopia

Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in College of development studies (Environment and Development) of Addis Ababa University

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ADDIS ABABA UNIVERISTY
COLLEGE OF DEVELOPMENT STUDIES

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The author accepts sole responsibility for the following: study conception and design, data collecting, data analysis and interpretation, and writing up.

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LIST OF ACRONYMS

CD	Cobb-Douglas production
COSAERAR	COmmission for Sustainable Agriculture and Environmental Rehabilitation in Amhara Region
CV	Coefficient of Variation
DPSIR	Drivers-Pressures-State-Impacts-Responses
EEA	European Environment Agency
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
EU WFD	European Water Framework Directive
GADD	Sustainable Development Analysis Grid
GWP	Global Water Partnership
IWRM	Integrated Water Resource Management
LR	Log-likelihood Ratio test
MCA	Multi Criteria Analysis
mDSS	MULINO Decision Support System
MESB	Most Economically Sustainable Block
METB	Millons of EThiopian Birr
MK	Mann–Kendall test
MLE	Maximum Likelihood Estimation
MK-PW	Mann–Kendall Pre-Whitening procedure
MK-VCA	Mann–Kendall Variance Correction Approach
MULINO-DSS	MULtisectoral, INtegrated and Operational Decision Support System
NetSyMoD	Network Analysis – Creative System Modelling – Decision Support
OECD	Organization for Economic Cooperation and Development
OWA	Order Weighting Average
PCI	Precipitation Concentration Index
PWC	Pair-Wise Comparisons
RBOs	River Basin Organizations
SAW	Simple Additive Weighting
SDGs	Sustainable Development Goals
SFM	Stochastic Frontier Model
TBL	Triple Bottom Line Framework
TE	Technical Efficiency
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
UNCED	United Nations Conference on Environment and Development
WSSD	World Summit on Sustainable Development
WUAs	Water Users' Associations

ACKNOWLEDGMENTS

First and foremost, I would like to praise and thank God. I'm grateful to my supervisors, Prof. Belay Simane and Dr. Ermias Teferi, for their patience and guidance.

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Abstract

The aim of the study is to analyze the sustainability of water management approaches in relation to sustainable development. Specifically, the study focus on the Koga scheme in Merawi town, Amhara Regional State. The problem that this study seeks to address is the challenge of achieving sustainable development in the Koga scheme. This includes measures that make sense from one point of view in Environmental Impact Assessment (EIA) mitigation measures may reduce the livelihood viability or resource access of other. Recognizing that not all adaptations are good has drawn attention to the need for sustainable adaptation measures, as well as defining which types of adaptation are desirable or not. Moreover, the water management such as Integrated Water Resource Management (IWRM) may not be effectively translated into good management that meets sustainable development aspirations. The data sources for this study include a combination of primary and secondary sources. Primary data sources include survey with key experts involved in the Koga scheme using snowball sampling, and household survey using stratified random sampling. Secondary data sources include hydro-climatic variables such as temperature, rainfall and runoff. The main methods used include technical inefficiency estimation, convergence theory, and scenario development, various nonparametric Mann-Kendall (MK) estimation techniques, elasticity estimation, sustainability analysis techniques such as the sustainable development analysis grid (GADD), and the multicriteria decision analysis using mDSS software. Even though there are some verifiable indicators for the implementation of Integrated Water Resource Management (IWRM) principles in Koga scheme, the sustainability assessment of IWRM is questioned. The six sustainable development dimensions (economic, social, ecological, ethical, cultural and governance dimensions) were not taken into consideration. Twenty sustainable development goals must be addressed immediately, and ninety-nine goals necessitate less immediate action. The Koga office and other stakeholders should take improvement measures for 119 out of 166 goals. Unlike the sustainability assessment of IWRM, the Environmental Management Plan (EMP) is promising to support sustainable development when the long term perspective of synergy is taken into account. Except for the planting of forest seedlings, the Environmental Impact Assessment (EIA) recommended measures in EMP were progressing quite well. The analysis showed planting of forest seedlings came out top as a sustainable measure in most cases. It may be the only way to accomplish sustainable development when the environment serves as a foundation to other pillars in some circumstances. The fact that farmers are primarily planting eucalyptus trees, and they were spotted turning fertile land into eucalyptus raises concerns. These practices may have negative implications for sustainable development, primarily due to the potential environmental damage caused by eucalyptus trees and the potential threat to food security. In terms of balancing the three pillars, except for training and extension services for farmers and cooperative organizations all measures maintained imbalance ratings across all three pillars. The various measures perform best on economic criteria while poor on environmental criteria. Despite a focus on economic sustainability, household perceptions of its relevance to overall sustainability, and orientation to it, result in a low level of economic sustainability measured through technical efficiency. Management inefficiency results in the wastage of around 60 percent of resources, posing a significant threat to future resource availability and sustainable production. The more than predicted positive impact on income may have been due to increased inputs and unsustainable practices, rather than efficient resource utilization. This can be misleading when determining farming feasibility, as long-term viability relies on efficient resource utilization rather than income. Huge wasted resources; significant regional differences; efficiency improvement more advantageous than doubling input in some areas (eg. Teleta block in the command area); and negative elasticity of output in some inputs, such as seed per hectare and land size, all necessitate planning to improve efficiency to the frontier and make the areas comparable in terms of technical efficiency. It requires 9.42 percent growth to achieve optimum efficiency/optimmum economic sustainability over ten years while over a five-year period, the economic sustainability catch-up effect with the most economically sustainable area requires a growth differential of 2.11 - 9.45 percent. The convergence targets are not over ambitious plans. More importantly, the local government should strive for maximum efficiency in order to develop a better long-term strategy to close the economic sustainability gap. The other aspects of sustainability of the most apparent indications of climate change in the area surrounding the Merawi station, where the scheme is based, are the rising maximum and average annual temperatures. Rainfall and runoff were highly concentrated during the main rainy season, implying a longer dry seasons. There was high runoff variability; even Koga has more runoff variability than Gilgel Abbay. Temperature has a greater influence on runoff than rainfall, with the Koga watershed being more sensitive than the Gilgel Abbay watershed in most circumstances. All these hydroclimatic conditions endangers the future water demand and supply balance for irrigation activities. The fact that farmers prioritize current production over future; adaptation and mitigation measures orientation at the household level was mostly for economic gains; economic objective has the relative importance of pillar for overall sustainability to farmers; and farmers' perception related to the primary motive for crop type selection was profit along with their technical efficiency level perception have negative implications for efficient resource use, which might jeopardize future resource availability and impede overall sustainable development efforts.

Keywords : Technical efficiency, convergence, elasticity, IWRM, EMP, sustainable development, triple bottom line and wedding cake frameworks

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background and justification

Irrigation boosts agricultural production while also enhancing the quality of life for millions of people. The agricultural yields of irrigated and rain-fed agriculture varies significantly (Rosegrant , 2002). However, resources particularly water are under increasing strain. Population growth, increasing economic activity, and higher living standards all result in an increased competition, and conflicts in the finite supply (GWT , 2005). Irrigated agriculture has emerged as an important solution to address the impact of climate change, but it also has significant environmental impacts. Large dams with storage volumes exceeding 3 million m^3, such as the Koga scheme, which is expected to create 77 million m^3 of water reservoir on the Koga River, due to the multiple purposes they serve, frequently trigger a large-scale change in the area (Degu et al. , 2011). Changes in the ecology of a landscape caused by the conversion of grassland or forest to make way for crops and animals. Biophysical factors may be among the environmental parameters to be evaluated, and water is a prominent category on an environmental checklist (GoS , 2000). Surface water hydrology, such as quantity, is a common environmental issue associated with irrigated agricultural expansion, and there is currently a growing tendency to hold it accountable for these effects in order to assure sustainability (Stockle , 2001).

Water serves a variety of functions. We are in a situation with development projects in which we have very distinct and competing interests in our water supplies. The management must confront the complexities and close interdependence of multiple interests openly. Due to water scarcity and drought across Europe, the UN was prompted to adapt the technique of Integrated Water Resource Management (IWRM), which now has official status as a framework in their report on sustainable development (Daniel et al. , 2011). The notion of IWRM has lately gained recognition to resolve the complicated difficulties of the previous water management efforts (Mukhtarov , 2008), it is without a doubt the most popular water management concept in the world right now (UNDP , 2006). The deterioration of water, the ineffectiveness, the economic waste of resources in traditional approaches to water management, ignoring social dimensions of the water sector and a lack of awareness of the limits of the resources themselves, the weaknesses of top-down management approaches (Xie , 2006); and through a policy reform assistance loan, countries adopted IWRM. Others have also undergone institutional water reforms prompted by a need for more inclusive and sustainable water governance, as well as the influence from international organizations (Jacobi et al. , 2007). The water management discussion were primarily focused on IWRM as the primary framework for defining water related policies (Gerlak and Mukhtarov , 2015).

The IWRM appears to be a relatively recent concept that evolved following the 1992 Dublin Conference and the 1992 United Nations Rio Summit (Wolsink , 2005). Many African countries have begun to manage water using an IWRM strategy. Ethiopia has incorporated IWRM principles into its policy and implemented different water programs. The principles of IWRM were designed in the 1990s to include the sustainable development agenda (GWP , 2005). Water can be thought of as being linked to greater social and economic goals. This is the most "integrated" method, bringing biophysical, social, and institutional aspects at a higher level of strategic planning. In this regard, the IWRM is truly novel (Mitchell , 1990). Integrated water resource management is a critical framework for achieving not only SDG 6 but also all other Sustainable Development Goals (SDGs) (UN Environment , 2018). It is a widely accepted international method contributing to economic development, social development, and environmental protection through a framework of mainly integrating and coordinating diverse aspects of water management in holistic manner (Tejada-Guibert et al , 2015). The Bonn Keys underlined essential stages toward sustainable development by satisfying the poor's water security demands and fostering decentralization and new collaborations, and it identified IWRM as the most capable tool. The 2002 World Summit on Sustainable Development (WSSD) in Johannesburg, South Africa, elevated IWRM to the top of the world agenda and the requirement for attaining sustainable development (Rahaman and Varis , 2005). The involvement, coordination, and inclusiveness all lead the way for sustainable development (Jusi , 2012). A recent assessment on the development implications of IWRM revealed positive results in social, economic, and environmental aspects (UNEP , 2012). Water resource management now has equal importance among the SDGs, and that other SDGs will only be met if the Water Goal is met (WEF , 2015).

It is unavoidable for large-scale development irrigation schemes to interact with pre-existing social and biological systems. These effects might include environmental, political, economic, or social sustainability goals and can be positive or negative (Ibeh and Walmsley , 2021). The effects can be minimized by proper execution of Environmental Impact Assessment (EIA) recommendations through examining the potential environmental effects of a development project (Fuggle and Rabbie , 2009). It has been recognized as a forward-thinking tool capable of informing various stakeholders about the likely effect of the project. As a retroactive tool, ideally investigate environmental effects throughout all project phases. It is one of the most effective management techniques, allowing for the early incorporation of concepts of sustainable development ambitions into a project (Gubena , 2016). When examining their shared commitment to promote sustainable development, the SDGs and environmental assessments's synergy becomes clear. It has been proposed that the scope of EIA is expanded to include the 17 SDGs, strengthening the commitment to these goals (Boess et al. , 2021). An assessment of potential environmental consequences ensures a way of harmonizing the three pillars of sustainable development prior to the approval of development projects (Wood , 2003). The assessments enable the project to be environmentally sustainable and acceptable to the surrounding community by avoiding or minimizing consequences. Apart from identification of potential impacts, it suggests mitigation strategies to minimize negative substantial impacts (Mekuriaw and Teffera , 2013). Identifying, avoiding, and mitigating consequences during the EIA process Glasson (1999), can be considered as steps that support sustainable development. The Rio 92 Conference encouraged governments and different institutions to recognize the importance of assessment and it is regarded as an important regulatory tool. Prior to the formulation of the SDGs, environmental impact assessment (EIA) assisted to the sustainable development of policies. The success of EIA depends on so many factors such as its guidelines, reporting, and execution and follow-up on EIA recommendations (Arebo , 2005).

Several countries have reviewed and established their national environmental protection legislation to incorporate provisions for EIA (Sanchez and Croal , 2012). As public concern about environmental deterioration has grown in recent years, Ethiopia's Environmental Policy was established in 1997 to conservation and sustainable use natural resources. The policy established the groundwork for EIA (Mellesie and Mesfin , 2008). EIA is a relatively new phenomena in Ethiopia, and it became a practice at the end of 2002. Previously few institutions approached the Environmental Protection Agency (EPA) to get their activities' environmental impact assessed (Damtie and Bayou , 2008). The Koga scheme is a significant experiment in the management of Ethiopia's water resources, having two management components: irrigation and watershed (Marx , 2013). Irrigation development plays a crucial role in raising productivity of the fertile land by providing it with the necessary amount of water and inputs. Additionally, watershed management helps to ensure dam life as well as environmental stabilization. Moreover, it is a three-component endeavor involving irrigation, conservation, and capacity building, with both management components expected to be treated as equally important (Sina , 2011). According to ADF (2001), the scheme is technically feasible, economically viable, environmentally sound, and socially desirable . It serves as a pilot project for the country, being the first large dam project undertaken in the Abay River basin since the extension of the Fincha'a reservoir in 1987. It was the first large operational dam project in an ongoing series of projects, and planed to be the country's first farmers self-administered large dam project (Eguavoen , 2011). The Koga scheme is a large scheme designed to ultimately to be managed by individual smallholder farmers. The scheme is positioned as a confidence builder, demonstrating that upstream uses do not have to negatively impact downstream populations (Kelly et al. , 2017). The Ethiopian government's decision to prioritize the project is consistent with the sustainable agricultural development.

The scheme is an important experiment within national IWRM that has received national and international attention. Moreover, the Koga scheme, as a major development project, is subject to certain environmental principles such as the IWRM approach. The principles mainly cover capacity development and participation of various stakeholders. The Koga scheme is consistent with the water resources management policy. One of the project's output outcomes is management and coordination, and the most significant positive impact of the project has been the development of farmers' capacities. It is also classified as environmental category 1. Category 1 projects may have negative and significant environmental consequences, necessitating a full Environmental Impact Assessment. An EIA was carried out, the impacts were identified, and mitigation strategies were taken into consideration in the project design approach and ideas. All these characteristics of the scheme underscore the importance of studying sustainable development and water management in the area.

Water management is crucial for sustainable production in agriculture. The Koga scheme is believed to contribute to sustainable development, as it contains irrigation and watershed components in water management. However, due to political unrest, poor water management practice, limited market linkages and other institutional challenges, the scheme has not reached its desired goals (Kassie and Alemu , 2021). In order to address these challenges and promote sustainable development in the area, it is essential to implement effective water management strategies that take into account the needs of both present and future generations. Therefore, the rationale for this study lies on the urgent need to assess the current state of water management's support to sustainable development based on the Integrated Water Resource (IWRM) and Environmental Management Plan (EMP). The sustainability assessment of EIA recommended measures in EMP consider the use of two perspectives : a triple bottom line and wedding cake framework perspective. The triple bottom line framework considers the economic, social, and environmental dimensions of sustainability with the same weight, while the wedding cake framework considers the environment as a base. By applying these frameworks to Koga scheme, this study identifies how EMP is fared at sustainable development considering trade off and synergy in sustainable development. At national level also the country's water resource is under pressure. By focusing on the Koga scheme, this study generates valuable insights that can be applied to other irrigation schemes in the country and beyond.

1.2 Concise literature review

Agricultural intensification through irrigation can reduce poverty through improvements in productivity, employment and incomes for farm households and farm labour; the linkage and multiplier effects with the wider economy; provision of opportunities for diversification of rural livelihoods; and multiple uses of irrigation supply (Smith , 2004). Irrigation remains a key technology to enhance agricultural productivity, food security, and livelihoods and reduce poverty in rural communities in developing countries (Mupaso et al. , 2023). The Ethiopian government has been making different interventions to alleviate poverty through irrigation developments that can minimize the effect of climate change on agriculture. In the Rift Valley Lake Basins in Ethiopia, irrigation improved household income and contributed to poverty reduction (Eneyew et al. , 2014). Similarly, poverty intensity and multidimensional poverty index of the Koga scheme area were lower than the national and regional averages. Irrigation has positive impact on multidimensional household poverty reduction. However, the incidence of poverty is still higher (Kassie et.al, 2018).

1.2.1 Models of Sustainable Development

Sustainable development has become the general guiding principle for human development. Its importance stems from the existing problems between over exploitation of natural resources and economic development. Various sustainability models have been developed to explain different aspects of sustainable development and highlight the importance of considering these elements when pursuing development. Each model provides a different perspective and focuses on a particular element of sustainability.

(1) Three Interlocking Circles model

The interlocking circles of sustainable model focuses the interdependence of the social, economic, and environmental components of sustainability. This paradigm is frequently given to Herman Daly and John Cobb, Jr., who first proposed it in their 1989 book, "For the Common Good" (Daly and Cobb , 1989) (see Figure 1.1). Sustainability is represented as three intersecting rings. The concept is founded on the idea that these three characteristics of sustainability are interrelated and must be balanced in order to attain long-term sustainability. This approach emphasizes the necessity of achieving long-term sustainability through the balance of these three dimensions. The approach has found widespread application in a variety of sectors, including environmental management, urban planning, and commercial strategy. The model has gained popularity due to a simple paradigm that gives equal importance to each component. Most sustainable development models are based on these three pillars (Keiner , 2005). Hansmann et al. (2012) emphasize the importance of balancing the three pillars of sustainable development: social, economic, and environmental. Previously it was depicted as actual pillars, a triangle, or overlapping circles. The "pillar" titles vary depending on the model version, but the most frequent are Economic, Social, and Environmental (United

Nations World Summit , 2005).

Depending on our thinking, we can resize the circles to demonstrate which aspect is more dominating. In business, leaders choose to depict the economy as the largest circle because it is critical to their success and makes their world go round.

(2) Three Legged Stool Model

John Todd, an environmental scientist, proposed the Three-Legged Stool Model of Sustainability in the 1970s. The concept emphasizes the significance of balancing three critical dimensions of sustainability. This approach is founded on the premise that any initiative or system that seeks to be sustainable must handle all three factors equally in order to achieve long-term success (Todd , 1981) (see Figure 1.2). The model takes the concept of the 'triple bottom line' perspective. The three elements are represented by three separate legs of a stool. If the legs are not equal in size, the stool will be unstable (but perhaps still be usable at least for a while). If any leg is missing, then the stool simply will not work. But if all three legs are the same length, the result will be a well-balanced stool which will serve its purpose indefinitely - a sustainable stool. The size of each leg represents the relative weight to each element of sustainability. What flaws exist in this model? In other words, without the environment, humans cannot have an economy or a socially cohesive society. Consequently, the environment cannot and should not constitute a leg of the stool of sustainable development. According to Grossman (2012), it is the foundation that every sustainable development paradigm, or stool, must rest on.

(3) The Egg/ 3 Nested Dependencies Model

Since its introduction by Paul Stern and associates in 1996, the 3 Nested Dependencies model has gained widespread acceptance as a means of comprehending sustainability (P. Stern et al. , 1996) (see Figure 1.3). The 3 Nested Dependencies Model assumes that social, economic, and environmental elements are interrelated and mutually reinforcing. Social aspects include people's institutions, culture, and behavior, whereas economic factors entail the production and consumption part. Environmental considerations include the natural resources and ecosystems that sustain life on earth. In this paradigm, the three dependencies are layered, which means they are interconnected and influence each other. For example, social influences can influence economic considerations, which can then influence environmental variables. Changes in the environment can also have an impact on social and economic variables. The environment is a pre-requisite for the development of human well-being. This viewpoint necessitates a sustainable development paradigm that prioritizes the environment.

(4) The Wedding Cake Framework

Rockstrom and Sukhdev's (2016) organized the SDGs into layers, with economic and society embedded like a 'Wedding Cake' depicted in Figure 1.4. Prof. Johan Rockström (Executive Director of the Stockholm Resilience Centre and Chairman of the EAT Foundation's Advisory Board) and Pavan Sukhdev (Founder and CEO of Gist Advisory) presented the framework at the 2016 EAT forum. The SDGs into three tiers: environmental as the base (consisting of goals 6, 13, 14, and 15), social in the middle (1, 2, 3, 4, 5, 7, 11, and 16), and economic (8, 9, 10, and 12) at the top. The layers are not equal in size, but rather the size shrinks as they move upward, resembling a wedding cake. The reasoning behind the shrinking was to illustrate that the size of each tier corresponded to its relative priority. The Wedding Cake Framework does provide a new perspective on sustainable development. The core ideal of

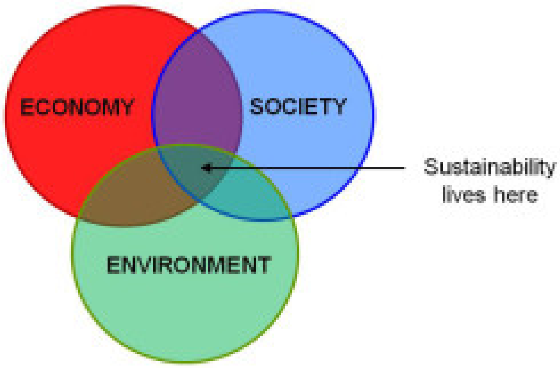


Figure 1.1: The Interlocking Circles model of sustainability

this model is that without a strong base, the cake will topple. In conclusion, this viewpoint indicates that economies and societies are viewed as integral elements of the environment (Rockström and Sukhdev , 2016). Its major criticism, however, is forwarded by scholars such as Bill Scott, deputy-director of the University of Bath's Institute for Sustainable Energy and the Environment, arguing that the economy, rather than society, should be the intermediary tier. For instance, the achievement of ending hunger (Goal 2) and attaining gender equality (Goal 5) can not led to meeting economic goals like sustainable growth (Goal 8) or resilient infrastructure (Goal 9) (Bill , 2017).

In this study, the order of layers must be determined during analysis. The sustainable development model proposed aligns with Bill Scott's concepts. Based on pairwise comparisons by experts, the economic pillar was placed in the intermediate layer of the wedding cake framework.

(5) Prism Four Model and Other Dimensional Models

Alternative models for the sustainability triangle have recently been presented. Prisms are one of the most intriguing of these structures. The 'prism of sustainable development' model, adapted from Spangenberg and Bonniot (1998), identifies four dimensions: Economic dimension (man-made capital); Environmental dimension (natural capital), and Social dimension (human capital) as the base for Institutional dimension (social capital) (See Figure 1.5). Other four-pillar models include economic, social, and environmental, with a fourth political or governance pillar (Zhang , 2013). There are also five and six-dimensional models of sustainability. Mitja and Andrej (2016) defined the five pillars of sustainability using economic, social, environmental, cultural and security aspects while in his empirical six-dimensional model of sustainable development, Steven et al. (2023) considered environmental protection, social harmony and equality, sustainable production, industry and infrastructure, sustainable consumption and socioeconomic behavior, sustainable governance, regulation and global relations, and acute poverty reduction as pillars. The other six dimensional models of sustainability employed in this study are the social, economic, ecological, cultural, ethical, and governance components of sustainable development (Villeneuve et al. , 2016).

Figure 1.2: Three Legged Stool Model of sustainability

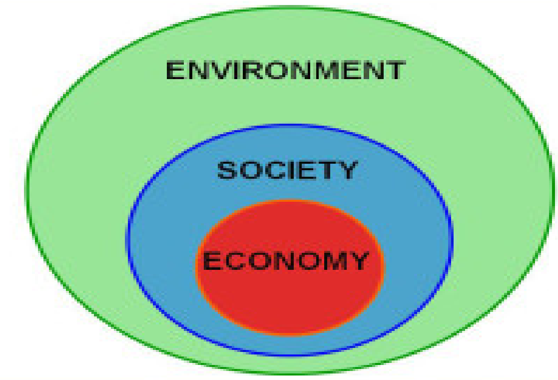


Figure 1.3: The three nested dependencies model

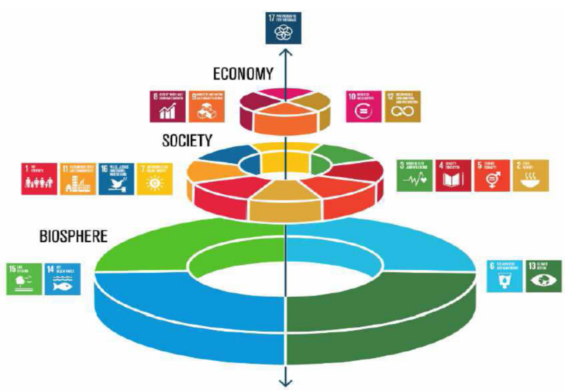


Figure 1.4: Wedding cake framework for sustainability

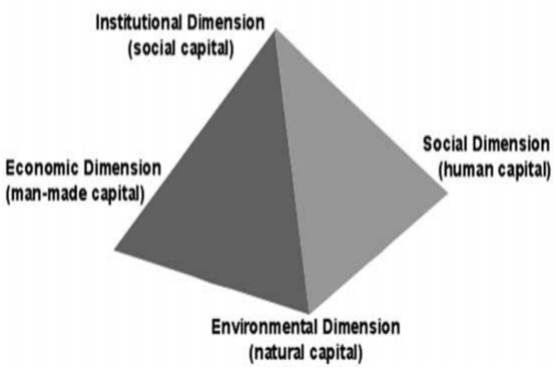


Figure 1.5: Prism model of sustainability

1.2.2 Water management approaches for sustainability

There are various approaches designed to archive sustainability. Integrated Water Resource Management (IWRM) and Environmental Impact Assessment (EIA) are two crucial approaches for sustainable water management. These approaches help in optimizing the use of water resources, avoiding undesired impacts on the environment, and ensuring long-term sustainability in water resources. In the quest for explanation about human-environment interaction, various frameworks have been developed including Environmental Impact Assessment (EIA) (Finnveden and Moberg , 2005), Strengths, Weaknesses, Opportunities, Threats analysis (Dyson , 2004), Political, Economic, Social, Technological, Legal, Ecological analysis (Recklies , 2006), and Driving Forces, Pressures, State, Impacts, Responses (DPSIR) framework (Kristensen, 2004). The use of these various approaches to manage water resources depends on the way different stakeholders understand human disturbance of waters. The management responses include prevention, mitigation, maintain or restore, adaptation and even do nothing strategies (Perrings , 2005). In frameworks such as the DPSIR framework, some measures aid in alleviating or avoiding human-induced pressures on the water environment, implying a proactive decision making. While still some others start analyzing the state of water resource based on observed hydrophysical and biogeochemical changes in the water environment, with reactive responses to combat water problems. Most water management approaches are under this category, mainly state or impacts oriented (Xingqiang , 2012).

Indicators of the state of water resources are redundant (UN CSD, 2001) and issue specific (OECD, 2003). Depending on the chosen system of description, the indicators can vary greatly from study to study. The water environment is mainly concerned with hydrophysical and biogeochemical changes (Xingqiang , 2012). They describe a wide range of characteristics, such as the quantity and quality of physical (e.g. temperature), biological (e.g. fish populations) and chemical phenomena (e.g. atmospheric CO_2 concentration) (Gabrielsen and Bosch, 2003). Water resources serve many functions including drinking water, agriculture, energy, production, navigation, recreation, and manufacturing. These things contribute to water shortages, which is likely to be worsened by climate change by affecting water demand positively while water supply negatively . This imbalance between demand and supply would make it difficult for water managers to accommodate the interests of many water-using interest groups at the same time. Because of the numerous connections and relationships, as well as the multiple interactions between temperature, rainfall, and runoff and their direct or indirect effects on agriculture, literature favors evaluating the trend of these factors to analyze the state of water resources.

Water resource and climate trends studies are summarized into many categories based on data type, scale (whether monthly, seasonal, or annual), and methodology. Some trend detection studies used annual, seasonal and monthly time scales for different periods such as studies by Francesca et al. (2007), and Zhang et al. (2015), while trends of monthly streamflow by Kahya and Kalayc (2004) and Shahzad et al. (2011). The methodologies includes Mann-Kendall (MK) nonparametric test in the study by Francesca et al. (2007) and Zhang et al. (2015), while a modified MK test by Lins and Slack (1999). Some authors employed two or more trend tests as mentioned by a study Kahya and Kalayc (2004) that employed the MK, Sen's method and Sen's innovative trend method (ITM) to examine the possible trends of monthly stream flows. Shahzad et al. (2011) examined trends in several hydro-meteorological variables for mean monthly data using MK test and trend-free pre-whitening approach. The trend results reveal significant increasing trends, decreasing trends, and even insignificant trends. Similarly, in Ethiopia, studies used various trend detection test methods such as the Mann-Kendall (MK) trend test and Sen's slope by Alemu and Dioha (2020) and Belay et al. (2021), a Mann-Kendall test by Tofu and Mengistu (2023) and the Mann Kendall test, Pettitt test and Sen's slope estimator by Malede et al. (2022).

Over the last century, there has been a dramatic rise in the demand for water mainly due to population growth and economic development. During the 20th century, the world's population increased by three times, wheras water withdrawals climbed by seven times (GWP , 2000). The past water resources management can not able to handle the world's water problems. These strategies typically involve sector-based, where each sector has been handled independently with little cross-sectoral cooperation, results dispersed and disorganized development of water resources. Water, especially river basins, is used for a multitude of purposes, many of which have unanticipated social and environmental consequences. The land and water use in upstream river areas affects the amount and quality of water in downstream places. In some cases, the current water crisis is the crisis of governance than a crisis of physical scarcity, as scarce water resources are allocated inefficiently, and social-environmental concerns are left unaddressed. This crisis in management has the tendency to grow unless there is a paradigm shift in the way water resources are managed. Given the drawbacks of traditional water resource management techniques, IWRM has arisen as a means of sustainable water management (Xie , 2006). Nowadays, most water management discussion rely on the principles of IWRM, as the primary framework for defining water policies at all levels (Gerlak and Mukhtarov , 2015). Since the 1990s, the principles of IWRM have received increased attention. Irrigation systems cannot achieve their intended goals unless appropriate organizations manage, maintain, and operate them.

The paradigm shift in water resource management evolved over various periods in relation to the forms of water resource management. According to Allan (2006), the paradigm considered water distribution and management as a political processes. It has developed new participatory and inclusive techniques amongst different institutions in order to deal with water conflicts, reflecting wide spectrum of efforts. This trend became clear once the definition of sustainability was introduced in the late 1980s. IWRM coordinates water, land, and related resource operations to optimize economic and social welfare in an equitable manner while ensuring the sustainability of essential ecosystems. Being a cross-sectoral policy strategy, it aimed to replace the fragmented sectoral approach to water resources and management. A recent UNEP (2012) survey on impacts of IWRM found that integrated approaches to water resource management have led to positive development impacts in social, economic, and environmental aspects. Due to insufficient user involvement and weak institutional structure for appropriate operation, maintenance, and irrigation service provision, schemes frequently fail to reach their goals in terms of sustainability (Yami and Snyder , 2012).

Many countries make reforms to their water policy, water legislation and water resource planning after IWRM was introduced in water management. However, countries are at different stages of implementation. According to UNEP (2012), 82 percent of 130 countries are implementing changes to their water laws. Still a lot, 79 percent of countries found to be in a slow implementation as far as policy and legal changes are concerned. The survey showed that 65 percent have developed integrated water resources management plans, as called for in the Johannesburg Plan of Implementation, and 34 percent of countries at an advanced stage of implementation. However, progress appears to have slowed or even regressed in some countries since the survey conducted in 2008. Water was included in national or federal development planning documents by about 67 percent of countries. Institutional reforms, though slow but showing efficiency gains, have been undertaken in 71 percent of countries. A study in Global Water Partnership (GWP) countries found that 21 percent of 95 countries were making good progress, 53 percent were making some progress, and 26 percent in the early stages. Out of the 85 Japan Water Forum countries, 28 percent were making good development, 57 percent were making some progress, and 15 percent were in the early stages (UN-Water/WWAP , 2006). According to Kidanemariam (2009), Ethiopia has shown that IWRM involves many changes to the existing system by creating a sense of ownership amongst all stakeholders in the IWRM pilot project in the Berki watershed. Tamiru (2011) also showed that the Gafarsaa catchment management in Ethiopia is not extended beyond the buffer area of the dam so that most activities beyond this area, though prominent, were not taken in to consideration about their effect on the water resource. There was no integration of all stakeholders for the catchment management and budget constraints. Addis Ababa Water and Sewerage Authority, as a stakeholder sector, did not take part in decision making for the land related developments in the area. There was no regular meeting time for all stakeholder sectors to deal on the issues of land developments and catchment management. The authority collaborated with voluntary non-governmental organizations and international fund donors on water supply programme, rather than the catchment management and environmental rehabilitation activities.

Sustainable development is becoming recognized as a strategy that should be followed for ecological, social, ethical, and political considerations. Environmental Impact Assessment (EIA) processes allow for the identification of technical constraints while planning and implementing sustainable development projects (Htun , 1990). The purposes of EIA are frequently considered as a future forecast, emphasizing environmental awareness, and as a mechanism for social learning by providing knowledge and a source of directing the development of societal values. The Principle 17 of the United Nations Conference on Environment and Development (UNCED) articulated the need for EIA for actions that have a significant impact on the environment (United Nations , 1992). The anticipated potential benefit from EIA implementation coupled with the continent's plethora of social, economic, and environmental challenges, EIA systems are being implemented in practically all African countries. It was envisaged that African countries be able to use environmental assessment and management methods to achieve sustainable development by 2015. Since these methods are built on EIA experiences and practices in more developed countries, there is a need to establish more comprehensive and sustainable approaches to EIA that suits Africans. That is, both recognizing the impact of policies, programs, and projects and offering mitigation measures as well as testing whether it is sustainable or meets sustainable development objectives are vital. The concept of intra- and intergenerational equity can be introduced into EIA to achieve project-level sustainable development. As a result, for EIAs shall ensure projects in such a way that social value to communities and larger economic value to investors may be met without depleting natural capital or straining the bounds of the environment

(George , 1999). However, EIA will not result in sustainable development, but rather aids (Bruhn-Tysk and Eklund , 2002). A country's well-legislated and structured EIA does not guarantee sustainable development unless there is effective practice (George et al. , 2020).

Studies on contribution of EIA for sustainable development in particular and evaluation of management options are few in literature. D.Odontsetseg et al. (2009) evaluated a set of 12 management options using the MULINO Decision Support System (mDSS4) software. The various options' sustainability analyses demonstrated that they all achieved best on environmental goals and worst on economic. Benini et al. (2010) evaluated different management scenarios by using indicators such as loss of agricultural income, loss of agricultural surfaces, number of artificial basins, hydrological balance, and presence of a riparian buffer using MULINO-DSS, with equal weight given to social, environmental, and economic concerns. The creation of artificial basins was determined to be the best scenario while current management scenario ranked eighth out of the 13 evaluated scenarios. The sustainability assessment of small-scale irrigation in Amhara region identified schemes like Tebi, Gulina, Alewha and Geray to some extent performing well and others like Mahibere Genet and Mylomy have no water totally, and Kility, Dana and Fetam actually performing badly (Bitew , 2013). In Geray irrigation project, different soil and water conservation intervention were applied since Dergue regime which were mostly physical measures but they did not reduce siltation from the watershed to a minimum level, increase the base flow of the streams and increase land productivity (Wubeshet , 1997). Cropping pattern and varieties in the project area where cereals, pulses, vegetables, oil crops and fruit were selected primarily to serve the purpose of meeting food requirement and source of income. The varieties were based on high yield, suitability to agro-ecology, farmers experience, disease resistance and early maturity, etc. In both cropping pattern and varieties the environmental and social sphere of sustainability were overlooked.

1.2.3 Overview of the concept of efficiency and models

This literature review will provide a concise overview of technical efficiency, which refers to the optimal use of resources to produce maximum with a given resource. Various methods and approaches have been used to measure and analyze technical efficiency. Technical efficiency concept dates back to the works Adam Smith and David Ricardo. However, the study of technical efficiency in its current form explained in the work of Farrell (1957), who established the stochastic frontier approach to measuring technical efficiency. The concept is now widely adopted in different sectors, including as agriculture, health care, and industry.

There are three types of Efficiency: technical efficiency, allocative and economic efficiency. Allocative efficiency depends on the most suitable mix of inputs given the level of prices and production technology. If a sector fails to choose an optimal mix of inputs at a given price level, it is considered allocatively inefficient. Combining technical and allocative efficiency results in overall efficiency. A firm is considered overall efficient when it achieves maximum output using a specific input level and utilizes inputs at the lowest cost possible. Generally, the term efficiency refers to technical efficiency. Efficiency is assessed by comparing actual and optimal values of an agent's outputs and inputs. There are two approaches technical efficiency measurement : input-oriented and output-oriented. The output-oriented approach asks the question, "by how much output could be expanded from a given level of inputs?" Conversely, one could ask, "by how much can input quantities be saved without changing the output quantity ?" This is an input-oriented measure of efficiency (Coelli and Battese , 2005). Both input and output oriented approaches seeks to maximize the outputs, minimize the inputs and thus maximize the efficiency.

(1) Frontier and Non-frontier models

Prior to Farrell (1957), efficiency was measured by analyzing average input productivity and constructing efficiency indices. The use of standard least squares methods to estimate efficiency has been criticized since it is inconsistent with the concept of the production function. The estimated functions are average or response functions since regression predicts the average output, not the maximum output. The frontier technique was developed as a more theoretically sound way to measure efficiency.

The frontier approach mostly preferred than average or response functions, and other non-frontier models. When a frontier function is estimated, the result is based on the most efficient firm. However, estimating an average function reflects an average firm. Frontier functions provide a useful performance benchmark. It is consistent with the theoretical definition of a production. In microeconomic theory, a production function (or frontier) is defined as the maximum output from a given set of inputs. These advantages make the frontier methodology popular in applied economic research (Haghiri , 2003).

(2) Parametric and Non-parametric

Frontier models can be parametric and non-parametric (Thiam et al. , 2001). Non-parametric models, commonly known as Data Envelopment Analysis, employ mathematical programming techniques. These approaches do not specify a functional form for production technology or make assumptions about the distribution of error terms. Although Data Envelopment Analysis is not susceptible to misspecification, it is not ideal for this study due to its inability to account for measurement errors and other statistical noise sources. Consequently, efficiency scores may be underestimated (Hansson and Öhlmér , 2008). With non-parametric methods, any deviation of an observation from the frontier must be attributed to inefficiency, which makes the results highly sensitive to outliers, measurement errors, and uncertainty. The parametric approach specifies a functional form for production technology and makes assumptions about error term distribution. Its main advantage over the non-parametric approach is the ability to express frontier technology in a simple mathematical form.

(3) Stochastic and Non-stochastic Frontier models

Parametric models can be classified as either non-stochastic or stochastic. The drawbacks of non-stochastic models explained in Murillo-Zamorano (2004) is that they do not account for statistical noise. Consequently, any deviation from the frontier is considered as inefficiency. In deterministic frontiers, all deviations in production performance are solely due to differences in efficiencies relative to a common family of frontiers. This approach ignores the influence of factors outside firm's control, such as bad weather or input supply breakdowns. By combining the two effects of exogenous shocks, both favorable and unfavorable and inefficiency into a single one-sided error term, and labeling the combination as inefficiency, deterministic frontiers present a major weakness. This oversimplification can lead to misinterpretation and is a significant limitation of these models, as noted by Førsund et al. (1980). On the other side, the stochastic frontier model, which was independently proposed by Aigner et al. (1977) and Meeusen and van Den Broeck (1977), solves the weaknesses of non-parametric and non-stochastic frontier approaches by introducing a double-sided random error into model specification. This approach considers uncontrollable factors independently of the inefficiency component.

Technical efficiency models have indeed evolved significantly since their inception, with various methods and approaches being developed to measure and analyze this critical concept. The stochastic frontier approach, data envelopment analysis, and malmquist productivity index are among the most influential and widely used methods in the field. Each of these methods has its own advantages and limitations, and their choice depends on the specific context and research questions.

(4) Technical efficiency estimation procedure

Regarding the estimation techniques, both the one-step approach and the two-step approach can be used to estimate household technical efficiency. In the two step procedure, we first estimate the error component model from stochastic frontier function to determine technical efficiency indicators. Subsequently, technical inefficiency thus obtained are regressed on explanatory variables that usually represent the firms specific characteristics. However, this approach is inconsistent with the assumptions related in the distribution of inefficiency in the estimation of technical inefficiency effect model and error component model. In the estimation of error component model, technical inefficiency of farmer is assumed to be normally, independently and identically distributed. However, the technical inefficiency indicators thus obtained are assumed to have one side distribution (i.e. greater or equal zero) unless all the coefficients of the factors considered happen to be simultaneously zero. In the first stage inefficiencies are assumed to be identically distributed, however, in the second stage this assumption is contradicted as inefficiencies are given a functional form. The second method, in one-step approach, estimates all parameters using the maximum likelihood procedure.

1.3 Conceptual framework

A number of sustainability criteria have been developed, based on both quantifiable and qualitative aspects of sustainable development. The sustainability assessment requires precise terms (Harmancioglu et al. , 2013). Environmental management is a broad, expanding, and rapidly evolving field that affects all humans and is critical in the pursuit of sustainable development (Barrow , 2006). Following the different sustainability assessment methodologies, this study considers three (social, economic, and environmental) and six (social, economic, and environmental, cultural, ethical, and governance) dimensions to evaluating how and to what extent environmental management plan (EMP) and IWRM achieved the sustainable development ambitions. IWRM enhances the these objectives through integrating and coordinating various activities in a sustainable manner (Tejada-Guibert et al , 2015). It is officially recognized as a new perspective to water management and a solution to sustainable development. The EMP has also the same objective. The goal of an environmental assessment is to make sure that developments are long lasting and do not harm the environment (Nkambwe and Chenje , 2006). Both the EMP and the IWRM are plans for sustainable development.

Various EIA-recommended management practices developed for the scheme in EMP are evaluated using a MULINO Decision support system (mDSS), while IWRM sustainability is assessed using a Sustainable Development Analysis Grid (GADD), ensuring expert participation and the use of three and six sustainability models, respectively. However, the effectiveness of such sustainability-oriented management plans in achieving the sustainability is dependent, and affected by the following essential aspects of sustainable development. The representation of the relationship that the study expects to see between variables, or concepts that the researcher wishes to investigate are provided in Figure 1.6.

1. Social views, technical efficiency, and water availability are all mediating factors. These elements demonstrate the effect of those plans on sustainability by showing how

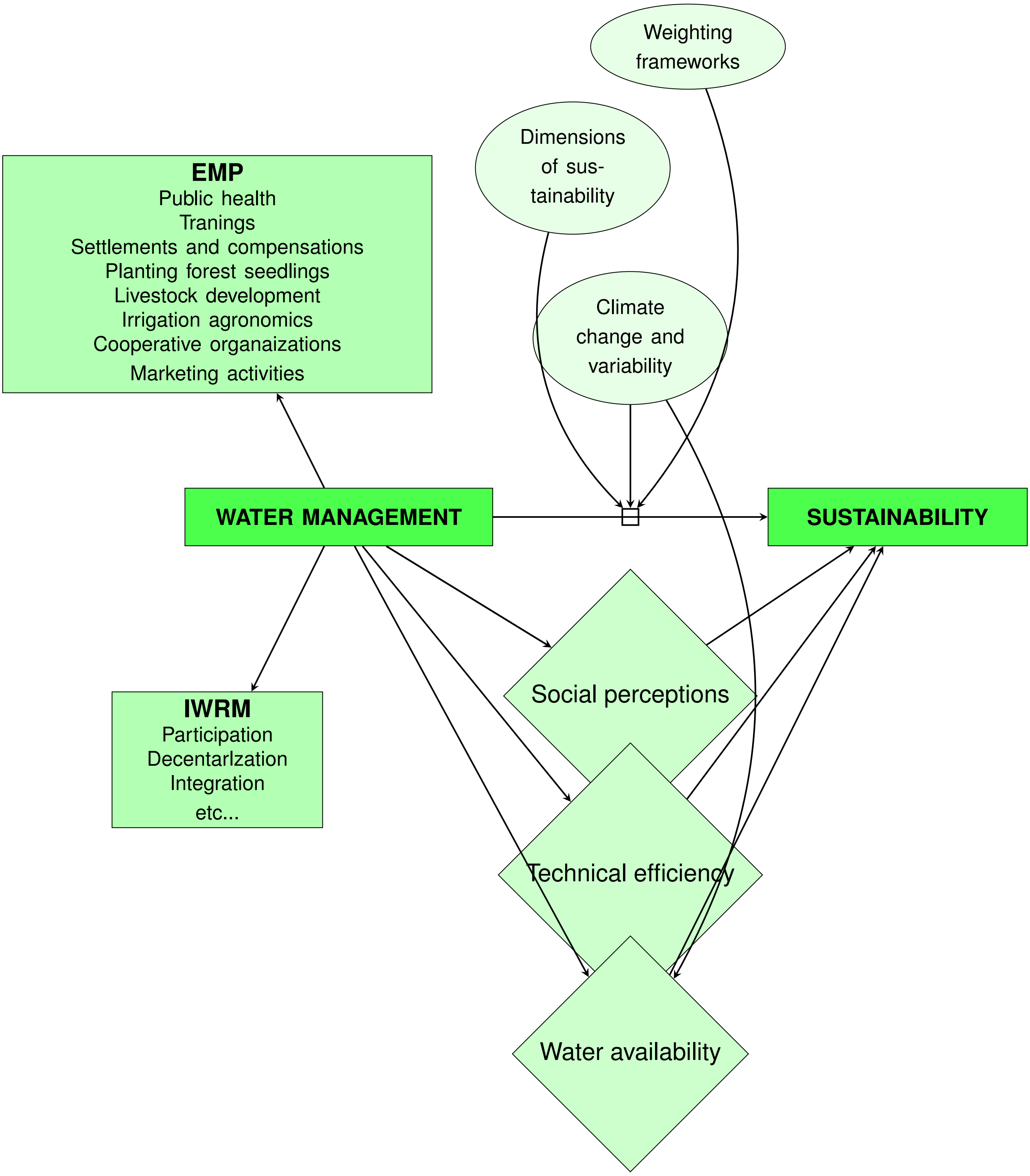


Figure 1.6: Conceptual framework of the study

and why the effect happens. The plans have an impact on social attitudes, technical efficiency, and water availability, all of which have an effect on sustainable development.

The attitude of farmers towards sustainability influences their intentions to implement various farming practices (Creemers et al. , 2019). To support efforts toward environmental, social, and economic sustainability, it is necessary to comprehend the decisions of farmers within their circumstances (Grover and Gruver , 2017). The quality of management in the scheme influences their perceptions of production, conservation, technical efficiency, and adaptation and mitigation orientations. The perceived value of sustainable agricultural practices, with socioeconomic positions and access to information due to good management, all affects sustainable development. It is concluded that emphasis on these social element could lead to a more sustainable agriculture. These can be achieve through proper water management plans and implementations (Füsun et al. , 2009).

Improved management practices play a crucial role in enhancing agricultural output by positively impacting technical efficiency. Experience sharing and skill transfer designed to boost the technical efficiency can be achieved by devising proper management (Bahta et al. , 2020). If a farmer is technically inefficient, it imply that considerable scope exists to increase output by improving farm management. Improvement in technical efficiency enables not only economic growth and prosperity but also could save unnecessary wastage of resources that otherwise be used for the future generation. Improving technical efficiency can be understood from a broader perspective beyond economic gain like environmental and overall sustainability.

On the other hand, ensuring water supply reliability while meeting consumption and environmental demands is one of the major focus area of river water resource management. This challenge is exacerbated by climate factors, be it the trend, variability and concentration of rainfall. Water availability is in short supply, owing primarily to climate change and ineffective management. For water allocations, some water management decisions are more important than a possible change in climate (Steinfeld et al. , 2020). The hydro-climatic condition in the area affects the sustainable development efforts in the area.

2. Moderating elements include sustainability dimensions, weighting frameworks, and climatic change and variability. The success of EMP is contingent upon the choice between a triple bottom line framework or a wedding cake framework. The evaluation should be based on both striking a balance between the three pillars (considering trade off) and adopting a long-term synergy perspective of sustainability. Climate factors determine water availability for various uses, mainly through its effect on runoff. Climate change have the greatest influence on water availability (González-Villarreal et al. , 2015). The IWRM in Africa also emphasized for its role in light of climate change (Amani et al. , 2015).

1.4 Study area description

The study focuses on sustainability assessment, economic sustainability, convergence, and hydro-climatic conditions. It includes an expert survey conducted through snowball sampling technique, the use of the Sustainable Development Analysis Grid (GADD), Network Analysis-Creative System-Modeling-Decision-support (NetSyMoD) approach, and mDSS software for sustainability assessment. Furthermore, a household survey using stratified random sampling, stochastic frontier model, inefficiency model, exponential growth model, convergence model, and scenario development were used to investigate economic sustainability and convergence. Trend, variability, and elasticity measures were applied to evaluate the hydro-climatic conditions in the Koga scheme command areas. This study area description provides an overview of the Koga scheme, focusing on its geographical location, climate, topography, and socio-economic aspects. The scheme aims to make progress on the livelihoods by promoting crop production, infrastructure, and access to social services. The Koga scheme, built on Koga River, was constructed by Ethiopian government and the African Development Fund for the purpose of large-scale irrigation scheme for rural farmers to make 7004 hectares of land irrigation, with the total size of the project being about 10,000 ha (Endrie et al. , 2016).

Geographical Location

The Koga scheme is situated in the Western part of Mecha Wereda in Ethiopia, covering an area of approximately 30,000 hectares. It is located 35 kilometers from Bahir Dar city, West Gojam Zone of the Amhara regional state, where agriculture is most common economic activity (Asres , 2016). It spans 22,000 hectares at the dam site, which drains into the Koga River. The river runs 64 km from its source in the Wezem area before reaching and filling the reservoir. In the Blue Nile's headwaters, the Koga River is a tributary of the Gilgel Abay River. Gilgel Abay flows into Lake Tana (Birhanu et al. , 2015). The scheme is the largest reservoir-operated irrigation scheme in the Tana Basin. Koga Reservoir, Ethiopia (shown in Figure 1.7a). The scheme has a catchment area of about 220 km^2 and a reservoir area of about 17 km^2.

Koga is a subbasin of the Abbay basin (Eriksson , 2012). The Abbay basin is located in northwestern Ethiopia. It is known as the Blue Nile Basin internationally (Eguavoen and Tesfai , 2012). The basin has a total area of 199,812 km^2, making it Ethiopia's second largest river basin. The basin accounts for 20 percent of total land area, 25 percent of population, and more than 40 percent of agricultural production (Awulachew , 2007). The Abbay river basin is divided into 16 sub basins (shown in Figure 1.7b) based on the basin's major rivers. Lake Tana is the largest fresh water lake in Ethiopia located north of the Abbay River Basin (upper Blue Nile River). It is also the source of water for the Abbay River / the Blue Nile River. The tana sub-basin covers an area of 15,123 km^2 and is fed by four perennial rivers (Gilgil Abbay, Megech, Ribb, and Gumera). Gilgel Abbay (4517 km^2) in the southern part of the Tana Basin, whereas Ribb (2156 km^2) and Gumara (1604 km^2), both in the eastern part of the Tana Basin, are the rivers that flow to the Lake. These rivers contributes 93 percent of the Lake's inflow (Kebede et al. , 2006). The Gilgel Abay and Gumara rivers contributes to roughly 70 percent of the Lake's inflow (Tigabu et al. , 2021). There are two river gauges in the Koga scheme which have been in operation at Wetet Abbay since 1959 and the then Ministry of Water Resources (MoWR) installed the gauge station at the dam site in 2003 (Nigussie and Yared, 2010) (shown Koga representing Koga Nr/@ Merawi and GA for Gilgel Abbay Nr. Merawi in Figure 1.7a). The gauges are maintained by the MoWR Hydrology Department (Teklie and Ashenafi , 2010). The gauging station used in the study is Koga Nr./@ Merawi with a drainage area of 244 Sq.KM. and station number of 111003 and lies on the Koga River before it joins the Gilgel Abbay River. On the other hand, the Gilgel Abbay Nr. Merawi gauging station with a drainage area of 1664Sq.KM. and station number of 111002 is located near Wetet Abbay twon, the location is near the Gilgel Abbay River bridge on the road connecting Addis Ababa and Bahir Dar city.

Climate

The Koga scheme experiences a tropical climate, characterized by two distinct rainy seasons. The average annual rainfall ranges from 1,200 to 1,500 mm, and the mean temperature is within 18℃ to 28℃ (Mecha Wereda , 2018). The Merawi meteorological station (shown M representing Merawi station and W for Wetet abbay station in Figure 1.7a) is located adjacent to the main dam area. The station is run by the National Meteorological Services Agency (NMSA). Moreover, the scheme is located approximately 8.5 km from the town of Merawi.

Topography

The Koga scheme is predominantly hilly and mountainous, with the elevations range from 1,800 to 2,500 meters above sea level.. The area is characterized by steep slopes, which can pose challenges for agriculture and infrastructure development (Mecha Wereda , 2018).

Soil and Land Use

The soil in the Koga scheme is predominantly fertile, with a high potential for agricultural production. The land is predominantly used for farming, with major crops including teff, wheat, maize, and pulses. There is also a small area dedicated to livestock rearing, primarily for subsistence purposes (Mecha Wereda , 2018).

Population and Settlements

The Koga scheme has a population with the majority residing in small, scattered settlements. The settlements are predominantly rural, with limited provision of basic social services such as education, healthcare, and water supply (Mecha Wereda , 2018).

Economic Activities

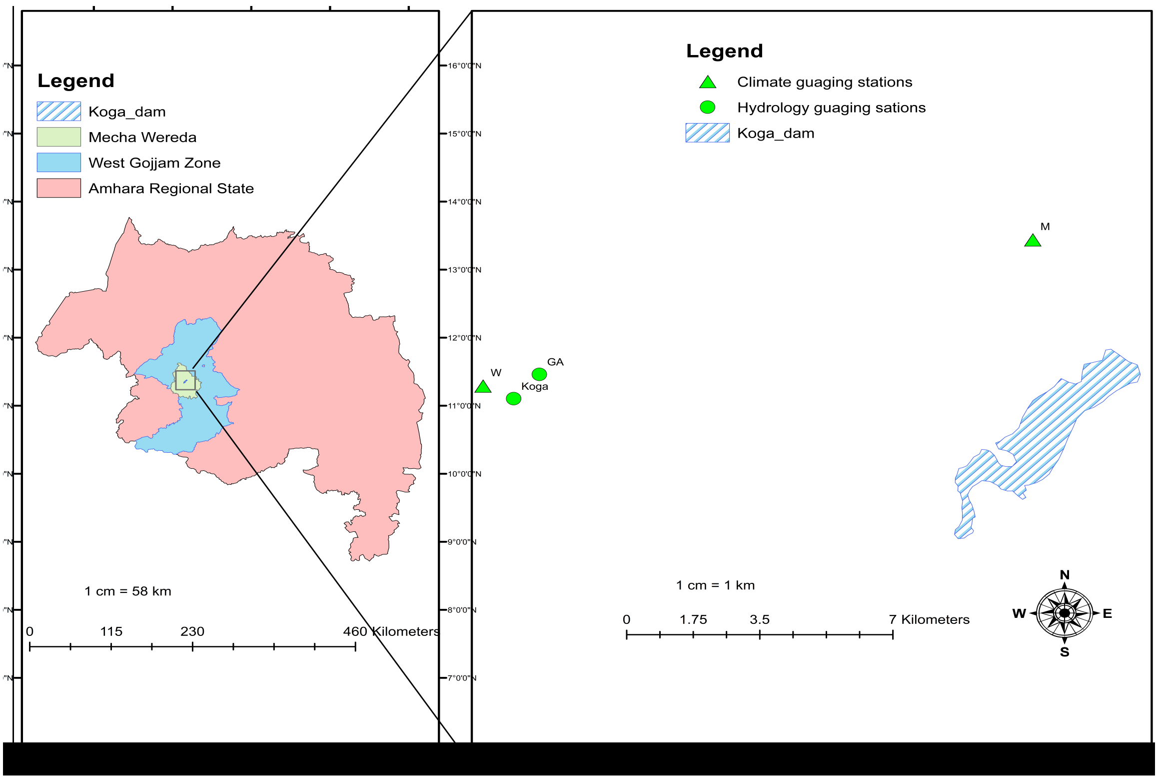
The Koga River is used for irrigation and sand mining (Dagnew et al., 2014). The primary economic activities incudes crop production and livestock rearing. The area is also rich in natural resources, including timber and non-timber forest products, which provide additional income for local households (Mecha Wereda , 2018).

Infrastructure

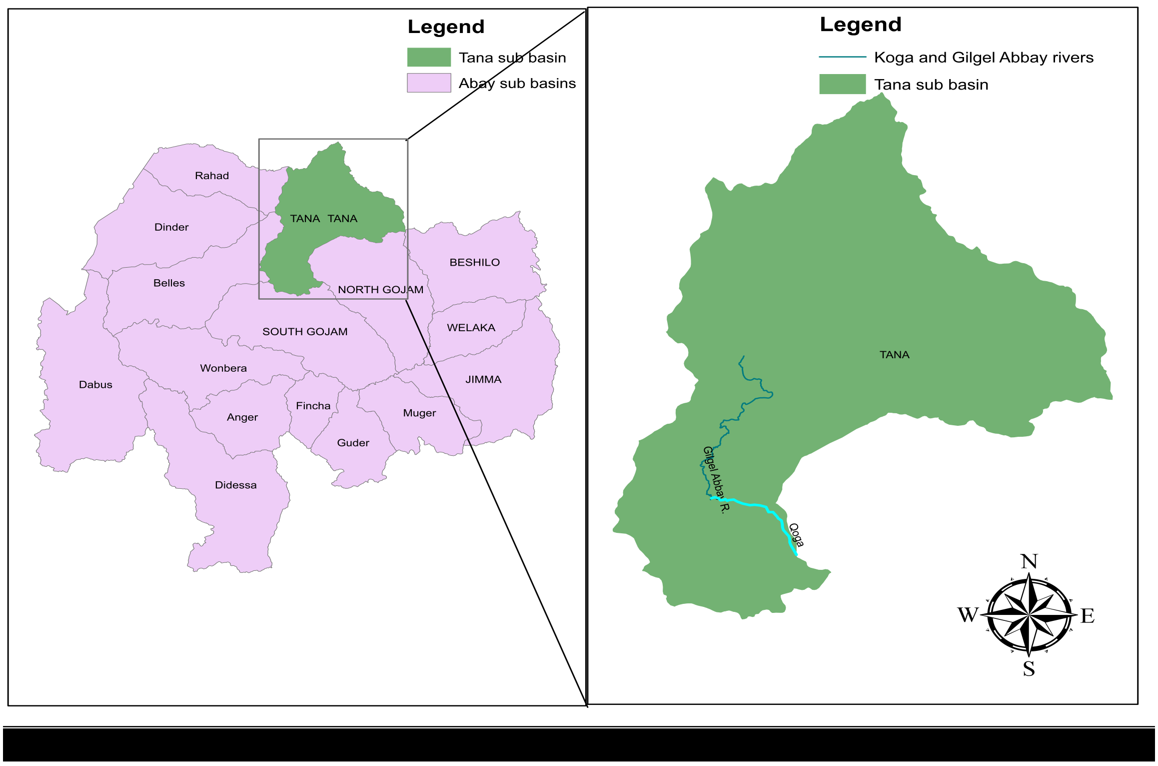
The Koga scheme has limited infrastructure, relying on unpaved roads for transportation. Access to electricity and clean water is also limited (Mecha Wereda , 2018).

Social Services

The Koga scheme has a limited number of social services, including a few primary schools and health posts. The availability of these services is often insufficient to meet the needs of the local people (Mecha Wereda , 2018).



(a) The Koga dam and hydro-climatic gauging stations



(b) Abay sub basins

Figure 1.7: Study area map

1.5 Statement of the problem

The United Nation's Sustainable Development Goals (SDGs) have become a reference point for policy-making processes worldwide (Kørnøv et al. , 2020). Sustainable development is increasingly accepted in different types of economy, such as developed, developing and transitional, and at different levels of intervention including at aggregate, sectoral and project level (Bond et al. , 2001). The evolutionary nature of sustainability may begin by ignoring the economic, then the social, then the environment, emphasizing the economy and the environment, and finally all three pillars considered (Ibeh and Walmsley , 2021). Sound public policy is defined as the integration of economic, environmental, and social sustainability that leaves no one behind across all policy areas. However, strategies or policies, programs, plans, or management practices that make sense from one point of view or for one group may jeopardize the viability of other groups' livelihoods or access to resources.

The balance between irrigation development and environment has been impacted by inappropriate irrigation practices. Although the World Water Assessment Programme has put water at the heart of environmental decision-making (WWAP , 2012), nonetheless, most water policy measures are framed in economic terms (Randy , 1997). Studies indicate that when the is a tension between development and the environment is skewed, there is a tendency to prioritize development over environmental concerns. For example, in initiatives in Ethiopia like the Plan for Accelerated and Sustained Development to End Poverty (PASDEP) and the Growth and Transformation Plan (GTP), the focus is largely on economic growth and poverty alleviation, with minimal attention given to environmental protection as a core component (Dejene , 2012). Recognizing that not all adaptations are beneficial has shifted focus to the need for sustainable adaptation measures that considers multiple objectives, as well as defining which types of adaptations are desirable. An underlying premise is that not all adaptation do necessary good. Trade-offs in short run and negative consequences are inevitable in certain measures. Identifying sustainable adaptations with little trade-off in the short run while maintaining long-term synergy in sustainable development or finding a balance between them is critical.

Ethiopia started reforming its water sector to a more decentralized and basin-level approach. The Abay River Basin Authority was firmly anchored in IWRM principles, such as emphasizing the importance of participatory decision making. The active participation of stakeholders, including at the basin level, is a fundamental principle of IWRM. However, the participatory decision-making mostly concentrated at regional level, rather than the farmers. As a result, they do not truly participate in decision-making process. The situation of the Abay River Basin Authority, which is a symbol of the adoption of IWRM principles, does not inevitably convert into good management (Beatrice et al. , 2015). Water resource management implementations did not conform to the water resources management policy and was not done on purpose using the IWRM approach (Mohammed , 2017). Despite its theoretical importance to sustainability, there is little evidence in the literature to substantiate the IWRM's support for sustainable development. Water management efforts were not in keeping with the goals of sustainable development, yet its support within the Koga scheme has not been thoroughly examined.

It is widely accepted that social and environmental issues are inextricably linked and, as such, should be given equal consideration in the context of EIA (Stolp , 2006), because humans are a component of the environment, it is necessary to incorporate social implications into the EIA process (Storm and Bunge , 1999). The first step in realising the potential of EIA for sustainable development is to understand how principles and understandings of sustainability within impact assessment are reflected in EIA policy, legislation and its follow-up procedure. Although sustainability is recognized as the overall purpose of EIA, it was found to be ineffective (Glasson , 1999); insufficient (Cadwell , 1993) and does not fully match public aspirations in terms of sustainable development (Murombo , 2008). In Bangladesh, mitigation measures along with monitoring program were inadequately implemented, implying difficult to achieve environmental sustainability of a project (Kabir and Momtaz , 2010). In South Africa, the effectiveness of EIA practice falls far short of sustainable mandate (Morrison-Saunders et al. , 2012). In most Sub-Saharan African countries, there is a strong positive association between EIA laws and the achievement of the SDGs, however, assessments of the role that EIA played were inadequate (Weaver et al. , 2008). In contrast, a review of recent Danish cases of environmental impact assessment (EIA) reports show the potential for a broader scope than the biosphere and environmental parameters that dominate an EIA context, especially population and human health (Ravn et al. , 2021). To some extent, EIA in the energy sector made good progress on sustainable development (Madlome , 2016). According to Madlome (2016), EIA recognized social issues equally with ecological ones at satisfactory level, with mitigation measures proposed being addressed to a reasonable degree of execution.

The Review of the Environmental Management Plan (EMP) of the Koga scheme indicated that, out of the major activities identified in EIA-recommended mitigation measures, planting forest seedlings and livestock development have shown satisfactory. Whereas, watershed management measures, public health and resettlement and compensation payment were unsatisfactory. The remaining activities were either didn't exist or not reported (Abebe et al. , 2007). The effectiveness of EIA implementation in terms of sustainability in the Koga scheme remains uncertain. Furthermore, there was no investigation of the sustainability assessment of these numerous EIA-recommended measures, particularly in terms of the perspectives of trade off and synergy in sustainable development. One of the study's goal is to fill this gap in the literature. There is a pressing need to evaluate and implement sustainable practices that balance agricultural production with environmental preservation and equitable social objectives.

The Koga scheme is designed to include, at least, explicitly combined the irrigation and watershed subsectors. It is designed to contribute to poverty reduction in accordance with sustainable agricultural development through irrigation, watershed management and capacity building sub-sectors (ADF , 2001). The irrigation and watershed management components are taken as equally important in planning documents (Sina , 2011). However, the scheme faces numerous challenges in achieving sustainable development and effective water management. In practice, the management is interested in the downstream area. The farmers also make the final decision with regard to appropriate crop selection based on largely for economic gains with little consideration to the environment (Benjamin , 2013). There are challenges of achieving the economic aspects of the scheme as well, with low crop yields posing a significant problem (Asmamaw et al. , 2021). Agricultural productivity and sustainable production is one area of focus (Yilak , 2013). This sustainable production relies heavily on resource utilization in agriculture, which requires the examination of technical efficiency in production.

In the setting of priorities, serious errors in judgment were made. The physical and engineering aspects of the scheme were effectively addressed. However, social and environmental issues have gotten little consideration. This is corroborated by the amount of money allocated for conservation. Moreover, upstream people are reluctant for watershed management (Gebre et al. , 2008). On the social side, major impoverishment risks were identified. The Koga scheme and the local municipality primarily concerned with material assets such as, land, houses, and compensation (Eguavoen and Tesfai , 2012). There was clear host-relocated households conflicts of interests. The former strongly oppose the practice of rewarding plots of land, which they see as unjust; because the government compensated them with money. Furthermore, stakeholder analysis, property valuation, compensation payments, community mobilization and awareness creation, and environmental monitoring and management all fell short. The complexity of the scheme requires a thorough understanding of social dynamics (Gebre et al. , 2008). In some cases, social considerations may even outweigh technical aspects in terms of importance. By taking into account the social implications of the scheme, project planners can ensure that the needs and concerns of all stakeholders are addressed, leading to a more sustainable and successful outcome. The current reports and research findings on sustainable development assessment of various management approaches were fragmented. These findings only discussed some activities in the scheme that were contrary to the concept of sustainability, and did not conduct a more rigorous analysis. There is also a paucity of empirical evidence, and there is still a limited knowledge of how the scheme is achieving economic sustainability.

The hydro-climatic conditions in the Koga scheme, including trend, variability in rainfall and temperature, pose additional challenges to sustainable development. This includes considering temperatures and rainfall patterns and their impact on water availability measured through the runoff volume. A decade of operation, whether owing to management issues or water availability, the irrigation system achieves less than 73.5 percent of 7004 ha irrigation needs (Birhanu et al. , 2014). According to Reynolds (2012), reservoir dries up for at least one month per year when the initial volume decreases by 11 to 22 percent, making the reservoir unsuitable for crop irrigation. A ten percent decline in seasonal rainfall from long-term average results in a 4.4 percent decline in output (Von Braun , 1991). Farmers in Koga scheme were unaware of the importance of irrigation scheduling and always applied the same amount of water for all crop type (Asmamaw et al. , 2021). Due to inefficient use, a substantial portion of water is lost on farms, and there is insufficient water to irrigate the design capacity (Getnet et al. , 2021). The main canal's water delivery performance was rated as inadequate. There was low adequacy and dependability for irrigation (Yeshi , 2018). The water applied at the farm levels of the Koga scheme is on average 2.21 times greater than the actual field demand, which is relatively maximum (Agide et al. , 2016). Farmers overapply water by approximately 30 percent of actual water demand, which accounts for on-farm water loss (Schmitter et al. , 2015). The intervention should be to match demand with reservoir release and to reduce excess on farm applications (Agide et al. , 2016). Few water usage and management techniques comply with the majority of the sustainability requirements; many are concerned with the achievement of one sustainability goal (Pires et al. , 2017). The consequence of not examining the current hydro-climatic situations including runoff sensitivity to climate factors in the area drags effort towards sustainable development.

It is critical to combine theoretical model assessments with locally focused social measurements of sustainability before embarking on public policy planning. The success of such plans and strategies for sustainable development is influenced by sustainability perceptions and climate changes. The effective integration of the various dimensions of sustainability will only be possible if perceptions of the core problems in these fields change as well. The study explores the relationships between climate factors, water resources, and sustainable development, with a particular focus on the role of IWRM and EMP in promoting sustainable development using different frameworks. It aims to provide comprehension into the current state of water resources and climate factors, as well as the effectiveness of existing management approaches in promoting sustainable development and agricultural sustainability.

1.6 Research questions

In view of the sustainability development and water management analysis, the following research questions guided this study:

1. Are the climate factors and the availability of water resource (temperature, precipitation, and runoff) improving?
2. How the temperature and precipitation impact water availability (runoff)?
3. How well do the IWRM and EMP support sustainable development?
4. How households and blocks in Koga scheme rated in terms of technical efficiency measure of economic sustainability?
5. How much efficiency improvement and speed are required to achieve an optimal level of economic sustainability?
6. What rate of efficiency growth differentials and speed are required to catch up with the most economically sustainable areas?
7. What rate of differential growth in efficiency and speed are required for the cross-over or leapfrogging phenomenon?

1.7 Objectives

1.7.1 General objective

To analysis sustainable development and water management in Koga scheme by applying the Triple Bottom Line and Wedding Cake Frameworks

1.7.2 Specific objectives

- To examine trend, variability and runoff sensitivity to climate factors in Koga scheme
- To measure the level of economic sustainability in terms of technical efficiency in production
- To assess economic sustainability convergency and cross-over phenomenon in agriculture
- To make sustainable development analysis of IWRM, and EIA-recommended mitigation measures

1.8 Significance of the study

The significance of this study lies in its potential to enhance sustainable development practices within the Koga scheme, addressing critical challenges related water management. The study's findings and recommendations have broader implications for similar irrigation schemes and water management projects in Ethiopia.

1. By evaluating IWRM current situations and future priority areas, the study aims to improve the performance of IWRM plan and implementation by devising improvement mechanisms for those that need immediate actions by the stakeholders.

2. The study's focus on EIA helps also identifying short run trade off and synergies in sustainable development. This contributes to minimizing significant short run trade off, as well as considering the long term perspectives in polices and practices.

3. By analyzing economic sustainability, the study provides insights into the economic viability and economic benefits of the Koga scheme in long term basis. This supports strategies to minimize wasteful practices in agriculture for the sake of production activities of the future generations to come. Moreover, the convergence results could be a valuable input in planning in agriculture.

4. Understanding hydro-climatic conditions and sensitivity aids in developing measures to cope with climate variability, and helps to improve water management. This enhances the scheme's resilience and ensure consistent water availability for agricultural productivity.

The study contributes to the existing body of knowledge on sustainable development and water management. The insights gained can be used by researchers, stakeholders and policymakers to develop and refine water management approaches to enhance sustainable development. The findings and recommendations enables the replicability and scalability of successful practices.

1.9 Scope of the study

This study aims to explore the Integrated Water Resources Management (IWRM) and Environmental Impact Assessment (EIA) water management approaches support to sustainable development within the Koga scheme. The study addresses the following key areas:

1. Assessment of current situations and future priority areas:
   The study evaluates current situation of IWRM in supporting sustainable development and future priority areas; examine how EIA recommended measures achieve sustainable development considering both trade off and synergies under triple bottom line and wedding cake frameworks and identify the strengths and weaknesses of these management approaches in achieving sustainability.

2. Economic sustainability:
   It analyzes the income benefits derived from the Koga scheme and assesses the economic sustainability of the scheme by examining the extent of resource utilization. Moreover, it has brought the concept of economic sustainability convergence to the frontier production, as well as becoming similar across different areas using technical efficiency as a measure.

3. Hydro-climatic conditions and comparative analysis:
   It examines the hydro-climatic conditions affecting the Koga scheme, including rainfall, temperature variations, and water availability measured by runoff trend and variability; evaluate and compare the degree of runoff sensitivity to climate factors in Koga watershed and to the other near by watershed, Gilgel Abbay watershed.

By addressing these issues, the study provides a comprehensive understanding of how IWRM and EIA support sustainable development, how farmers fared in resources utilization measure of economic sustainability and hydro-climatic conditions in the area.

1.10 Limitations of the study

It is important to acknowledge the limitations of the study to provide and all-encompassing understanding of its scope and the context within which the findings should be interpreted. The following limitations and future areas of research were identified during the research process.

- The study did not explore for causal chains, derivers and pressures that could determine the current state of the water resource such as temperature and rainfall. The future field of inquiry might be the successive steps that look into derivers and pressure, such as environment variables that influence temperature, rainfall and other determinants of runoff generation. This includes the examinations of land use land cover, soil, topographic characteristics on runoff, including the dam construction and operation effects.
- The study did not employ a structural breaks model to better reflect pre-dam and post-dam scenario. This fails to fully comprehend the hydro-climatic conditions in Koga scheme, particularly after the post-dam period.
- Irrigation had a greater impact than anticipated in income measure in Koga scheme. However, it will be deceptive because inflation may affect earnings from the sale of output. Future research should consider inflation-adjusted income to make comparison more meaningful and accurate of the before and post-project income earnings.
- Current convergence study employed a cross-sectional data, relying on comparing findings among farmers. The use of scenario development does not capture the full extent of the inter-temporal changes in economic sustainability. Rather than depending on scenario development as a methodology, future research should focus on examining convergence at the panel data level. More researches are crucial to comprehend the dynamics of agricultural production efficiency and detect trends in the field.
- The assumption that there is no technological change and the most efficient farmers would remain in the same frontier is unrealistic. The reliance on these unrealistic assumptions, though necessary to simplify the complexities, may not fully reflect the real-world conditions in Koga scheme.
- The IWRM sustainability evaluation involves weighing and assessment of the sustainable development goals. What is most important is the scheme's progress, not its beginning. Future research could compare the scheme as it expands by finding opportunities for improvement in react and act indexed goals.
- Evaluation of sustainability is more sensitive to pairwise comparison of criteria weights (as provided by the wedding cake framework) and triple bottom line frameworks. Even little changes in the existing weight affect the rank order of the measures. Despite the fact that some rankings are unaffected by weight changes, the smallest change in existing weight can reverse the ranking of EIA-recommended measures in terms of support to sustainable development. The weight of the criteria influences the two most desired sustainability measures: training and extension courses, and planting forest seedlings. Changes in the weights of the economic and environmental sustainability criterion may result in a reversal of the ranking between these measures. The criteria weighting, based on expert judgement, may not grasp the most accurate representation of the sustainability model, particularly in the layered approach of wedding cake framework. The study also failed to show clearly the most desired sustainable development model from triple bottom line and wedding cake frameworks, and making the interpretations accordingly. While the EMP sustainability study can only be successful if the core issue of criterion weighting in these sectors is addressed. There is still more work to be done in terms of

sustainability integration; should it be considered as a balance across all three sustainability dimensions rather than a hierarchy with the environment at its core; should we be more concerned with short run trade off/ balancing effects or long run synergy? Because the decision between these frameworks is likely to have an impact on that organization's policies and programs, much more research on this topic is required in the future.

1.11 Structure of the dissertation

The dissertation is divided into five chapters. The first chapter is a broad introduction that focuses on background and justifications, a concise literature review, the statement of the problem, research questions, objectives and other sections. The second chapter is devoted to a study of economic sustainability, as well as the spatio-temporal economic sustainability convergence in several blocks of the Koga scheme. Chapter three examines runoff sensitivity to changes in climate factors in Koga scheme: a comparative study. Chapter four examines the sustainable development analysis of IWRM and EIA-recommended mitigation measures. Chapter five synthesizes the major findings related to sustainable development analysis, economic sustainability and convergence, and hydro-climatic conditions in Koga scheme.

CHAPTER 2

TECHNICAL EFFICIENCY INDICATOR FOR ECONOMIC SUSTAINABILITY AND CONVERGENCE IN KOGA SCHEME: ETHIOPIA

[1]

Abstract

The study sought to determine the extent of agricultural sector performance in terms of economic sustainability and its convergence to the frontier production, as well as the catch-up effect, utilizing technical efficiency as a measure. Data were collected via a questionnaire designed to include household demographics, farm-specific variables, inputs, and outputs. The empirical model used stochastic frontier and technical inefficiency models to analyze economic sustainability. Inefficiency parameterizations, convergence theory, and scenario development as a methodology were employed for the convergence analysis. Farmers' average technical efficiency indicator of economic sustainability is 0.40, demonstrating low economic sustainability due to a significant resource waste. As far as the long-term perspective of economic sustainability is concerned, about 60% of inputs that may have been used for next farming operations were lost. Efficiency improvement is crucial in planning due to significant differences between sustainable and unsustainable households or blocks, huge waste of resources, output growth potential from efficiency improvement compared to returns to scale, and negative elasticity of output in some inputs (e.g. seed per hectare, land size). A household requires 9.42% growth to achieve optimum efficiency over ten years, and 15.46 years if a minimum reasonable growth rate of 6 % per year is assumed. Over a five-year period, the economic sustainability catch-up effect requires a growth differential of 2.11-9.45%. Household size, consultation visits, male heads, the sharecroppers' mentality, and non-farm income are thought to facilitate convergence at the frontier while fostering experience sharing towards a similar level of sustainability. On various grounds, the expected growth rate and speed of convergence were discovered to be reasonable targets.

Keywords

Technical efficiency; economic sustainability; capacity utilization; convergence

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2.1 Introduction

Sustainability in agriculture is a prerequisite for the transition to global sustainable development (Dung and Hiep, 2018). There have been attention to the issues of evaluating agricultural measures and assess the sustainability aspects of certain practices (Latruffe et al., 2016). Sustainable development, while highly desired, has become an oxymoron. The greatest dilemma facing humanity today is how to reduce poverty and inequality in the world without further transgressing planetary boundaries. In the face of these growing reconciliation difficulties, the vaunted three pillars of sustainability highlighted at the Rio+20 conference have become the major trilemma of sustainability in the twenty-first century (Martine and Alves , 2015). There is quite a lot of enthusiasm for more guidelines on economic sustainability, emphasising its relative importance in terms of achieving total sustainability (Bayramoglu et al. , 2018). Economic sustainability has to maintain its ability to survive and develop for overall sustainability. Economic factors were the most important criteria for sustainability, followed by environmental factors (Ceyhan , 2010). Experts and farmers give more weight to economic goals (Ahtiainen et al., 2015). Most water policy measures are shaped and explained based on the economic benefits (Stringer , 1997), and water as an economic good while providing a safety net for the poor (Donkor , 2003). For farms, economic sustainability is mostly linked to the basic goal of farmers and the reason for their economic activities. In the Koga scheme, there have been tremendous landscape and livelihood changes (Eguavoen and Tesfai , 2012), but the scheme arises from higher agricultural productivity needs.

The economic sustainability indicators used in different studies not only reflects different interpretations but also on the different purposes and scope. The definition used for economic sustainability is essential to guide the selection of these indicators. The economic dimension considers the overall business viability and efficiency of an agricultural system. Contextually, economic sustainability is generally viewed as economic viability, a farming survival in the long term across generations or to a successor. These, in turn, depends on resource availability. The approach of this study on the selection of indicator is based on two groups of literature review works as a benchmark. The first benchmark paper by Latruffe et al. (2016) and based on a paper by Van Cauwenbergh et al. (2007). The indicators of economic sustainability in these papers cover a relatively few, mainly measured through economic viability in terms of profitability, liquidity, stability, and productivity. The measurement of economic sustainability usually limited to such economic indicators. The judgment on these indicators showed that the first three categories have often been used in the analysis of the financial statements, which have a pure accounting view that does not consider productivity and opportunity costs. While the second benchmark paper is a literature review by J. Spicka et al. (2019). It provided an alternative way of measuring economic sustainability in agriculture that includes economic viability, transferability, independence, and efficiency components. The judgment on the relative relevance of each component shows that the first two problematic indicators are, while the efficiency that it includes or at least associated with autonomy.

The assessment of papers as a benchmark shows that technical efficiency got relative importance as a measure of economic sustainability relative to other indicators. Productivity and efficiency have important implications for evaluating the economic viability and sustainability. Although both are cooperative concepts, efficiency measure is more accurate than productivity measure because it imply a relative performance to the most efficient frontier. Inefficiency occurs when production operates within its frontier (Coelli et al. , 2005); with the gap between actual and the frontier reflecting inefficiency (Osiewalski et al. , 1998). According to Page (1980), Murillo-Zamorano (2004), and Shih et al. (2004) technical efficiency is defined as the maximum possible amount of output given set of inputs or the minimum inputs to produce given level of output. Technical efficiency index measures the ratio of actual production to maximum potential output, with a relative concept. The role of efficiency for production has been widely got attention world wide (Bravo-Ureta et al., 2007). It is at the heart of agricultural production, as farmers can expand and maintain the scale of production through efficient use of resources (Udoh 2005; Ali 1996). The analysis of efficiency occupies a special place in economic theory and actually consists of resource management methods, since efficiency is essentially the most appropriate way of expressing the extent to which factors of production are available to a nation.

There is no a-priori reason for both technical and allocative types of efficiency to increase or decrease simultaneously nor their relative contribution should be of equal importance for output growth. It seems unclear to determine the main source of output growth from a high levels of technical or allocative efficiency (Karagiannis and Tzouvelekas , 2001). The latter also takes into account how the intervention is distributed to benefit the community as a whole, which is generally accepted in welfare economics (Palmer and Torgerson , 1999). Achieving technical efficiency is a universal goal that is applicable in any economic system. On the other hand, the other types of efficiencies suppose the objective is profit maximization. The profit maximization should not be applied as a general measure of performance, while technical efficiency is usually accepted. In particular, measures of technical efficiency is less sensitive to assumptions of perfect knowledge, perfectly competitive markets, and the profit maximization objective (Uvarovsky et al. , 2000). As noted by Sadoulet (1995), technical efficiency is an optimal productivity target. When measuring efficiency, the focus is mainly the technical efficiency, achieving technical efficiency is perhaps the greatest concern (Tsionas and Kumbhakar , 2006). Measuring the economic performance needs an examination of production decisions and technical efficiency. Consequently, better economic performance is indicated by higher technical efficiency. A prerequisite for economic sustainability is a degree of high technical efficiency that ensures the economic viability and sustainability of the operations (Gusmi, 2013). The course of efficiency over time is used as an indicator of sustainability (Gomes et al., 2009).

Although previous studies in Ethiopia identified a stochastic frontier model that could be used to calculate technical efficiencies, applications developed from these findings were limited to generating technical efficiency indices. The use of efficiency in terms of economic sustainability is largely absent in the literature. Technical efficiency is a crucial tool for partially decoupling economic growth from environmental degradation costs. Improvement in technical efficiency enables not only economic growth and prosperity but also could save unnecessary wastage of resources that otherwise be used for the future generation. Improving technical efficiency can also be understood from a broader perspective beyond economic gain like environmental sustainability. However, this unnecessary wastage of resources is emphasized in this study in terms of resource availability for future production during the professional life of a farmer. While farmers might redirect those resources to other activities that the long-term perspective may not always be fully considered or realized by farmers, redirecting these resources can also mean conserving other resources that might otherwise be utilized for these activities.

Studies on agricultural productivity growth have identified three stages (Ruttan , 2002). These includes a focus on measuring single-or partial-factor productivity and then total factor productivity (TFP), while the third stage on productivity and efficiency convergence tests. The studies incudes advanced calculation methods, such as efficiency convergence testing (Kneller and Stevens 2003; Carvallo and Kasman 2003). Literature on convergence pose so many questions, such as, are farmers producing at maximum capacity? Are they on the same level of efficiency? Can farmers catch up to the frontier or others? Are there any successful farmers to emulate?. A change in technical efficiency is an important aspect of catch-up and convergence; indicating the ability to adapt global technology (Rao and Coelli , 1998).

Efficiency convergence raises some interesting concepts that includes convergence moment approach towards or away from the frontier; the catching up moment approach, which highlights the same level of efficiency over time; and convergence to the average level (Purwono and Yasin , 2020). Meanwhile, it takes mainly the following forms: convergence among countries (Barro and Sala-I-Martin , 1992) and convergence at the frontier (Battese and Coelli 1995; Kumbahakar and Wang 2005). It is unrealistic to expect a given firm's inefficiency level to remain constant over time. According to Battese and Coelli (1995), a decrease in inefficiently over time is an indication of convergence. The policy objective should be minimizing this inefficiency gap. However, the issue of inequalities in agricultural development among countries and regions also continues to capture public attention. Excessive developmental differences in spatial systems are now considered negative characteristics. The question is, "when will all of this gap be closed?". Convergence could be the fastest or the slowest. Regions not only successfully catch up in terms of efficiency score, but also discourage efficiency imbalance among regions (Purwono and Yasin , 2020). Finally, means of improving technical efficiency and thus, accelerating the rate of convergence remains a long-standing question in development economics. According to Melaku (2018), each year, lessons from development initiatives' actions must be documented, distributed using appropriate communication channels, and expanded to a broader spectrum of farming communities.

There are a significant amount of researches on efficiency convergence, but very few on regional and local technological efficiency variations, and none analyzed the research idea in terms of economic sustainability and convergence perspectives. The benchmark papers discussed in the literature suggest that the long-term perspective of production and economic sustainability is better understood through the measurement of technical efficiency. The number of year it takes for a farmer to achieve fully technically efficient, and minimize differences with other farmers if it grows at a faster rate is also crucial for policy making. The previous literature also lacked information on the expected rate of change in technical efficiency for convergence. However, this study goes beyond identifying the farmers' technical inefficiency by investigating the required efficiency growth rate and time to achieve optimum and comparable economic sustainability across different blocks in the Koga scheme. That way, an increase over time indicates an improved economic sustainability, indicating temporal convergence. Due to data limited to cross sectional, the study has brought scenario development to see the inter-temporal changes in economic sustainability. Minimizing regional inequalities, on the other hand, indicates spatial convergence in economic sustainability in the Koga scheme.

2.2 Literature Review

The field of agricultural sustainability has seen an explosion of indicators, which is a source of confusion for potential users (Riley 2001; Lebacq et al. 2013). Composite indicators and single indicators are the two general approaches that can be seen in the literature for developing economic sustainability indicators and measuring sustainability in general. The choice between single and composite indicators depends on the research idea, nature of the study, and the available data. The need for a composite index has been emphasized in the literature, but due to data aggregation, ideological and other issues, none of the currently available composite indices have found general acceptance (Dewan , 2006). Composite indicators can also disguise serious deficiencies in some dimensions and make it difficult to identify appropriate corrective actions (Fisher et al. , 2001). The use of separate individual indicators, on the other hand, offers the possibility of a detailed interpretation and analysis, which gives the reader a deeper understanding of sustainability. Single indicators offer simplicity and clarity, easy to understand and interpret. They often provide a straightforward measure that can be easily communicated.

Some studies have used separate individual indicators and composite indicators, usually index numbers, to measure economic sustainability specifically, as well as sustainability in general. From a long-term perspective, organic farming in India has proven to be an economically feasible solution for small tea growing farmers, based on the annual income of one hectare of tea cultivation over 10 years. Organic conversion lead to sustained and high yields for producers. The income from organic tea can rise even more if the producers rely on the optimal use of resources. To understand the economic sustainability of small scale growers, a cost–benefit analysis, which is a separate individual indicator, was further performed using the indicators of Net Present Value and Benefit to Cost ratio (Deka and Goswami , 2021). The other study tha used a single indicator is a study by Bayramoglu et al. (2018). The level of sustainable income was used as a measure of economic sustainability in agricultural enterprises. Economic sustainability was defined in the study as the generation of an income by an agribusiness that covers people's livelihood, depreciation and interest on capital. Therefore, economic sustainability has been divided into three components, which take into account the income required to cover living expenses and the depreciation and interest costs. The income that provides economic sustainability has been termed "sustainable income". If the sustainable income is greater than or equal to the sum of subsistence expenses, depreciation and interest, the agribusiness is economically sustainable. If the sustainable revenue is less than the sum of subsistence expenses, depreciation and interest, agribusiness is not economically sustainable. Enterprises that achieved this level of income level were classified as economically sustainable. Based on the results of the analysis, more than 150 enterprises in Turkey's Konya province were found to be unsustainable. A study by Pourzand and Bakhshoodeh (2014) in Iran classified regions into sustainable, relatively sustainable and unsustainable. Technical efficiency is considered as a key element among the triple elements of sustainable development, such as economic, social and ecological. The technical efficiency for sustainable regions are higher. The article by De Koeijer et al. (2002) highlighted that average technical efficiency of only 50 percent implies that there are significant opportunities to improve sustainability even without technological improvements and without trade-offs between the economy and the environment.

Hepelwa (2013) conducted a study that utilized composite indicators, focusing on the technical efficiency index as a measure of sustainability. The index consisted socio-economic and catchment-related variables to provide an indicator of the sustainability. Greater technical efficiency in crop production was associated with a large amount of agricultural produce per land, and minimizing the land usage. Most farmers in Sigi catchment of north-eastern Tanzania had a technical efficiency below 0.3, none of them had 0.9 or more. The implication is that there was a room for technical efficiency improvement and the sustainability of the watershed's resources. The low efficiency led to deforestation as farmers were constantly looking for more arable land. The gist of this result is a large quantity of forest could be saved if efforts aimed at efficiency improvement.

Economic sustainability and its convergence studies are scarce in the literature. The following section reviews efficiency convergence as it is contextualized in this study to show economic sustainability. Empirical results in convergence have found contrasting findings. The results of a balanced panel of 126 countries from 1970 to 2014 demonstrated no global agricultural convergence. The finding put forwarded a solution for convergence to happen in these countries such as international trade, irrigation systems, livestock and structural transformation. On one hand, countries within the same level of economy status showed a tendency for catch up such as Sub-Saharan African countries, low-income countries, less developed countries, and agriculture-based countries. However, all of the lagging country groups were even farther behind advanced countries than they were in 1970. The findings also suggest that more countries are closing at the frontier (Yuan et al. , 2021). Using provincial data from 2002 to 2017 in Indonesia, the efficiency data exhibited both catching-up patterns and accelerating towards the frontier. It has numerous practical implications, one of which is that it can inform how performances are expanded (Purwono and Yasin , 2020). Improving regional production efficiency is frequently regarded as a means of reducing regional inequality. Another study in Indonesia from 1990 to 2010 found that there is regional convergence in the overall efficiency, pure (technical) efficiency, and scale efficiency measures. The efficiency dispersion is decreasing over time, approaching the frontier at 9 percent per year in overall efficiency. Provinces with low efficiency were catching up to the most efficient ones, and appeared to be the quickest. It was expected to cut the differences in half over 5.6 years. Coordination in the form of policies and technology transfer could facilitate this convergence (Carlos , 2020). A study in Russian agriculture found technical efficiency divergence results between 1993 to 1998. Based on data from 75 territorial units technical efficiency, there was a growing gap between regions. When it comes to the development of efficiency, the initial conditions are the most important. Those regions with favorable initial conditions prosper and their technical efficiencies grow over time, while marginal regions become increasingly inefficient (Uvarovsky et al. , 2000). A study that looked at relative productivity levels and decomposed productivity change in European agriculture between 2004 and 2013 tested whether or not Total Factor Productivity is converging among member countries. The findings lend support to the productivity convergence hypothesis across a member of countries. Policies should also pay close attention to the learning process as a key driver of differences between countries, particularly, in laggard regions (Barath et al. , 2016).

In Ethiopia, average technical efficiency also varies across regions; yet, no study is available that shows the convergence in these regions. The minimum 50 percent in the South Nation Nationalities Region (SNNP), Tigray is 52, Oromia is 54 to a 57 percent in the Amhara region, the highest score. At the zonal level, the score ranges from 33 to 62 percent (Melaku , 2018).

2.3 Methods

2.3.1 Data type, source and description

This study employed a household survey in twelve blocks/areas of the Koga scheme to determine the economic sustainability and its convergence indicated by technical efficiency measures.[2] The accuracy and consistency of survey are indeed a significant aspects of research methodology. To ensure these aspects are maintained, test-retest reliability is often used for the questionnaire in Kudmi block, 3km away from dam site. This method involves administering the same questionnaire to the same participants at two different time points, particularly within a short time frame, and then the comparison of responses for a small group of respondents after repeating some questions. High test-retest reliability guaranteed that the questionnaire is

[2]Although the formal designation, blocks, in the study area is mostly utilized, regions or areas were used interchangeably to refer to the twelve blocks in the Koga scheme command areas.

consistent and accurate. The questionnaire was designed to include household demographics, farm operational and farm-specific variables to fit into the model of technical inefficiency. On the other hand, output, income and factors of production was based on the microeconomic theory of production for use in Translog's stochastic frontier model (see Appendix Table 5.11).

2.3.2 Sample size and sampling procedure

The level of precision required by users, the desired confidence level, and degree of variability were used to determine the appropriate sample size. According to Cochran (1977), the sample size can be calculated using two equations given below.

$$n_0 = \frac{z^2 pq}{e^2} \tag{2.1}$$

Where, n_0 is sample size given in equation 2.1 when population is infinite, z is the selected critical value of desired confidence level, p is the estimated proportion of an attribute that is present in population, q =1-p and e is the desired level of precision. Assuming the maximum variability, which is equal to 50 percent (p = 0.5) and taking 95 percent confidence level with 5 percent precision, the calculation for required sample size is as follows: p = 0.5 and hence q =1-0.5 = 0.5 ; e=0.05; z=1.96 so that n_0 = 384. While, the correction equation to calculate the final sample size is given by equation 2.2. Here, n_0 is the sample size derived from equation 2.1 and N=12,000 is the population size.[3] In this case, the sample size (384) less than 5 percent of the population size (12,000). Since n_o/N is negligible then n_0 =384 is a satisfactory approximation to the sample size. So, the researcher does not need to use the correction equation to calculate the final sample size.

$$n = \frac{n_o}{1 + \frac{n_o - 1}{N}} \tag{2.2}$$

Moreover, the 7004 hectares of total irrigation land and the irrigation potential of each irrigation block were used to determine the appropriate sample size in each block. A list of blocks or areas along with the irrigation potential (hectares) summary data received from the project office in Merawi town is provided in Appendix Two : B (see Table 5.10). The greater distance (it ranges from 3-19.7 Km) the blocks from the main dam was challenging to collect data from all the twelve blocks. However, maximum effort was made to collect survey data from 384 households in 2017/18 using stratified random sampling technique by proportional allocation method based on irrigation potentials. The objective is to examine how and to what extent the agriculture fared at economic sustainability and convergence. Since one of the objectives is to examine regional differences, each block was taken as a stratum during the study.

As indicated in pie chart Figure 5.1, from the total potential 7,004 hectares of irrigation land in the Koga scheme, the highest portion of the land approximately 864 hectares (12.3%) is in the Tekledib block, while the lowest, some 290 hectares of land (4.2%) in Amarit. Therefore, based on the stratified random sampling technique by the proportional allocation method, the largest sample (24%) was drawn from two blocks of Tekledib and Adbera, the two areas with the largest abundance of irrigation land in the study area. In fact, Amarit's lowest sample accounts for only 5.2% of the total sample size (see Pie chart Figure 5.2). The 384 surveyed households used approximately 533.13 hectares or 7.6% of the total potential during the survey. The highest proportion of arable land in the sample is in the Tagelwedefit block, around 13.8%, and the lowest in the Enguti and Amarit regions (see Pie chart Figure 5.3[4]).

[3]The beneficiaries are the populations of the scheme area which is located in the Mecha Woreda is believed to comprise about 12,000 households

[4]Color for pie-chart figures should be used in print

2.3.3 Estimation techniques and models

(1) Stochastic Frontier Model

The basic stochastic frontier model developed simultaneously by Aigner et al. (1977) in the first group and Meeusen and van Den Broeck (1977) in the second group, which assumes that the deviation from the maximum is due to technical inefficiency and random noise, was used. The true nature of production is stochastic, especially in agriculture. The choice of this technique is based on the variability of agricultural production resulting from so many factors such as climatic hazard, and management inefficiencies. The prodution function under this model is given by equation 2.3.

$$Y_i = f(X_i; \beta)exp(V_i - U_i), i = 1, ...n \tag{2.3}$$

Where, Y_i is the product produced in the i^{th} plot/farmer, X_i is a vector of inputs used in the i^{th} plot, and β is a vector of parameters to be estimated. Aigner et al. (1977) proposed stochastic models by assuming that the disturbance term has two components, that is, V_i and U_i. The error component V_i represents the symmetric disturbance that captures random errors caused outside the firms' control such as measurement errors, random shock, and statistical noise. The U_i component of the error term is the asymmetric term that captures the technical inefficiency of the observations and is assumed to be independent of V_i, and also to satisfy that $U_i \geq 0$. The non-negative component (U_i) reflects that each firm's output must be located at or below its frontier. Therefore, a technically efficient plot that represents a maximum attainable output (Y_i*) is given in equation 2.4.

$$Y_i* = f(X_i; \beta)exp(V_i), i = 1, ...n \tag{2.4}$$

The efficient plot can serve as a benchmark to calculate the technical efficiency of all other plots. The technical efficiency of the plot (TE_i) is given by in equation 2.5. Technical efficiency (TE_i) can be defined as the production capacity of a producer in relation to the maximum production of a plot using a given amount of inputs and available technology.

$$TE_i = [Y_i/Y_i*] = exp(-U_i), i = 1, ...n \tag{2.5}$$

Before estimating the model parameters using the Maximum Likelihood Estimation (MLE), the functional specification of whether Translog or Cobb-douglas function should be used was determined. The stochastic frontier production function using the flexible Translog (TL) specification in equation 2.6 was found to be more appropriate than Cobb-Douglas based on the log-likelihood ratio test.

$$LnY_i = \beta_o + \sum_{k=1}^{n} \beta_k Ln(X_{ik}) + \frac{1}{2}\sum_{k=1}^{n}\sum_{j=1}^{n} \beta_{ij} LnX_{ik} * LnX_{ij} + V_i - U_i \tag{2.6}$$

Where, ln is the natural logarithm, Y_i is the total value of the output, β's are the coefficients of the parameters to be estimated, X_is are factors of production, V_i is the idiosyncratic error resulting from measurement errors in the use of input and/or output, and U_is are the non-negative random variables used to measure an individual household's technical inefficiency. lnX_{ij} and lnX_{ik} contain the squares and the interaction terms of the input variables. The factors of production (X_is) were defined in terms of per hectare to standardize measurements and facilitate comparisons across different areas. It allows for uniformity and easier interpretation of data, especially when comparing results across different land size plots. Moreover, the elasticity measure enables us to compare how production is sensitive to changes in input variables that are measured in different units.

The initial idea was to focus on a common dominant crop by measuring its output in physical quantity as it is indicated in questionnaire (see Table 5.4). However, this approach had to be revised because there was no single crop type that was dominant across all farmers surveyed. Despite efforts to collect data specifically on the dominant crop type, it was found that households differed in their major or dominant crop. In addressing this challenge, the researcher ended up using income data instead. Data were collected in two forms: physical units and monetary values. An approximate prices during the study period were used to convert the physical units into monetary values. Subsequently, the data on monetary values were utilized without modification, as no significant difference was observed between the two measures. This may be due to the nature of crop being mostly cash crop. By focusing on income, the study can provide recommendations that are applicable regardless of the specific crop type. This approach aligns with the overarching objective of farm business, where income serves as a consistent measure irrespective of the variety of crops cultivated by farmers.

(2) Inefficiency Model

The determinants of technical efficiency in the inefficiency model was estimated based on equation 2.7 and the variables given in Table 5.11.

$$U_i = \delta_o + \sum_{i=1}^{n} \delta_i Z_i + W_i \tag{2.7}$$

Where, Z_is are various demography, operational and farm specific variables. Since the dependent variable in equation 2.7 is defined as technical inefficiency, a negative coefficient represents a positive impact on technical efficiency, vice versa. In view of the fact explained in literature about the draw back of two-step estimation, such as the violation of assumptions regarding the normality, independence, and identical distribution of inefficiency term due to a functional form given to it, the stochastic frontier and inefficiency models were obtained simultaneously.

(3) Capacity Utilization

The stochastic frontier model is also used to estimate capacity utilization. Capacity utilization/potential yield was estimated by scaling up actual output by the efficiency score generated from this model (i.e. by dividing the current production or the actual production by the efficiency score) by the following equation 2.8.

$$Potential - yield_i = \frac{100}{technical - efficiency - index} * actual - output \tag{2.8}$$

Furthermore, to understand the economic sustainability level of the scheme, capacity utilization and inefficiency loss measures using both output and input orientation was performed using indicators of cost (input) saving by considering method from Kibret et al. (2016), output loss measured as proportion of potential output, output growth with efficiency improvement and loss in Millions of Ethiopian Birr (METB) (See Table 2.3).

(4) Exponential Growth Model

The exponential growth is used to model various real world phenomena, such as the population growth of bacteria, compound interest, economic growth, etc. Productivity is modeled the same way, and it explains the long term growth path. A study by Abid et al. (2018) used five different forecasting models such as linear trend model, quadratic trend model, exponential growth model, S-curve trend model and double exponential smoothing model to find the best fitted model for area and production of potato in Pakistan. The study showed that exponential growth model was appropriate due to lowest values of the forecasting errors. There is an exponential growth of food production to meet the needs of the growing population (Karthikeyan et al. , 2020). Akpan et al. (2014) modelled agricultural productivity in Nigeria using the exponential growth rate. Exponential growth model widely applied because its compounding effect and feedback loops with snowball effect; an increase productivity leads to a further rise in productivity. A small change in efficiency leads to a significant overtime. The exponential growth equation for the accession and benchmark block or the target level is given below in equation 2.9 and 2.10.

$$Y_{t_c} = Y_{o_c}(1 + g_c)^n \tag{2.9}$$

$$Y_{t_T} = Y_{oT}(1 + g_T)^n \tag{2.10}$$

Where, Y_{o_c} is the initial level of economic sustainability measured by the actual level of income relative to potential or technical efficiency, and Y_{o_T} is the targeted level of economic sustainability for the accession block, g_c is the expected average annual efficiency growth rate for the accession block, g_T is the expected average growth efficiency of the benchmark. The variable n typically represents the number of years.

(5) Efficiency Convergence Model

Economic growth convergence is a tendency towards the world production function (Kumar and Russell , 2002). The current study adopted an efficiency parameterization from which the rate of efficiency improvement and speed of convergence for economic sustainability can be assumed and computed. Thus, efficiency improvements are also explicitly related to economic sustainability improvement and convergence in this model.

A block's economic sustainability performance should be known from a comparison with a certain benchmark, be it the frontier or most sustainable bock. To examine the tendency of blocks to become optimum and catch up in terms of economic sustainability levels measured by technical efficiency indices, including crossover or leapfrogging phenomena, the identification of each blocks' frontier and benchmark block for analyzing temporal and spatial convergence in economic sustainability was initially done using technical efficiency estimation. Then, one can start with the relations given by the exponential growth in equation 2.9 and equation 2.10 concerning the actual level of economic sustainability measured by output per potential output, that is, the technical efficiency of two blocks with different initial conditions and expected growth rates of efficiency improvement. The current study makes use of the theory of growth and technical efficiency catching up for the temporal and spatial dimensions of economic sustainability convergence by identifying the rate of growth in efficiency improvement and speed of convergence that blocks with low initial levels of economic sustainability grow at a higher rate in technical efficiency to catch up the level of economic sustainability of the benchmark block or blocks.

I. Temporal Economic Sustainability Convergence

The inefficiency term ($U_i \geq 0$) indicates the gap between actual and frontier level of output for each block in the area, and economic sustainability convergence implies a shrinkage of U_i over time. The target is optimum efficiency or optimum economic sustainability contextualized in this study. The expected average growth efficiency at the optimal level of economic sustainability (i.e g_T = 0) is zero since it is the maximum point. Therefore, temporal economic sustainability convergence is achieved when the technical efficiency score is one, i.e Fully-efficient. Hence, temporal economic sustainability convergence achieved when the Y_{tc} curve exactly touches the optimum economic sustainability line, a value of one, according to equation 2.11.

$$Y_{o_c}(1+g_c)^n = 1 \tag{2.11}$$

Therefore, the temporal convergence methodology tries to answer: (1) What rate of efficiency improvement is needed for blocks to attain an optimum level of economic sustainability?; (2) What is the speed of convergence (n) for each block to attain an optimal level of economic sustainability?

II. Spatial Economic Sustainability Convergence

The study is based on a deductive approach that is designed to answer convergence questions using a convergence theory that defines the relationships between two or more economies. The theory is also known as the catch-up effect in economics, and it primarily addresses the relationship between less developed and more developed areas. It basically states that less-developed areas will grow faster than more developed areas. This progress is primarily due to advanced technologies, production, and establishments in developed areas. Because developing areas lag behind developed areas, they can simply replicate developed areas' technologies, methods, and establishments. Such replications could include utilizing developed areas' production technology as well as implementing their advanced services.

The theory of convergence is based on assumption that there is no technological change and the most efficient block would remain in the same frontier. The approach sets out to identify temporal economic sustainability convergence emphasizing a movement to the frontier not due to technical change (shifts in the frontier) for economic sustainability. Although there is evidence of technical change in farming households and agriculture, there is pessimism about the potential for farming technologies in Ethiopia, and urban ignorance about the intelligence of illiterate farmers (Mellor and Dorosh , 2010). While there has been progress in adopting modern agricultural technologies, many smallholder farmers still lack access. These still indicated very little transformation in the utilization of technologies in production, as many farmers still rely on traditional methods, such as on oxen plows and rain-fed cultivation (Diriba , 2020). This lack of technological advancement has led to skepticism about the potential for technical change in the agriculture sector, suggesting to some extent assume no, if not, little technical change.

For spatial convergence, the level of economic sustainability in accession and benchmark blocks are equal over time according to equation 2.12.

$$Y_{o_c}(1+g_c)^n = Y_{o_T}(1+g_T)^n \tag{2.12}$$

III. Speed of Convergence

By taking the logarithm and rearranging the terms, the time, n is usually in years, when the economic sustainability balance of two areas or the optimum level of sustainability will be achieved is given according to equation 2.13. This time frame of economic sustainability convergence is determined by the initial or relative level of economic sustainability, as well as the growth differential between accession and benchmark areas.

$$n = \frac{log(Y_{oT}) - log(Y_{oc})}{log(1+g_c) - log(1+g_T)} \tag{2.13}$$

(6) Proportional Offset, or the Proportional Overlap Hypothesis

To make efficiency growth rate comparison more meaningful and accurate, the proportional offset of the catch-up effect contextualized for the study, α_{ij}, in equation 2.14 according to (Papava 2012 ; Papava 2014) is calculated.

$$\alpha_{ij} = \frac{TE_i}{TE_j} \tag{2.14}$$

Where, *TE* is technical efficiency for blocks *j* (the less sustainable blocks) and *i* (the reference block). If the expected efficiency growth of block *j* is equal to r_j, then the efficiency growth of block *j*, corresponding to the efficiency growth in block *i*, under the catch-up effect hypothesis i.e. the adjusted efficiency growth of the *j*-th blocks (less sustainable blocks ($r_{ij}*$), is given by equation 2.15:

$$r_{ij}* = \frac{r_j}{\alpha_{ij}} \tag{2.15}$$

Consequently, $r_{ij}*$ is the hypothetical efficiency growth of block *j* which can be used to measure relative efficiency growth against block *i*. If we divide the hypothetical efficiency growth quotient for block *j* ($r_{ij}*$) by the expected efficiency growth of block *i* (r_i) in equation 2.16, we obtain a value that indicates how many times the efficiency growth of block *j* really exceeds that of block *i* for convergence analysis.

$$\beta_{ij} = \frac{r_{ij}^*}{r_i} = \frac{r_j}{r_i\alpha_{ij}} \tag{2.16}$$

(7) Scenario development

Due to the difficulty in calculating historical productivity growth, scenario-based analysis was used in cross-sectional data. Cross-sectional data doesn't provide temporal information and the dynamics. In order to do so, the researcher created scenarios that logically assume data from surveys (as in so many real instances). One type of methodology used in this study for forecasting the future expected growth rate of efficiency is scenario development. It is based on a literature analysis of the current situation, the development of informed assumptions about the expected growth rate of efficiency in the future, and government plans and reports. The researcher incorporated logic into the analytical process. The study's scenarios gain rigor through analysis. The scenario development process involves also two plans: one for short-term planning (five years) and one for long term planning (ten years). The short-term strategy corresponds to spatial economic sustainability convergence, whereas the long-term strategy corresponds to temporal economic sustainability convergence.

2.4 Results and Discussion

2.4.1 Descriptive Statistics

2.4.1.1 Demographic variables

In this section, the demographic variables of the survey's sample households, such as age, gender, and household size, are described to better understand the decision-making environment in which agricultural production takes place. The survey included 384 farmers, with 66.9 percent of the heads of household being men. This suggests that male household heads predominantly dominate agricultural production in the survey. While both men and women engage in productive activities, their responsibilities and functions often differ. More than 98 percent of respondents were over the age of 30, indicating that the majority of the sampled farmers are active and energetic, capable of effectively and efficiently performing their tasks. The average household size was six, with most members considered part of the labor force (see Table 5.12).

2.4.1.2 Socio-economic variables

The average total land size of the households sampled was approximately 1.39 hectares. Off-farm income activity participation was obtained by 50 percent of the sampled farmers. This demonstrates that farmers participated in off-farm income-generating activities in a moderate manner. In terms of education, the average year of schooling for a head was about 1.33 years. The majority, if not all, of the sampled farmers are not receiving formal education, with only a small percentage receiving basic education.

Manure is a major input for agricultural production in the Koga scheme. The majority of farmers (56.5 percent) used organic fertilizer, manure. In terms of farming management, in order to become more productive, they used various water and soil conservation mechanisms even though farmers had fertile or good soil, which is confirmed by 52.8 percent of households. During the survey, only 15 percent of households had access to credit. The majority of farmers (81.8 percent) used their own irrigated lands for production, while 3 percent were sharecroppers. Farmers from the adjacent Kebeles in the Koga scheme welcomed the project due to their expectation to engage in sharecropping. The majority of farmers are members of farmers' associations (see Table 5.12).

2.4.2 Translog Stochastic Frontier and inefficiency model results

The Stochastic Frontier Model's assumptions about two-component disturbance term, which represents uncontrollable random errors like measurement errors, random shocks, and statistical noise, as well as technical inefficiencies such as management inefficiency, have been validated using the perception results. In the survey, approximately 67% of farmers (as shown in Figure 2.1a) believed that production loss was attributed to a both natural factors, as well as inefficiencies in management. Before estimating model parameters with the Maximum Likelihood Estimation (MLE) technique, it was critical to test the model's specification and validity. The production function must be determined from the available data. The study used flexible Trans-log (TL) specification to specify the stochastic frontier production function and then performed a log likelihood ratio test to see if the Trans-log (TL) reduces to the CD function. In Cobb-Douglas, the coefficients of the squared and interaction terms of the trans-log frontier variables are zero. As a result of the log-likelihood ratio test, the TL functional form is more appropriate than Cobb-Douglas (see LR ratio test results in Appendix in Table 5.15). The diagnostic test in the functional specification demonstrated that the squared and interaction terms of the trans-log frontier input variables are not zero. Furthermore, at the 5 percent level of significance, the hypothesis that all determinants in the inefficiency effect model are simultaneously zero is failed to accept (see LR ratio test results in Appendix in Table 5.16). As a result, these variables explain differences in farmer inefficiency.

The maximum likelihood estimates of the two models: Translog stochastic frontier model and inefficiency model are shown in Table 5.13 on page 209 and Table 5.14 on page 210.[5] Due to the presence of second order coefficients (cross products of variables) in the function, the coefficients are not directly interpretable. Thus, elasticities at the variable means (where x_i

[5] Some variables that proved to be highly statistically insignificant were ignored and eliminated during the regression process in both models

Table 2.1: Output elasticities and returns to scale

Inputs	Output elasticity
$Labor_{hec}$	0.274151733
$Agrochemicals_{hec}$	3.378649967
$Fertilizer_{hec}$	0.652794115
$Wateruse_{hec}$	0.154369789
$Manure$	-0.961085255
$Soilconservation$	0.443043276
$Landsize$	-1.535831718
$Seed_{hec}$	-1.180356717
Returns to scale	1.74377717
Significance level	5%

and x_j are variable means) are calculated using equation 2.17 (Chiona et al. , 2014) and the elasticity results are shown in Table 2.1.

$$e_{X_i} = \beta_i + 2\beta_{ii} Lnx_i + \sum_j \beta_{ij} Lnx_j \tag{2.17}$$

The qualitative dummy variables need to be adjusted before interpreting the coefficients. Since the output is in logarithmic form, the elasticities of the output are calculated by taking the antilogarithm of the coefficients and subtracting one. Then by multiplying with 100 we can have the percentage change of the output due to the change in the value of the dummy variable from 0 to 1. The adjusted elasticity of the output for these dummies (denoted by $\beta_i^{adjusted}$) is given by equation 2.18.

$$\beta_i^{adjusted} = 100 * (e^{\beta_i} - 1) \tag{2.18}$$

The output elasticities of various input variables was in between 0.15 to 3.37, while the returns to scale were 1.74. Doubling all inputs results in a more proportionate change in output, which is around 174 percent. The stochastic frontier production function exhibits increasing returns to scale. The implication is that there will be a lower average input requirements per unit of output as production level increases. The elasticity while holding inputs manure, land size and seed per hectare which were found to have negative elasticities constant, appears to be 4.9. Farm output or revenue has the highest responsiveness to agrochemicals per hectare, followed by land size. A 1% increase in the dominant factors of production, which is agrochemicals per hectare, will lead to about 3.38% increase in revenue, ceteris paribus at 5% level of significance. While agrochemicals are critical for enhancing agricultural production, their adverse effects on the environment and human health cannot be overlooked. To balance the benefits of agrochemicals, the farmers should use only recommended agrochemicals based on soil and crop needs. This implies the right type and amount of agrochemicals at the right crop and time, reducing overuse and environmental contamination as far as sustainability is concerned.

Unlike farmers' high concern on shortage of water in the area, it statistically proved that value of output is less responsive to changes in water use per hectare.[6] A 1% change in water use per hectare will only leads to 0.15% change in farm output value. Even though a significant proportion of households (about 56.5%) are applying manure, households with

[6] In absence of volumetric measure, water schedule from farmers' points of view measured by hours of water release in a week as proxy was used.

access to manure are producing 96.11% percent below the output value compared to their counterpart without access. This may be due to properties of the soil, resulting in the acidity of the soil influencing the efficiency of nutrient usage. The soil type is generally light clay nit soil in its nature (Abebe et al. , 2020). It is not possible to give a conclusive evidence based on the soil type of the area and the manure they apply. The effect of manure depends on various factors such as the composition of the manure itself such as, decomposition rate, the specific characteristics of the soil, and the intended crops. Understanding the nutrient needs and growing conditions of specific crops is also essential. Future area of research should investigate these determining characteristics. Whereas, by persuading households to conserve soil and water, output could increase by 44.30% (see Table 2.1). Other input variables such as land size and seed per hectare had a negative output elasticity coefficient, implying negative relationship with the level of output, while labor per hectare had the expected positive coefficient.

The technical inefficiency model result shows the determinants of technical efficiency in production in sampled households (see Table 5.14). The positive coefficients of access to credit and the two types of land ownership (i.e., own and rented land) indicate that these variables increase the level of technical inefficiency of farming households. Other statistically significant determinants including household size, frequency of consultation visits, male household head, and non-farm income have a positive impact on technical efficiency. Larger families have greater chance of being more efficient; indicating the benefit of greater labor availability during the peak farming period. Due to the traditional production system in the area, most activities require more labour and time including harvesting and threshing operations that are carried out using mainly human and animal power. Households with larger families are more technically efficient, indicating the benefit of increased labor supply during peak farming season, as confirmed by Tekalign (2019) and Andaregie and Astatkie (2020). The study also have shown the positive effect of extension services on farmers' technical efficiency. Access to advisory services offers farmers enormous productivity and efficiency gains through the mechanisms of providing access to technical knowledge and new skills and facilitating the introduction of new technologies. The advisory service is provided by Development Agents (DAs). These agents are typically trained agricultural professionals who act as a coordinators, communicators, educators, and translators; linking farm households to government, NGOs, credit institutions, and other related services (Belay and Abebaw , 2004). Marios (2006), Zewdie et.al (2021), Tekalign (2019), and Andaregie and Astatkie (2020) all agree that extension services contribute positively to efficiency improvement.

Off-farm income (also known as non-farm income) by easing financial restrictions on the timely purchase of inputs such as labor, capital,and fertilizers helped improve technical efficiency. The positive impact of off-farm income also confirmed by Tekalign (2019) and Andaregie and Astatkie (2020). In contrast to the availability of off-farm income as an alternative to credit, credit access had a negative effect on technical efficiency unlike a study by Marios (2006) and Tekalign (2019). The money received in the form of loans was not used for productive activities. Farmers were reluctant to return it. Political instability and unrest in Ethiopia during the time may contribute to this effect. Women head of households were technically less efficient than men. The share cropping agreement is very efficient in comparison to other types of land ownership agreements in the Koga scheme. The vast majority of farmers (81.8 percent) farmed exclusively on their own irrigated lands. Sharecropping takes a little share (3 percent). Farmers should use resources wisely and conduct business in accordance with the performance of share croppers. They should develop the share cropping mentality. They should learn and share experiences from share cropping arrangements in order to close the efficiency gap between themselves and their more efficient counterparts.

2.4.3 The level of economic sustainability

The study brings an idea that the difference between actual production and its frontier is a measure of each area's performance in terms of economic sustainability. The closer the technical efficiency for a farmer or a block is to one, the more economically sustainable it is. In essence, a region minimizes production losses and avoids wasting resources on production, thus promoting greater economic sustainability.

The average technical efficiency of households was 0.406, with a range of 0.210 to 0.844 at the individual household level. There is a disparity in technical efficiency across different blocks, with Bered having the highest score of 0.537 and Teleta having the lowest score of 0.334. The most efficient household found in Adibera, while the least efficient one in Enguti block. The production level being discussed is operating below its maximum possible output. In other words, if this production system were operating at full efficiency, it would be able to produce 100% of the potential output. However, it is currently only producing 40.6% of that potential output. This means there is still a significant amount of potential output that is not being realized, and there are potentials for output growth by improving the efficiency of the production process. The equivalent of 59.4% of potential output was lost due to farmer mismanagement rather than natural factors. The model captures the technical inefficiency from mismanagement, considering uncontrollable factors independently of the inefficiency component. There was a significant loss in output and prevalence of wasteful practices, which limited the availability of resources for future agricultural endeavors, thereby affecting the sustainability of economic activities. Conversely, those who wasted less were considered more economically sustainable, as efficiency is a means of capitalizing on resources. In the context of the research question, the data indicate an imbalanced level of economic sustainability as measured by technical efficiency. The average technical efficiency at scheme level is taken as the separation between the most sustainable and least sustainable blocks after sorting the data in descending order of efficiency. The first six areas in Table 2.2 i.e. Bered, Adebera, Enguti, Amarit, Kudmi and Tekeldib areas are more economically sustainable in the sense that they perform better than the average in terms of economic sustainability, while Lasi, Ambomesk, Andenet, Chihona, Tagelwedefit and Teleta areas are the less economically sustainable. Bered (i.e. closer to its production frontier) and the Teleta (farthest from its frontier) blocks were the most economically sustainable and unsustainable blocks, respectively.

In terms of how producers fared in terms of technical efficiency, the performance can differ depending on the sector they belong to. In agriculture, a score below 0.5 is typically considered low (Fuglie and Kostecki , 2001). In the industry sector, a score below 0.8 is considered low (Lovell and Schiff , 1994). For the service sector, a technical efficiency score below 0.7 is considered low (Berger and Humphrey , 1997). A general rule of thumb, however, is that a technical efficiency score below 0.6 is considered low, while a score above 0.8 is considered high in agriculture (Kumbahakar and Lovell , 2013). In a study by Dolawicz et al. (2012) a technical efficiency score of 0.6 or below is also regarded as low. According to these standards, Koga command areas have a low technical efficiency of 0.406, implying a low economic sustainability level. In the context of a technical efficiency score, lower values imply inefficient resource allocation and utilization, which can result in deteriorated economic sustainability. Farming practices in Koga scheme have demonstrated a low level of economic sustainability, with significant wasteful practices in terms of resource usage. This, in turn, jeopardizes sustainable farming. None of the blocks has achieved even a medium level of economic sustainability. Since economic sustainability analysis is at the block level and all blocks exhibited a low level, recommendations truly be uniformly applied to all blocks. At household level as well, with the majority of farmers scoring below 0.6 while very few farmers

Table 2.2: Level of economic sustainability indicated by technical efficiency indices

Block	Obs	Mean	Std. Dev.	Min	Max	Economic Sustainability Rank
Bered	25	.5370046	.138557	.3830217	.8023841	1
Adebera	46	.4832234	.133429	.2731431	.8448437	2
Enguti	22	.4564803	.1291142	.2107766	.7098315	3
Amarit	20	.4227877	.1075114	.2441547	.6254351	4
Kudmi	25	.4207961	.0631542	.3087295	.5657611	5
Tekel dib	46	.4062251	.0681146	.2763674	.6655779	6
Lasi	27	.3887784	.078006	.2618589	.5877768	7
Ambo mesk	40	.3840171	.0923274	.2466739	.6325205	8
Andenet	31	.3815641	.0819283	.2589183	.680037	9
Chihona	29	.3611123	.0740531	.2377005	.6303187	10
Tagel wedefit	35	.3354337	.0516425	.2533908	.4817964	11
Teleta	38	.3346901	.0424171	.2663759	.4612831	12
Overall TE	384	.4061844	.1069547	.2107766	.8448437	Low

have achieved a score of 0.8 or above, recommendation would benefit almost all.There was a significant loss in output and prevalence of wasteful practices, which limited the availability of resources for future agricultural endeavors, thereby affecting the sustainability of economic activities. Conversely, those who wasted less were considered more economically sustainable, as efficiency is a means of capitalizing on resources. In the context of the research question, the data indicate an imbalanced level of economic sustainability as measured by technical efficiency. The average technical efficiency at scheme level is taken as the separation between the most sustainable and least sustainable blocks after sorting the data in descending order of efficiency. The first six regions in Table 2.2 i.e. Bered, Adebera, Enguti, Amarit, Kudmi and Tekeldib regions are more sustainable in the sense that they perform better than general average in terms of economic sustainability, while Lasi, Ambomesk, Andenet, Chihona, Tagelwedefit and Teleta blocks are the less sustainable. Bered (i.e. closer to its production frontier) and the Teleta (farthest from its frontier) blocks were the most economically sustainable and unsustainable blocks, respectively.

In terms of how producers fared in terms of technical efficiency, the performance can differ depending on the sector they belong to. In agriculture, a score below 0.5 is typically considered low (Fuglie and Kostecki , 2001). In the industry sector, a score below 0.8 is considered low (Lovell and Schiff , 1994). For the service sector, a technical efficiency score below 0.7 is considered low (Berger and Humphrey , 1997). A general rule of thumb, however, is that a technical efficiency score below 0.6 is considered low, while a score above 0.8 is considered high in agriculture (Kumbahakar and Lovell , 2013). In a study by Dolawicz et al. (2012) a technical efficiency score of 0.6 or below is regarded as low. According to these standards, Koga command areas have a low technical efficiency of 0.406, implying a low economic sustainability level. In the context of a technical efficiency score, lower values imply inefficient resource allocation and utilization, which can result in deteriorated economic sustainability. Farming practices in Koga scheme have demonstrated a low level of economic sustainability, with significant wasteful practices in terms of resource usage. This, in turn, jeopardizes sustainable farming. None of the blocks has achieved even a medium level of economic sustainability. Since the economic sustainability analysis is at the block level and all blocks exhibited a low level, recommendations truly be uniformly applied to all blocks. At household level as well, with the majority of farmers scoring below 0.6 while very few farmers have achieved a score of 0.8 or above, recommendation would benefit almost all. In contrast to the quantitative outcomes of the maximum likelihood estimates, a significant number of households (45%) believed that they were technically efficient and their land was reaching its full potential (see Figure 2.1d). The differences between the findings from the model and perceptions results can provide valuable insights into the discrepancies between theoretical constructs and real-world perceptions. It highlights the limitations of understanding technical efficiency and the importance of considering model generated figures in understanding the state of efficiency. The two findings underscore the necessity of refining perceptions to better align with the model results. As a result, it is essential for farmers to receive appropriate information regarding their level of efficiency, as this perception may adversely affect efforts towards improving technical efficiency. Although the twelve areas are close together and face similar natural and market conditions, there are differences in economic sustainability. The differences can be attributed to different factors, which are household specific (shown in Table 5.14). The plot analysis (se Figure 5.4a- 5.4h) shows that the variation in economic sustainability is confirmed by the determinants in the inefficiency model. The trendline for the plot shows that all farm and household specific variables except household size (shown in Figure 5.4b) associated with this variation in the degree of economic sustainability.[7]

By prioritizing technical efficiency, resources can be utilized effectively and could lasts long benefiting both current and future generations as the population continues to grow. By focusing on cost savings, such as conserving natural resources for future generations, we can reduce our environmental impact, which is a significant concern in today's world. This enables to make sustainable balance between resource consumption and availability. Conversely, low economic sustainability in agriculture implies that agricultural systems are unable to maintain long-term financial stability and resilience. Inefficient resource use is a significant contributing factor. The consequences of low economic sustainability in the sector are diverse and can have substantial implications for farmers, economic, social, and environmental aspects. These include food insecurity, as low technical efficiency in agriculture can lead to decreased crop yields, which may result in food shortages and increased food prices. This can further intensify hunger and malnutrition issues (FAO , 2013). It will also crate economic instability from reduced income for farmers (World Bank , 2013). Consequently, farmers and their families may face difficulties in managing financial instability and the loss of livelihoods, which can lead to increased tensions within communities and potentially contribute to social unrest. Low economic sustainability can also exacerbate environmental degradation, as farmers may resort to unsustainable practices, such as excess use of fertilizers, and deforestation, in an attempt to maximize short-term profits (Peltoniemi et al., 2015).

2.4.4 Capacity utilization and inefficiency loss

This section analyzes inefficiency loss primarily using input oriented and output oriented measures.[8] The central theme of this section is how much output could be increased given the input level or inputs saved given the current output level. The perusal of Table 2.3

[7]Trend line based on a microsoft excel scatter plot with a smooth line including the trend line. The correlation between variables depends on whether the scatter plot slants down/up from left to right.

[8]A production plan is technically inefficient if a higher level of output is technically achievable for the given inputs (output-oriented measure), or that the observed output level can be produced using fewer inputs (input-oriented measure)

Table 2.3: Capacity utilization, and inefficiency loss indicators

Block Name	Actual output (METB)	Potential output (METB)	Inefficiency Loss(METB)	Growth potential [[(1/TE)-1]*100%]	Cost/input saving [[1-(TE/1)]*100%]
Bered	2.1734	4.047265144	1.873865144	86.21814413	46.29954
Adebera	2.3254	4.812266956	2.486866956	106.9436207	51.67766
Enguti	1.046075	2.291610394	1.245535394	119.0675041	54.35197
Amarit	1.26545	2.993109781	1.727659781	136.5253294	57.72123
Kudmi	0.7052	1.675871045	0.970671045	137.6447881	57.92039
Tekel dib	1.65294	4.069024785	2.416084785	146.1689344	59.37749
Lasi	0.810005	2.083461941	1.273456941	157.2159359	61.12216
Ambo mesk	1.88311	4.903713923	3.020603923	160.4050705	61.59829
Andenet	1.06684	2.795965344	1.729125344	162.0791631	61.84359
Chihona	0.731	2.024301028	1.293301028	176.9221652	63.88877
Tagel wedefit	0.967015	2.882879687	1.915864687	198.1215066	66.45663
Teleta	0.738	2.205024887	1.467024887	198.7838601	66.53099
Overall	15.364435	37.82625576	22.46182076	146.1936007	59.38156

analyzed capacity utilization and inefficiency loss as measured by four different but related concepts: (1) cost (inputs) savings , (2) production loss measured as a percentage of potential production, (3) production growth potential with efficiency improvement, and (4) loss in Millions of Ethiopian Birr (METB). These four indicators of inefficiency loss were used to conduct a deeper analysis of the extent to which households or agricultural areas are falling behind capacity to better understand the level of economic sustainability. The inefficiency loss attributed to management inefficiency, regardless of sample size, ranges from 0.970671045 to 3.020603923 METB, totaling METB 22.46182076. When the loss is divided by the sample size, the loss per household ranges from 38,605.9 to 86,383.0 ETB. On average, a household lost 58,494.3 ETB. Alternatively, it could have saved inputs between 46.29 and 66.53 percent, with an average of 59.4 percent. While the growth potential with efficiency improvement ranged from 86.21 to 198.78 percent, the average growth rate of with improved management, including appropriate resource allocation, was 146.19. During the study period, METB 15.364435 were produced, although the total potential was METB 37.82625576 from 384 sample households. Consequently, the agribusiness can increase agricultural production by 59.38% (i.e. 1-TE) of its potential or 146.19% of current production or avoid the loss of METB 22.46 by applying the technology and techniques of the best practice with full efficiency farms.

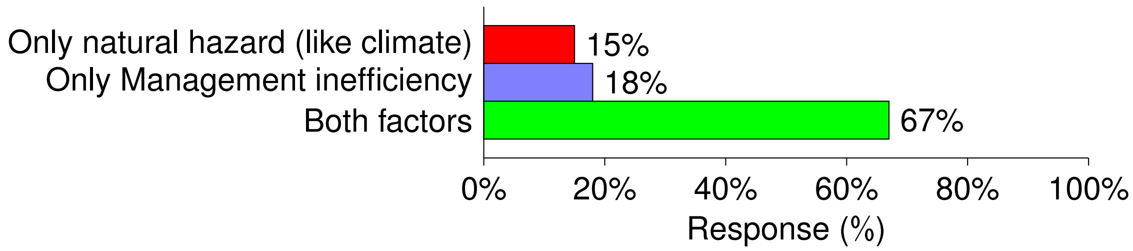
Alternatively, households can achieve current production levels by reducing inputs that could otherwise be reasonably saved for the farmer's working life or for transfer between generations to a successor. The importance of sustainable development is associated with current and future resource management with economic gains and protecting environment. Therefore, efficient use of resources are the major theme of sustainable development, taking into account that each generation's resources are affected by the consumption of previous generations. Increasing resource efficiency with the aim of significantly reducing costs that are unsustainable or are supported by unsustainable measures. Significant savings in resources could be achieved by reducing costs in areas that have proven to be unsustainable. For the input-oriented approach results, we need to first estimate the output-oriented approach then get estimates of an input-oriented inefficiency from the relationship between them. Using an input-oriented approach according to Kibret et al. (2016), farmers in the Koga scheme could reduce their inputs by an average of 59.38% if they could achieve optimal levels of economic sustainability or fully efficient counterparts [i.e. 1-(0.4061844 / 1.00)100] but still perform the same with the given technology.

Similarly, at the block level, the most economically sustainable block can increase production by about 46.29% of potential or 86.21% of actual production or avoid a loss of METB 1.87 and alternatively reduce its inputs by 46.29 % if it could achieve an optimal economic level of sustainability or fully efficient counterparts [i.e. 1-(0.5370046/1.00)100], with no change in level of output produced.

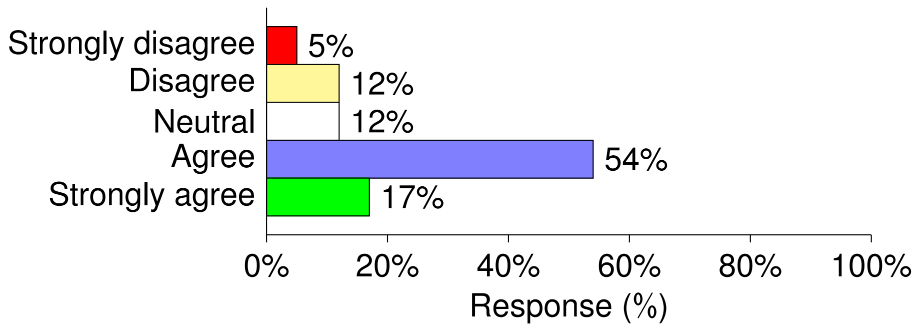
The second economically sustainable block can increase production by about 51.67% of potential or 106.94% of actual production or avoid a loss of METB 2.48 and alternatively reduce its inputs by 51.67% if it could achieve an optimal economic level of sustainability or fully efficient counterparts [i.e. 1-(0.4832234/1.00)100], with no change in level of output produced. On other hand, it takes a 10.01% cost /input saving [i.e. 1-(0.4832234/0.5370046)100] to achieve the level of the most economically sustainable block. For the economically third sustainable block (Enguti), production can increase by about 54.35% of potential or 119.06% of actual production or avoid a loss of METB 1.24 and alternatively reduce its inputs by 54.35% if it could achieve an optimal economic level of sustainability or fully efficient counterparts [i.e. 1-(0.4564803/1.00) 100], with no change in level of output produced. On other hand, it takes a 14.99 % cost /input saving [i.e., 1-(0.4564803/0.5370046)100] to achieve the level of the most economically sustainable block.

For the rest, production can increase in a range of 57.72% to 66.45% of the potentials or 136.52% to 198.12% of actual production or avoid losses from METB 0.97 to 3.020 and alternatively they could reduce their inputs from 57.72% to 66.45% if they could achieve an optimal level of economic sustainability, with no change in level of output produced. On other hand, it takes a 21.26% to 37.53% cost/input saving to achieve the level of economic sustainability of Bered.

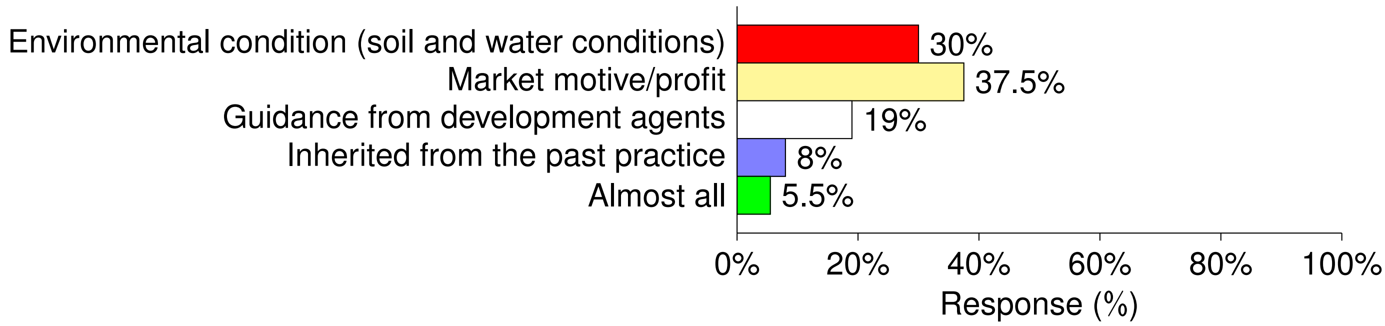
Similarly, in the least economically sustainable block, production can increase by about 66.53% of potentials, or 198.78% of actual production, or avoid a loss of METB 1.46, and alternatively reduce its inputs by 66.53%, if it could achieve an optimal level of economic sustainability or efficient counterparts [i.e. 1-(0.3346901/1.00)100], with no change in level of output produced. On other hand, it takes a 37.67% cost /input saving [i.e., 1-(0 .3346901/0.5370046)100] to achieve the level of the most economically sustainable block.
The Koga scheme had significant production growth potential from management efficiency but lost more income and wasted significant amount of resources, making it less sustainable. According to Asfaw et al. (2014), technical efficiency improvements could lead to a 36% input savings and 42% rise in agricultural production. The current study's results far exceeded the input savings and growth potential revealed in the above study. The inefficiency loss, particularly the input saving (ranges from 46.29954 to 66.5 percent, with an average of 59.38 percent) and growth potential outcomes with efficiency improvement (an average 146.2 percent), in this study indicates a highly wasteful practices in agriculture, signifying low economic sustainability. The wasteful practices may be attributed to cognitive thinking of farmers, such as production and efficiency related perceptions. Decision makers are constrained by attitudes and sustainable perceptions that prevent them from making completely rational decisions. These perceptions constitute environmental perceptions, socio-cultural perceptions, economic perceptions, and life satisfaction perceptions as an important components (AlWaer et al. , 2008). Existing research on the impact of farmer characteristics has primarily focused on broad aspects such as education and experience (Latruffe et al. , 2005), with no in-depth examination of farmers' perceptions. The level of technical efficiency was related to the anthropocentric environmental attitude. Efficient farmers had an anthropocentric environmental attitude, whereas inefficient farmers had an ecocentric attitude (Torres et al. , 2019). Few farmers associate the



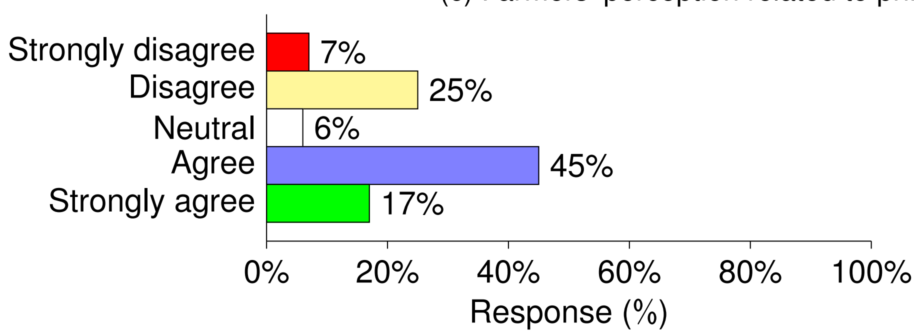
(a) Farmers' perception related to sources of output loss in farming



(b) Current production is more important than future high production



(c) Farmers' perception related to primary motive for selecting crop type



(d) A farmer is getting the maximum output from inputs and technology

Figure 2.1: Production and efficiency related perceptions

environmental conservation with economic benefits (Sulewski and Gołaś , 2019). One of the perception issues is whether farmers choose a higher production now or a higher production (living standard) in the future. The significance of current production (current standard of living) to future high production influences how farmers manage resources and participate in various conservation activities. The majority of farmers in the survey (71%) believe that current production (current high standard of living) is more important, and this belief may cause farmers to disregard the environment or resource availability for future generations if resources are not used efficiently (see Figure 2.1b). Low technical efficiency may be attributed to this perception behavior and farmers' perceptions related to their primary motive for selecting crop types (see Figure 2.1c). Additionally, the fact that farmers believe they are technically efficient also contribute to this issue (see Figure 2.1d).

2.4.5 Irrigation for Greater income in agriculture

Irrigation is essential for generating higher and more stable incomes. It is the main source of production intensification, and the availability of water affects the revenue from production in Koga scheme. According to the stochastic frontier model results, a 1 percent increase in water use affects the value of production or income by around 0.15 percent. A study by Limenh (2022), Kassie (2019) and Yeshiwas (2020)) also found similar findings of a positive impact of irrigation on income in Koga scheme. However, most farmers in the scheme were not happy with their current farming performance. This can be the result of problems related to shortage of seeds, fertilizers and water availability. One of the specific goal of the scheme is agricultural production. Income was one of the objectively verifiable indicators to the scheme's success outputs. It focused on raising households' income from 2,800 ETB to 5,400 ETB which would be a means of verification for its success (ADF , 2001). To obtain an accurate estimate of each household's income, data on output in physical units and revenue from sales were collected. These figures were triangulated to provide a more accurate estimate of their income for comparison of pre-project and post-project income (see major/dominant crops taken into account in Table 5.5). The seven crops that account for approximately 90 percent of the farming activity include three cereal crops - barley, maize, and wheat - and four vegetables - cabbage, pepper, potato, and tomato (Yang et al. , 2020).

The average overall annual income (based on sample with Koga scheme) was ETB 40,011.54948 per annum (See Table 2.4). This figure can be triangulated with a study by Tegen and Enkuahone (2022) that found a total net income within 36,250.00 to 437,995 ETB. The effect of irrigation technology on annual income can be understood in three different ways. The first effect is an increased return under the rainfed irrigation system, while the second effect is an additional return from irrigated agriculture that was estimated to be more than three times the return under the rainfed farming system (before the Koga project).[9] With the project, the return under rainfed irrigation system was estimated to rise to over 100 percent increment in annual income and to rise the overall annual income by 340 percent (See Table 2.4). Thirdly, irrigation makes it possible to grow cash crops which have high return that can be possible through irrigation.

When we compare the pre-project and post-project annual income in the sample households, the overall yearly income following the usage of irrigation changed by 1,418 percent when compared to the level of income under rain fed before the project (provided that the return under rainfed farming system before the project according to Table 2.4). Just over 15 times pre-project earnings. The 1,418 percent observed change in annual income in

[9]The project is interchangeably used to refer the Koga scheme

Table 2.4: Average annual income of sample households in Koga scheme

Return	Output (birr)
Return under rainfed farming system [before the project] (See : ADF (2001))	ETB 2,635 per annum
Return under rainfed farming system [with project estimated] (See : ADF (2001))	ETB 5,489 per annum
Additional return under irrigated agriculture (See : ADF (2001))	ETB 8,267 per annum
The average overall annual income [estimated income after the project]	ETB 11,596 per annum
The average overall annual income [based on sample after the project]	ETB 40,011.54948 per annum

the sample households is a huge figure as far as the 340 percent anticipated change is concerned. The source of this variation is a combination of higher irrigated production in all seasons, including changes in rainfield production with irrigation technology.

Therefore, the success of the project depends meeting anticipated expectations for post-project rainfed return, additional return from irrigation and total overall annual income in the sample households. The anticipated average yearly income was attained by nearly (more than 96 %) all households. Moreover, by around 245 percent, they made more money than was anticipated. Only 3.4 % of sample households had yearly incomes that were lower than the predicted post-project average annual household income.

The primary goal of the irrigation dam is to supply enough water during the dry and short rainy seasons. The additional return under irrigated agriculture in the sample households was ETB 34,522, given the return under the rainfed farming system [with project estimates]. Based on the sample, the additional return under irrigated agriculture was around 317 percent higher than the projected additional return. The scheme also help to increase the productivity during rainy season. Given the estimated additional return from irrigated agriculture in Table 2.4, the return from rainfed farming with project in sample households was ETB 31,744. Which is a 478 percent increase over the estimated return under the rainfed farming system with the project [projected].

The income measures of economic sustainability suggested in some papers, however, have some flaws. When we are comparing pre- and post-project income achievements with wasteful practices from technical efficiency statistics, the source of the increased income could be the utilization of more inputs and unsustainable practices, rather than the efficient use of resources. This income comparison result may be misleading when determining the feasibility of farming, as long-term viability ultimately depends on efficient resource utilization.

2.4.6 Spatio-temporal economic sustainability convergence

The debates between the use of more inputs and improving technical efficiency are a crucial topic in the field of economics and agricultural production. Both approaches have their own merits, but the most effective strategy depends on the behavior of production function. The research questions evolved during the research process due to what happened in the initial finding about the level of economic sustainability, and the characteristics of the production function in the stochastic frontier model. Finally, it is ended up adding convergence into the research questions. In this study, the economic sustainability convergence study was triggered by low levels of economic sustainability in the area, significant differences between sustainable and unsustainable households or blocks, and significant inefficiency loss measured by wasted resources, growth potential with efficiency improvement compared to returns to scale, and negative elasticity of output in some inputs, such as seed per hectare and land size.

The value of returns to scale (RTS) is 1.74, which means that if farmers double all inputs, the output value will increase by 174%. When we compare the returns from scale up of all resources with growth potentials from efficiency improvements in Table 2.3 5^{th} column, the growth potential results of about 198.78% in the Teleta block is higher than output to be gained when inputs double. This is an argument that corroborates technical efficiency improvements are more advantageous than the use of more inputs. Under these circumstances, it doesn't pay more to invest in new technology and use more inputs in agriculture.

The stochastic frontier model results also help to determine whether or not increasing some inputs is beneficial. Some inputs, such as land and seed per hectare, have unintended negative impacts when increased. The elasticity of output to land size is negative. There are several reasons for this negative relationship between land size and output elasticity. The law of decreasing returns states that as more land is added, the returns to labor and capital inputs on that land decrease, leading to a decline in the marginal product of these inputs. This diminishing returns effect results in a negative relationship between land size and output elasticity. The seed rate per hectare also had negative elasticity due to may be overcrowding of plants. There is an optimal seeding rate for each crop, beyond which adding more seed results a diminished amount of resources such as water, nutrients, and sunlight for plants (Porter et al. , 2005). According to Deininger and Binswanger (1999), the potential for productivity gains through technical efficiency improvements is much greater than through input expansion alone. As a result, all of the aforementioned factors prompted the need for planning for efficiency improvement in the agricultural sector, as well as a convergence study as a research idea.

2.4.6.1. Temporal convergence to optimum level of economic sustainability [Scenario 1]

The study employs convergence as an elimination of inefficiency gap in production and a movement toward a specific level; the concept of optimum level economic sustainability is derived from the concept of optimum efficiency, contextualizing efficiency convergence, which is defined as approaching optimum level of efficiency. This section is also related to the convergence of efficiency, which is predominantly followed by the classical literature of Battese and Coelli (1995), that defined the general convergence as a condition of movement toward a point resulting in the elimination of distance from the production frontier. In other words, the efficiency level increases over time and eventually converges to the optimum efficiency level, indicating optimum economic sustainability in this study.

Each block's level of economic sustainability as measured by the technical efficiency is much lower than the optimum level. The dynamics of the temporal economic sustainability convergence of each block show the expected growth rate in technical efficiency and speed of convergence to this optimum level. The graphical illustration represented by the intersection between the exponential growth of each block's technical efficiency curve and the optimum economic sustainability line determines the speed of convergence and the expected growth rate of efficiency improvement. As stated in Table 2.5, data on the initial level of economic sustainability, measured by the relative actual output to potential output, the speed of convergence, and results showing the expected annual growth rates in efficiency with their adjusted growth indices required to achieve convergence to the optimum level of economic sustainability for each block is provided.

Table 2.5: Expected annual technical efficiency growth indices and temporal convergence

Block Name	Actual Output (METB)	Potential Output (METB)	Relative Actual output (TE)	Relative Target level (TE=1)	Annual growth Indices	Adjusted growth indices
Bered	2.1734	4.047265144	0.5370046	1.00	0.064148407	0.064148407
Adebera	2.3254	4.812266956	0.4832234	1.00	0.07543757	0.067882471
Enguti	1.046075	2.291610394	0.4564803	1.00	0.081577878	0.069345205
Amarit	1.26545	2.993109781	0.4227877	1.00	0.089902793	0.070781135
Kudmi	0.7052	1.675871045	0.4207961	1.00	0.090417542	0.070851067
Tekel dib	1.65294	4.069024785	0.4062251	1.00	0.094267056	0.071309714
Lasi	0.810005	2.083461941	0.3887784	1.00	0.09908122	0.071732418
Ambo mesk	1.88311	4.903713923	0.3840171	1.00	0.10043639	0.071823018
Andenet	1.06684	2.795965344	0.3815641	1.00	0.101141801	0.071865456
Chihona	0.731	2.024301028	0.3611123	1.00	0.107224716	0.07210397
Tagel wedefit	0.967015	2.882879687	0.3354337	1.00	0.11542232	0.072097215
Teleta	0.738	2.205024887	0.3346901	1.00	0.115669893	0.072091688
Overall	15.364435	37.82625576	0.4061844	1.00	0.09427802	0.071310862
Assuming	the speed of	convergence	n = 10 Years			

According to Table 2.5 & Figure 2.2, households, on average, need to grow at 9.42 percent for the next 10 years of the planning period in the agricultural sector to reach the optimum level. The data revealed that the farther distances are from the optimal level, the higher the growth indices are expected to be, and vice versa. The most unsustainable block, Teleta, is expected to grow annually at 11.56 percent (which is 1.81 times faster than the most economically sustainable block, Bered, for the next 10 years of the planning period to achieve an optimum level of economic sustainability. Whereas, the most sustainable block need to grow relatively a lesser rate of 6.41 percent.

The direct comparison of the expected growth rates of different blocks is misleading and inaccurate since the initial technical efficiencies differ significantly from block to block. Thus, the more accurate can be obtained after the proportional offset hypothesis, or the proportional overlap hypothesis is taken into consideration. [10] Thus, the study indicates that after taking adjustments based on proportional offset hypothesis, in terms of economic sustainability, other less sustainable blocks exceed growth to Bered within the range of 1.06 times to 1.124 times: for example, Adebera by 1.06 times and Tagelwedefit by 1.124 times to achieve temporal convergence. These can be compared with the before adjustment counterparts with a range of 1.18 to 1.8 times that Adebera exceeds by 1.18 times and Teleta by 1.8 times.

[10]The proportional offset hypothesis, or the proportional overlap hypothesis: "*If the level of economic development of one country is times higher than the level of economic development of another country, achieving the same economic growth in the former will be times more difficult than in the latter*"

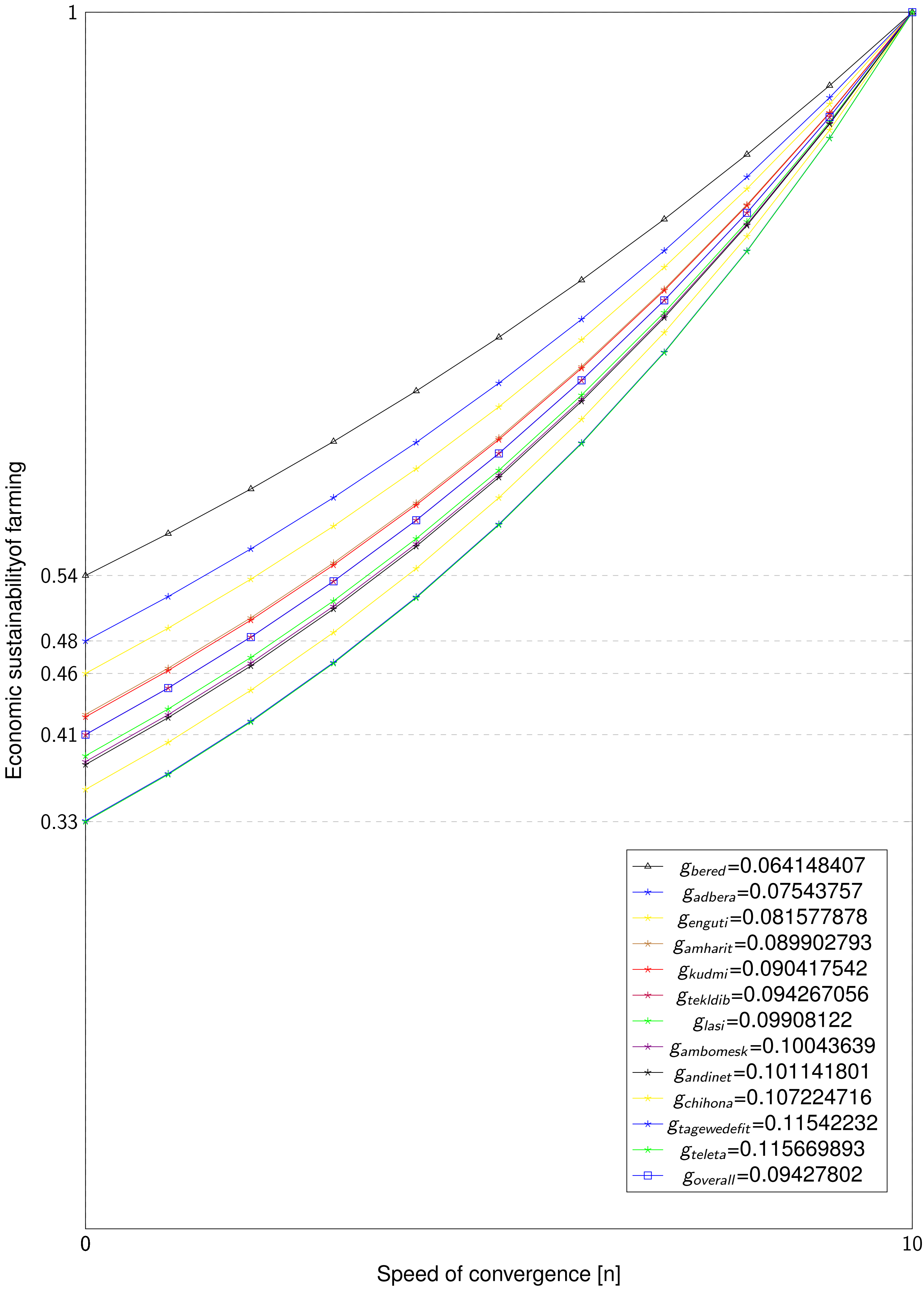


Figure 2.2: Expected growth rates for temporal economic sustainability convergence

Table 2.6: Speed of temporal convergence to optimum level of economic sustainability

Block Name	Relative Actual output (TE)	Relative Target level (TE=1)	Speed of Convergence [n]
Bered	0.5370046	1.00	10.6703324
Adebera	0.4832234	1.00	12.48137694
Enguti	0.4564803	1.00	13.4584594
Amarit	0.4227877	1.00	14.77434785
Kudmi	0.4207961	1.00	14.85538194
Tekel dib	0.4062251	1.00	15.46018054
Lasi	0.3887784	1.00	16.21354842
Ambo mesk	0.3840171	1.00	16.42502369
Andenet	0.3815641	1.00	16.53500044
Chihona	0.3611123	1.00	17.48044234
Tagel wedefit	0.3354337	1.00	18.74637766
Teleta	0.3346901	1.00	18.78446474
Overall	0.4061844	1.00	15.46190008
Assuming	g_c=6%, g_T=0%		
Growth differential	[ln ($1+g_c$)-ln $(1+g_T)$]	= 0.058268908	

The dynamics of the economic sustainability convergence of each block and the optimum level of economic sustainability concerning the same six percent efficiency growth rates is shown in Table 2.6 and Figure 2.3.[11] The abscissa in Figure 2.3 contains the period, usually in years, necessary to achieve optimum economic sustainability, and the vertical axis indicates the evolution of economic sustainability where inputs are being used to their utmost capacity therein in each block and overall at project level at the same six percent efficiency growth rate or approximately at 5.82 percent growth differentials with growth at optimum efficiency. Accordingly, if all blocks are growing at 6 percent, overall the farming system at the household level would need 15.46 years to become optimally economically sustainable. Whereas, the most economically sustainable block would need only 10.67 years and the most unsustainable would need about 18.78 years. When we analyze the technical inefficiency model results here in terms of economic sustainability convergence to wards the frontier, those determining variable that are found to have positive effect on technical efficiency facilitate this temporal convergence. These household-specific variables, including household size, frequency of consultation visits, male household head, and non-farm income, could make such kind of convergence the quickest and help to achieve high growth rates in efficiency. However, great care should be taken when considering household size recommendations in to practice, as they should not contradict other social measures such as family planning.

[11] However, under the proportional overlap hypothesis, Adebera's, Enguti's, Amarit's, Kudmi's, Tekledib's, Lasi's, Ambomesk's, Andenet's, Chihona's, Tagel's, Teleta's & Overall 6 % growth corresponds to (5.4),(5.1),(4.72),(4.7),(4.54),(4.34),(4.3),(4.26),(4.0),(3.75),(3.74) & (4.53) % growth in Bered respectively ; i.e. in real terms Bered is growing faster than other areas

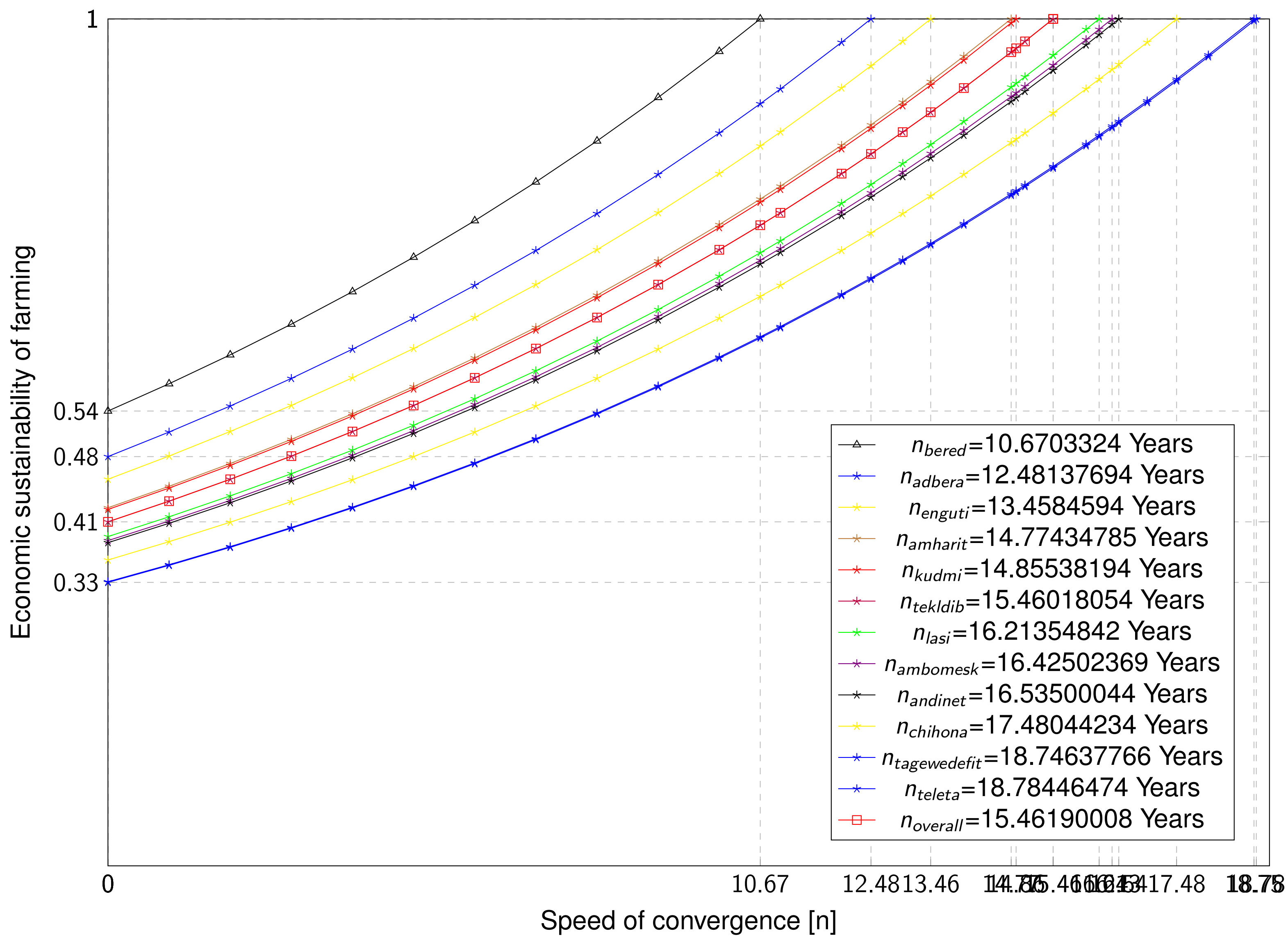


Figure 2.3: Speed of temporal economic sustainability convergence

2.4.6.2. Spatial economic sustainability convergence [Scenario 2]

The spatial economic sustainability convergence suggests, through experience sharing, a relatively low technically efficient blocks have the opportunity to adopt the techniques of the most technically efficient block and hence become equally economically sustainable in terms of technical efficiency measure. As Wibisono (2005) indicated, technological transfer as the primary driver of regional income convergence and contends that government policies have a significant role on this process. The argument advanced in this debate is that, while management inefficiency varies greatly across different segments of the same state or area, farmers can reap the benefits of management efficiency from high-economically sustainable areas.

The technical efficiency, moreover, have a standard deviation (Std. Dev.) of 0.1069547, reflecting unbalanced economic sustainability among farmers in the project. Table 2.7, Figure 2.4, Table 2.9 and Figure 2.5 provide the growth rate in technical efficiency of least efficient blocks, growth differentials, and a fiver year plan to become equal in economic sustainability levels by technical efficiency measures. Therefore, if the low levels of the economically sustainable block at the beginning of the period grow more rapidly in technical efficiency than those with high levels of sustainability, then convergence occurs, implying that the less economically sustainable blocks are catching up. The production loss that separates it from the best practice benchmark block (that is, Bered) explains the relative performance of each block in economic sustainability.

The growth differentials and the speed of convergence were calculated in order to perform an economic sustainability convergence analysis between accession blocks and best-performing blocks in terms of efficiency measure. Table 2.7 includes the relative economic sustainability of each block to the most economically sustainable, the target level of the relative sustainability, the five year speed of convergence, and the results showing the expected annual growth differential efficiency, which is the difference in the efficiency growth rates between two blocks to achieve spatial economic sustainability convergence. Overall, areas need a 5.58 percent growth differentials, that is, they have to register a 5.58 percent higher efficiency growth rate of MESB to catch up for the next five years. While the second most economically sustainable block, Adebera, need only a 2.11 percent higher efficiency growth rate and the most unsustainable block needs a 9.45 percent higher efficiency growth rate for spatial convergence in the next five years. Highly economically sustainable areas require a lesser growth rate in technical efficiency to catch up the most sustainable ones.

Table 2.7: Growth differentials and spatial convergence to MESB

Block Name	Technical efficiency Relative to MESB level	Target relative Technical efficiency level	Growth Differentials [ln$(1+g_c)$-ln$(1+g_T)$]
Bered	1	1	-
Adebera	0.899849647	1	0.021105518
Enguti	0.850049143	1	0.032492223
Amarit	0.787307409	1	0.0478273
Kudmi	0.783598688	1	0.048771653
Tekel dib	0.756464842	1	0.055819844
Lasi	0.723975921	1	0.064599429
Ambo mesk	0.715109517	1	0.067063916
Andenet	0.710541586	1	0.068345561
Chihona	0.672456623	1	0.079363534
Tagel wedefit	0.624638411	1	0.094116468
Teleta	0.623253693	1	0.094560326
Overall	0.756389051	1	0.055839883
Assuming	the speed of	convergence	n = 5 Years

According to Figure 2.4, a six percent efficiency growth rate of the most economically sustainable block and about 8.26 percent of the second most economically sustainable, the convergence point between these blocks, that is, curve intersection between the exponential growth of technical efficiency curve for two blocks after five years will be achieved at technical efficiency of about 0.72, and for the most unsustainable block, the same point of convergence will be achieved at a rate of 16.51 percent. Overall at the project level, it needs 12.08 percent growth rate to catch up with the level of economic sustainability of Bered at 0.72 states of efficiency. However, taking the catch-up effect into account to compare efficiency growth rate across blocks, that is, the relative efficiency growth against Bered, the second most economically sustainable block's 8.26 percent growth corresponds to 7.43 percent growth in Bered (8.26: 1.111= 7.43). The most unsustainable block's 16.51 percent corresponds to 10.29 percent growth in Bered (see Table 2.8).

The numbers given in Table 2.8 are based on region-standard, which in this example is Bered. For a "region-standard"; selecting a block with highest economic sustainability level in Koga scheme, and following this standard, the rates of efficiency growth in others would be adjusted similarly. The value that indicates how many times the efficiency growth of less sustainable blocks really exceed that of the most economically sustainable block, Bered, for spatial economic sustainability convergence is provided also in Table 2.8. Accordingly, it ranges from 1.2 times to 1.7 times growth rates, averaging a 1.5 times growth rate. The values are much lower than the pre-adjusted growth rate comparisons. For instance, the pre-adjustment growth rate is 0.082609603/0.06=1.37 times while pos-adjustment value is 1.2 times for Adebera block.

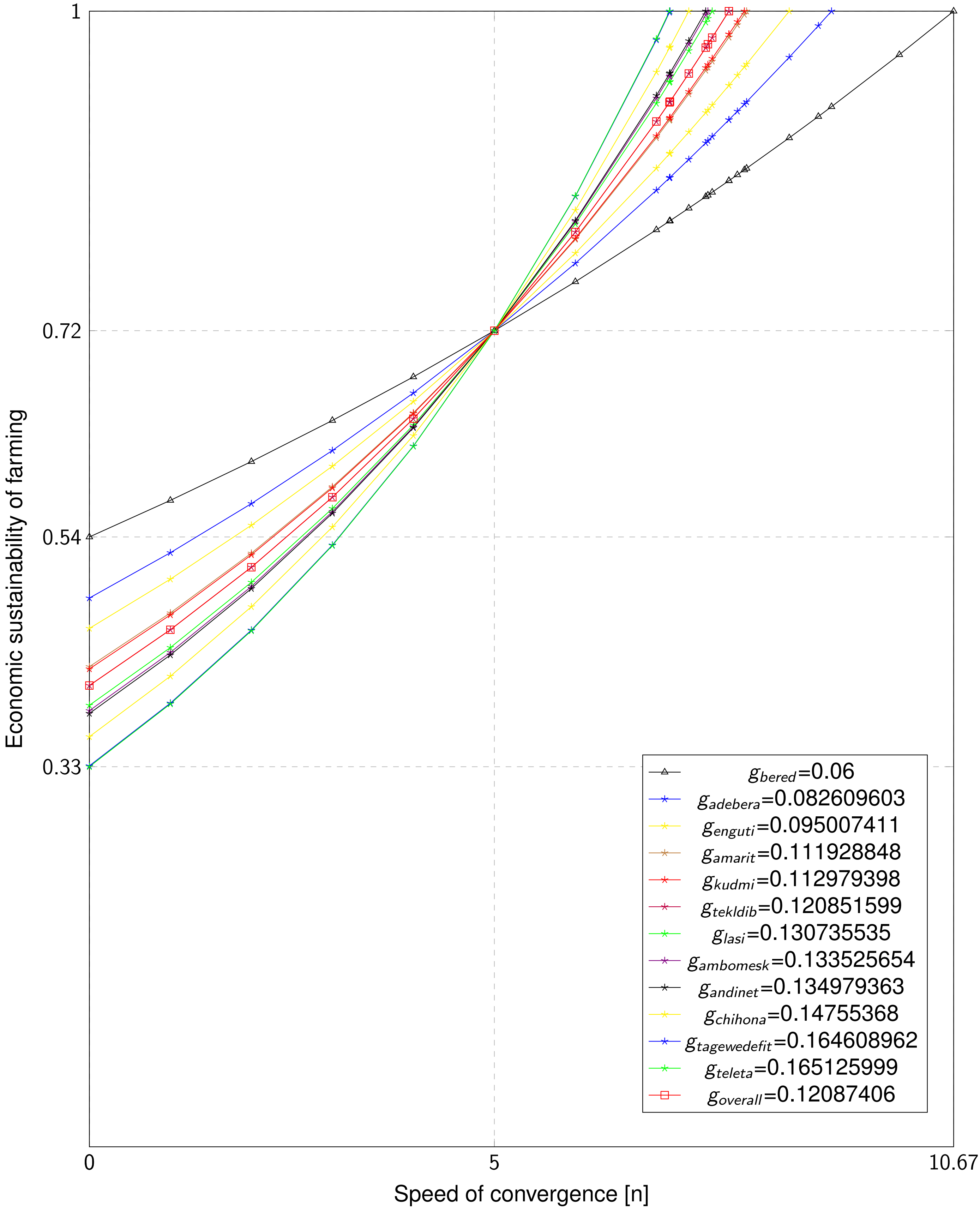


Figure 2.4: Spatial economic sustainability convergence

Table 2.8: Real efficiency growth rates adjusted for the catch-up effect

Block Name	Expected efficiency growth rate for next 5 years	Ratio of expected growth in a given block to that of Bered	Level of economic sustainability indices i.e. TE	Proportion of catch up effect(α_{ij}) i.e. ratio of sustainability of Bered to that of a given block)	Hypothetical efficiency growth rate i.e. after adjustments ($r_{ij}*$)	Ratio of a given block's hypothetical growth to Bered (β_{ij})
Bered	0.06	1	0.5370046	1	0.06	1
Adebera	0.082609603	1.376826717	0.4832234	1.111296763	0.074336222	1.238937036
Enguti	0.095007411	1.58345685	0.4564803	1.176402574	0.080760968	1.346016138
Amarit	0.111928848	1.8654808	0.4227877	1.270151899	0.088122411	1.468706854
Kudmi	0.112979398	1.882989967	0.4207961	1.276163444	0.088530508	1.475508467
Tekeldib	0.120851599	2.014193317	0.4062251	1.321938502	0.091419986	1.523666429
Lasi	0.130735535	2.178925583	0.3887784	1.381261408	0.094649379	1.577489657
Ambomesk	0.133525654	2.225427567	0.3840171	1.398387207	0.095485466	1.591424432
Andenet	0.134979363	2.24965605	0.3815641	1.407377162	0.095908451	1.598474177
Chihona	0.14755368	2.459228	0.3611123	1.487084766	0.099223449	1.653724157
Tagel wedefit	0.164608962	2.7434827	0.3354337	1.600926204	0.10282108	1.713684674
Teleta	0.165125999	2.752099983	0.3346901	1.604483073	0.102915389	1.715256478
Overall	0.12087406	2.014567667	0.4061844	1.322070961	0.091427816	1.523796926

Table 2.9: Speed of spatial convergence to MESB

Block Name	Technical efficiency Relative to MESB level	Target relative Technical efficiency level	Speed of Convergence [n]
Bered	1	1	-
Adebera	0.899849647	1	2.163707401
Enguti	0.850049143	1	3.33105613
Amarit	0.787307409	1	4.903186191
Kudmi	0.783598688	1	4.999999978
Tekel dib	0.756464842	1	5.72257039
Lasi	0.723975921	1	6.622640834
Ambo mesk	0.715109517	1	6.875296459
Andenet	0.710541586	1	7.006688872
Chihona	0.672456623	1	8.136235712
Tagel wedefit	0.624638411	1	9.648685329
Teleta	0.623253693	1	9.694189063
Overall	0.756389051	1	5.724624775
Assuming Growth differential	g_c =11.2979398 % , 0.048771654	g_T=6%	

To ascertain the rate at which the catch-up effect occurs between blocks, the study analyzed the minimum and reasonable maximum growth rates in technical efficiency based on a literature analysis of the current situation and the development of informed assumptions. The dynamics of the spatial economic sustainability convergence with the same maximum reasonable growth of 11.29 percent average efficiency in less sustainable blocks as against a minimum 6 percent growth rate of Bered is shown in Table 2.9 and Figure 2.5.[12] Accordingly, the second most economically sustainable block, the most economically unsustainable block and overall at project level needs about 2.16, 9.69 and 5.72 years to catch up the level of economic sustainability of the benchmark block respectively. Generally, given about 4.87 percent growth differentials between "accession blocks" and the most sustainable block, it needs about 2.16, 9.69 and 5.72 years to catch up for Adebera, Teleta, and Overall respectively. The most economically sustainable block catches up to the quickest, while the slowest for the least sustainable areas, such as for Teleta block.

The curve of intersection between exponential efficiency growth rate curve of two blocks will be achieved at technical efficiency of about 0.61, 0.94 and 0.75 for Adebera, Teleta, and the overall project level is about 2.16, 9.69, and 5.72 years respectively. The interpretation is that most economically sustainable areas catch up in the early stages of economic sustainability. The government's support in technology transfer and experience-sharing mechanisms is critical for this type of economic sustainability convergence to happen more quickly.

[12]Under the proportional overlap hypothesis, Adebera's, Enguti's, Amarit's, Kudmi's, Tekledib's, Lasi's, Ambomesk's, Andenet's, Chihona's, Tagel's, Teleta's & Overall 11.29 % growth corresponds to (10.17),(9.6),(8.9),(8.85),(8.54),(8.18),(8.08),(8.03),(7.6),(7.06),(7.04) & (8.55) % growth in Bered respectively

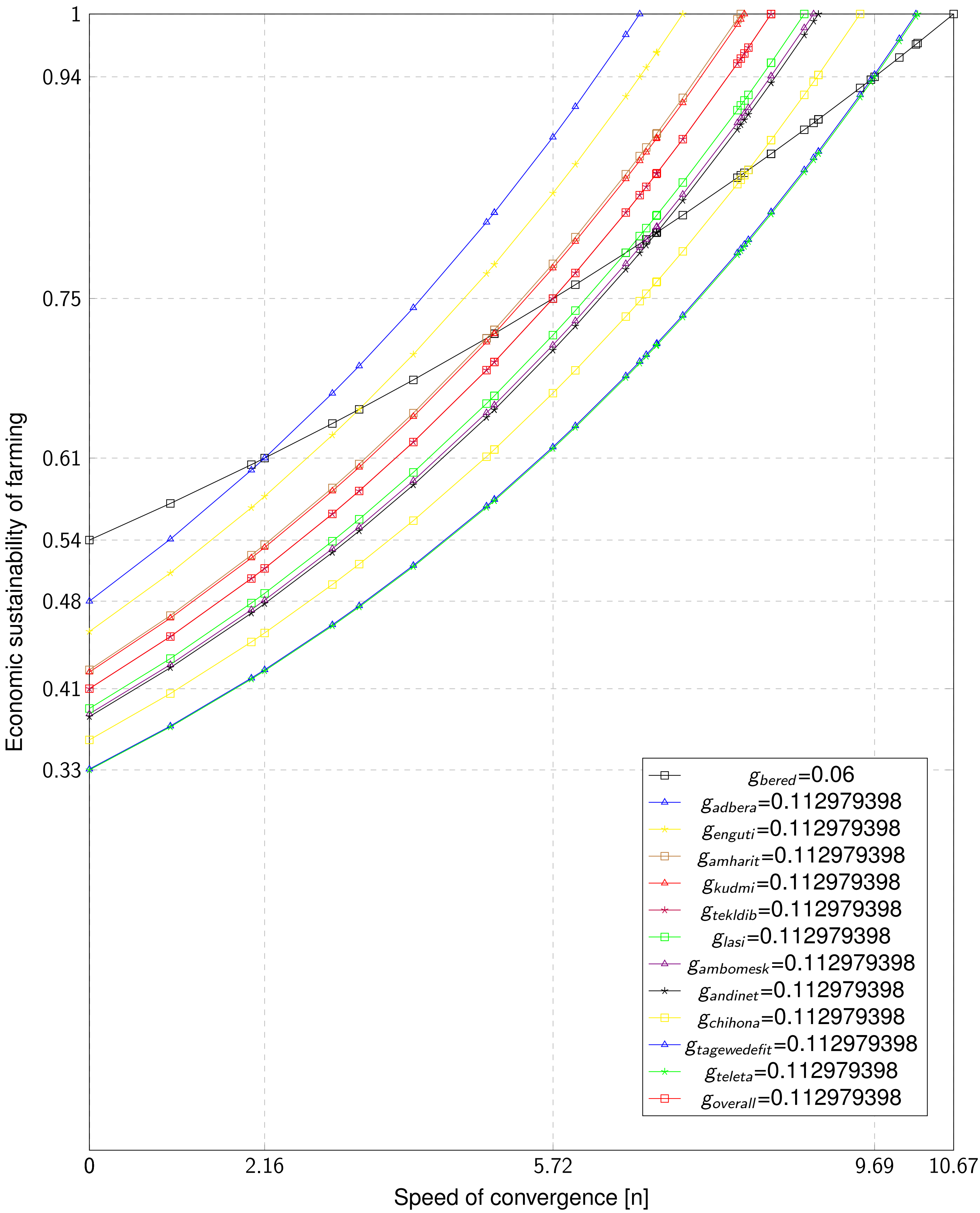


Figure 2.5: Speed for spatial economic sustainability convergence

2.4.6.3. Cross-over or leapfrogging phenomenon in economic sustainability [Scenario 3]

Initially, economically less sustainable blocks may not only eliminate their differences with more sustainable one, indicating spatial convergence, but they may also be at higher level. This phenomenon could again cause differences in the level of economic sustainability in the command area. Table 2.10 and Figure 2.6 show the cutoff points of technical efficiency state (can be considered as state of economic sustainability in this study) and growth differentials given five years of the speed of convergence and a 6 percent efficiency growth of the most economically sustainable block.[13] It will take only slightly greater than 2.11 percent higher efficiency growth rate of Bered for Adebera to surge ahead in terms of economic sustainability, similarly, the cutoff point technical efficiency is about 0.72 beyond which the Adbera will become more economically sustainable than Bered. However, for the most economically unsustainable block, it requires more than 9.45 percent higher efficiency growth rate of Bered to surge ahead to become the most economically sustainable after five years. At the project level, overall it needs more than 5.58 percent higher efficiency growth rate to surge ahead of the most economically sustainable block.

As far as leapfrogging time is concerned in Table 2.11 and Figure 2.7, with growth differentials of about 0.0487 (provided that all blocks are growing at a rate of about 4.87 percent higher than the most sustainable block) and two growth rates given in Table 2.11, overall at project level it will take more than 5.72 years to surge ahead (i.e beyond 0.75 level of efficiency). At the project level, it will take more than 5.72 years to surge ahead (that is beyond 0.75 level of efficiency). The second most economically sustainable block surge ahead of Bered after 2.16 years with 0.61 states of efficiency beyond which Adebera will become the most sustainable block in the project area. For the most economically unsustainable block, it will take more than 9.69 years, that is, beyond 0.95 states of efficiency to surge ahead of Bered in the level of economic sustainability.

In Figure 2.7, for "accession blocks" growing at a rate of about 11.29 percent and the most economically sustainable block growing at a rate of 6 percent, the abscissa points of 2.16, 5.72 and 9.69 and the ordinates 0.61, 0.75 and 0.94 are showing cutoff leapfrogging times and states of economic sustainability beyond which Adebera, overall at project level, and Teleta respectively surge ahead.

Generally, the implications of the major findings of the convergence analysis are divided into short- and long-term objectives, taking into consideration of the minimum and maximum reasonable growth rates and plans. The short-term goal (5-year plan) aims to attain same level of economic sustainability through technical efficiency measures, which refers to the catch-up effect. A growth rate that allows farmers to become fully efficient within a 10-year timeframe is considered the long-term plan. Meanwhile, the long-term plan (10 years) focuses on achieving fully technically efficient farms in each block, thereby promoting temporal convergence. Ethiopia can incorporate these targets in its five-year and ten-year development plans. The assumed growth rate, including the maximum and minimum targets, were compared with other findings and evidences to validate the scenario development as a reasonable target or not. The comparison helped to ensure that the scenario development was based on realistic assumptions and supported by empirical data. This process is important for creating a robust and credible plan for future growth and development.

[13] NB: There was a little deviation of growth differentials as a result of exponential function and its log-transformations

Table 2.10: Growth differentials for leapfrogging phenomenon in economic sustainability

Block Name	Growth Differentials $[\ln(1+g_c)-\ln(1+g_T)]$	State of Technical efficiency [TE]
Bered		
Adebera	0.021105518	0.718633291
Enguti	0.032492223	0.718633291
Amarit	0.0478273	0.718633291
Kudmi	0.048771653	0.718633291
Tekel dib	0.055819844	0.718633291
Lasi	0.064599429	0.718633291
Ambo mesk	0.067063916	0.718633291
Andenet	0.068345561	0.718633291
Chihona	0.079363534	0.718633291
Tagel wedefit	0.094116468	0.718633291
Teleta	0.094560326	0.718633291
Overall	0.055839883	0.718633291
Assuming	g_{bered} =6%	Speed of convergence = 5 years

Some studies have shown that the source of growth in Ethiopian agriculture comes from efficiency improvements rather than the use of more inputs. Technical efficiency improvements have been the primary driver of productivity growth, rather than increased input use (Bekele and Holden , 2011), while improvements in technical efficiency, which has been a major contributor to agriculture (Asfaw and Holden , 2015). The majority of the increase in productivity can be attributed to improved technical efficiency. When the source of the change is broken down, an increase in technical efficiency is the main contributor. The challenges of modern agriculture in Ethiopia and input access challenges show agricultural growth comes from efficiency improvement. The Ethiopian government stated that the planned agricultural growth rate for 2021 was 5.9 percent, with a potential of 8 percent.

According to Ethiopian Agricultural Transformation Agency ATA (2000), the growth rate of technical efficiency in Ethiopian agriculture during the year in question was approximately 2.5 percent. The World Bank (2005) projected the technical efficiency growth rate in Ethiopian agriculture to be around 3.5 percent for the year 2005. Technical efficiency growth rate in Ethiopian agriculture for the year 2010 was roughly 4 percent (IFPRI , 2010). The Ethiopian Central Statistical Agency CSA (2015) indicated that the technical efficiency growth rate in Ethiopian agriculture for the year 2015 was about 5 percent. The African Development Bank AfDB (2020) estimated the technical efficiency growth rate in Ethiopian agriculture for the year 2020 to be around 6 percent. It is crucial to mention that growth rates have been increasing. Technical efficiency growth rates in Ethiopian agriculture have surpassed 6 percent in some areas (Tegegne , 2002).

In 2013, the efficiency trend for Ethiopian farm households reached 61 percent, marking a 7 percent increase from 54 percent in 2011 (Wondemu , 2016). Birhanu et al. (2021) reported a 10 percent assumed change in technical efficiency. According to Wassie et al. (2015), the average annual change in technical efficiency was within 1.2 percent and 10.2

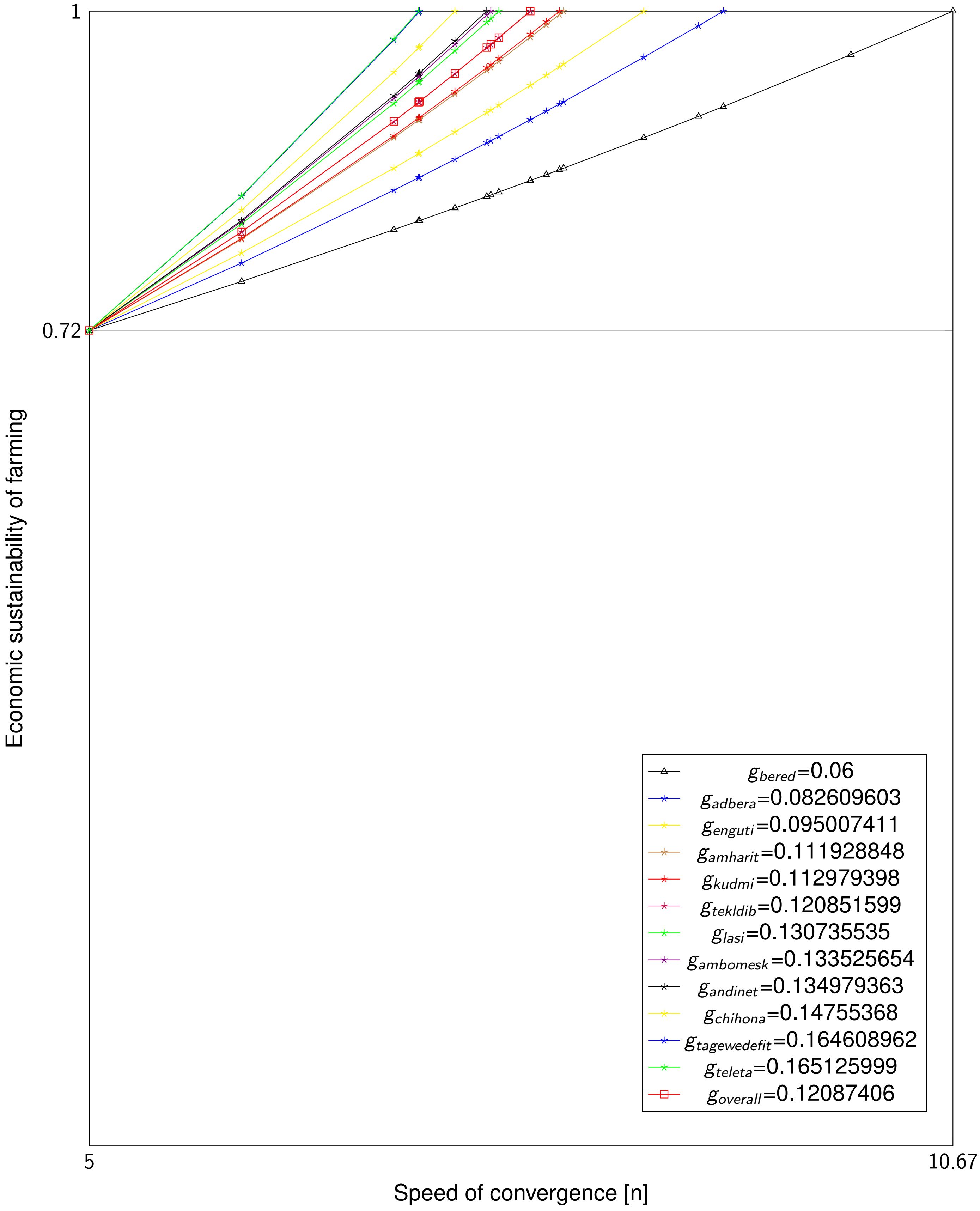


Figure 2.6: Growth differentials for cross-over in economic sustainability

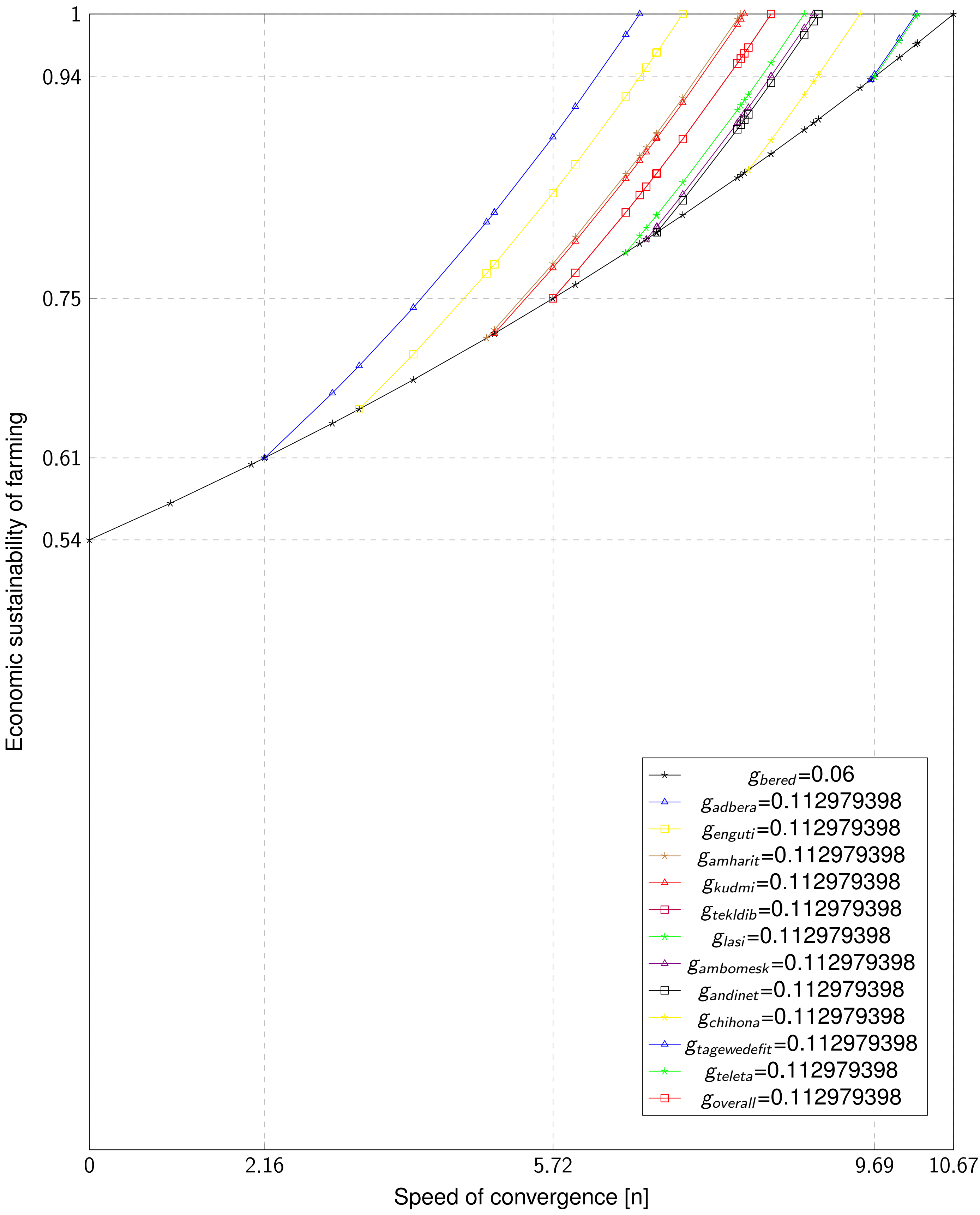


Figure 2.7: Speed for cross-over phenomenon in economic sustainability

Table 2.11: Speed of leapfrogging phenomenon in economic sustainability

Block Name	Cross-over/ leapfrogging time [n]	State of Technical efficiency [TE]
Bered		
Adebera	2.163707401	0.609161565
Enguti	3.33105613	0.652038536
Amarit	4.903186191	0.714590725
Kudmi	4.999999978	0.71863329
Tekel dib	5.72257039	0.74953618
Lasi	6.622640834	0.789895542
Ambo mesk	6.875296459	0.801610379
Andenet	7.006688872	0.807771136
Chihona	8.136235712	0.862725213
Tagel wedefit	9.648685329	0.942207022
Teleta	9.694189063	0.944708555
Overall	5.724624775	0.74962591
Assuming Growth Differentials	g_c =11.2979398% ,g_{bered} =6% =0.048771654	

percent. Tilahun et al. (2016) found results, with a minimum annual change of 1.3 percent and a maximum change of 10.8 percent. Tenaye (2020) reported technical efficiency for Ethiopian farm households was 16.4 percent between 1994-2004, 19.4 percent between 1999-2009, 11.23 percent between 1994-1999 and 11.6 percent between 2004-2009 under different models. In the studies conducted by Tefera and Holden (2013), Abebe and Taffesse (2012), Asfaw and Abebe (2011), and Tesfaye and Kassa (2016), the results show that technical efficiency increased at more than 10 percent per annum. Tefera and Holden (2013) found that technical efficiency increased by 12.7 percent per annum. Abebe and Taffesse (2012) reported an increase of 11.5 percent per annum in technical efficiency. Asfaw and Abebe (2011) observed an increase of 11.3 percent per annum, while Tesfaye and Kassa (2016) found that technical efficiency increased by 10.7 percent per annum.

Based on the available empirical evidence, the scenarios of both temporal and spatial economic sustainability convergence through efficiency change are considered to be reasonable assumptions. The maximum and minimum growth rates in technical efficiencies are also deemed to be reasonable. A 6 percent increase in efficiency is considered a reasonable minimum target, while a 11.29 percent increase is seen as a maximum achievable goal. In order to connect the realities, we aimed to provide a clear justification for the finding. The 9.42 percent expected growth rate at the project level in the first scenario for temporal economic sustainability over 10 years as a long-term plan, along with a 5.58 percent growth differential for catching up in the next five years, were not overly ambitious and are attainable.

Investigating the degree of economic sustainability in agriculture has substantial implications for both research and practical applications. This study assists in understanding how agricultural practices can be maintained over time without depleting natural resources or causing environmental degradation. It helps identify the most efficient methods for production while minimizing negative environmental impacts, which is crucial as human activities put pressure on natural resources and ecosystems. It contributes to the development of a framework for evaluating the long-term economic viability of various agricultural systems. The research expands our understanding of various aspects of agriculture, including resource management and technological innovation. It has practical applications for both farmers and policymakers. It can help farmers implement sustainable methods that are both environmentally friendly and economically successful. Moreover, the findings can aid policymakers in developing policies and programs that promote sustainable agriculture through management efficiency and efficient use of resources, such as strengthening extension services.

2.5 Conclusions and policy implication

The study aimed to investigate how agriculture fared in terms of economic sustainability and its convergence, specifically focusing on the efficient utilization of resources. In conclusion, the study on economic sustainability in agriculture in the Koga scheme has shown low levels, with significant inefficiency and wasteful practices in resource utilization. The findings indicate the importance of technical efficiency improvements to promote economic sustainability. Even though the success of the scheme in terms of increasing income by a large margin is evident, it is important to consider resource utilization to achieve this increase. Farmers prioritize current production and standard of living over future. This perception may lead to inefficient resource use and disregard for environment, as the efficient use of resources is crucial for the long-term viability of farming. The study highlights the importance of appropriate information on efficiency levels for farmers, as mis-perceptions can hinder progress in improving efficiency. The need for efficiency improvement is apparent mainly due to significant wasteful practices, and negative elasticity of output in certain inputs. Therefore, planning for efficiency improvement is a precondition for economic sustainability in agriculture. The analysis suggests that in order to achieve optimal levels of sustainability, a growth rate of at least 9.42 percent over a 10-year period is necessary. Additionally, a growth differential of 5.58 percent is needed for short-term goals aimed at achieving the same level of economic sustainability through efficiency measures. Ethiopia can incorporate these short-term and long-term objectives into its five-year and ten-year development plans to promote economic sustainability and growth in the agricultural sector. The study posits these plans are reasonable targets. Generally, study contributes to our understanding of the technical efficiency indicator of economic sustainability and the implications for resource management and environmental conservation for future use. By focusing on improving technical efficiency, the agricultural sector can contribute to a balance between economic growth and environmental conservation for sustainable production.

CHAPTER 3

RUNOFF SENSITIVITY TO CHANGES IN CLIMATE FACTORS IN KOGA SCHEME: A COMPARATIVE STUDY

[1]

Abstract

The study aimed to investigate the degree of sensitivity between runoff and the two climate factors, such as temperature and rainfall, using data from 1983 to 2016 for climate and 1959 to 2012 for hydrological records. Several estimation techniques, including Mann-Kendall (MK), von Storch's pre-whitening procedure (MK-PW), and the two types of Variance Correction Approaches (MK-VCA), were employed for trend analysis, and an elasticity estimator was used for hydro-climatic sensitivity assessment. The results showed climate has changed. The rise in average temperature trend in Merawi, where the scheme is located, was consistent with those in Wetet Abbay station. Rainfall was highly concentrated in main rainy season (June-September), which contributes more than 80 percent. Total rainfall and total runoff showed no statistically significant trends. However, temperature trends, rainfall distribution (unimodal), and precipitation concentration index are some justifiable indicators to have an irrigation scheme in the area. Temperature emerged as the most influential factor affecting runoff than rainfall in most years. The nonparametric estimate is -1.43367 in Koga watershed. However, both temperature and rainfall have shown a more than proportionate change in runoff. In comparison to Gilgel Abbay, Koga watershed mostly demonstrated greater sensitivity. A rise in annual temperature at the Merawi station, a negative temperature elasticity of runoff, and the dominance of temperature, combined with a statistically insignificant trends in total rainfall and total runoff, contributed to the difficulty in sustaining the Kog watershed. These factors also posed a challenge to the reservoir's ability to meet irrigation demand during the dry season.

Keywords

Trend analysis; sensitivity; MK, pre-whitening procedure (MK-PW); Variance correction approaches(MK-VCA)

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3.1 Introduction

Water availability is an essential aspect of irrigation agriculture. The topography of the land, proximity to bodies of water, latitude, prevailing temperatures, wind patterns, and other factors all work together to influence the volume of precipitation in a location. The states of Mawsynram and Cherrapunji are the world's first and second wettest. Annual rainfall ranges from 11,871 to 11,777 millimeters. Most of Africa receives about 1,000 millimeters of rain per year on average. Ethiopia is ranked fifth among African countries in terms of rainfall. Uganda received 1,295 millimeters of rain, Nigeria received 1,197 millimeters of rain, Ghana received 1,169 millimeters of rain, Rwanda received 1,164 millimeters of rain, and Ethiopia received 1,158 millimeters of rain (Bo Lang, 2014). The mean annual rainfall in Blue Nile Basin is within 800 to 2200 mm (Engida and Esteves , 2011). The Amhara Region's mean annual rainfall is 1,150 mm. The region receives plenty of rain, but highly concentrated and variable (Mesfin et al. , 2021).

Equatorial countries have abundant rainfall and no distinct dry season, such as Gabon and the Republic of the Congo. Unlike the equatorial, East Africa has a long dry season in general, with most of Ethiopia experiencing two rainy seasons. In Ethiopia, the main rainy season accounts 50-90 percent of rainfall. Similarly, seasonal variability characterizes the Blue Nile River's water flow, 82 percent of the annual flow in few months. Data from weather stations in Ethiopia's eastern and southeastern regions revealed that the Precipitation Concentration Index (PCI) is greater than 11 (Mulugeta et al. , 2017). The Upper Wabe Shebelle River Basin has similar results (Harka et al. , 2021). The northeastern basin of the Upper Blue Nile had a PCI value within 11.43 to 28.39 with a mean of 18.84, showing an irregular precipitation pattern. A similar irregular distribution also found in the center and southwest Upper Blue Nile in Ethiopia (Samy et al. , 2019).

The main water resources challenges in Ethiopia are variability, seasonality of rainfall and rainfall distribution, not abundance. Extreme seasonal fluctuation is also the feature of rivers in Ethiopia (Taye et al. , 2020). The main rainy season (Kiremt) rains are more reliable, providing water mainly for agriculture. Agricultural practices depend on four months of the "Kiremit" season in the absence of irrigation technology. A high temperature, along with a low precipitation trend, the concentration and variability of precipitation, make rain-fed agriculture difficult. Thus, rainfall concentration, variability and climate change negatively impact agriculture during rainy season (Dile et al. , 2013), which in turn, initiated irrigation technology in Ethiopia. Under these circumstances, irrigation has a paramount importance for sustainable agriculture. One of the adaptation strategies is the construction of irrigation dams. The importance of decoupling agriculture from the strong association with rainfall variability was recognized, and priority was given to agriculture (Yilak , 2013). The effectiveness of such an adaptation measure is severely endangered by climate change, variability and sensitivity of water resource to climate factors. The Ethiopian government's decision to prioritize the Koga scheme was prompted by frequent droughts and food shortages, with the overarching goal of reducing poverty and improving food security.

The Koga River generates 72 percent of its flow during the main rainy season, while low runoff during the long dry season (ADF , 2001). The river and irrigation dam are threatened by so many factors on both the demand and supply side. The irrigation water requirement of almost 15 to 21 mm more irrigation water was expected compared to the baseline period (Kumilachew and Hatiye , 2022). A rising demand for irrigation water can be attributed to climate change. In one way or another, climate change has started to negatively impact water resources.

Climate change is significantly affecting natural resources, with water being particularly vulnerable (Dursun Y., 2017), and one of the most sensitive sectors. Changes in the temperature and precipitation components of climate can directly affect the magnitude of the runoff component (Kinfe, 1999). However, it is not yet clear how changes in the precipitation and temperature series may have affected runoff, and what the main factor is (Birsan et.al., 2005). Examining how and to what extent runoff is sensitive to climate variables, such as temperature and rainfall are essential to make informed water resource management decisions to cope with climate variability by identifying the dominant climate factor affecting hydrological variable. Although rain (water availability) is the most essential input for plant growth, temperature is also the critical factor in determining water needs for irrigation (Wang et.al, 2016). This demand is fully met in rainy seasons, while water shortage is occurring during the long dry season (Gedefaw et.al , 2019). The Koga reservoir failed to supply water to meet the irrigation needs as per the project design. After about a decade of operation, whether due to management problems or water availability, the irrigation system generally reaches less than than 73.5 percent of the design capacity (Birhanu et al. , 2014). Out of the design capacity to irrigate 7004 ha, only 5,343 ha (76.3 percent of the planned area) irrigated in the 2016/17, and 5,000 ha in 2014 due to shortage of water and water distribution problems (Abiyu and Alamirew , 2014).

On the supply side, runoff is a better indicator of surface water availability than precipitation (J. Russ , 2020), freshwater availability for agriculture is also quantified in terms of river runoff (Damkjaer and Taylor , 2017), precipitation as the main factor driving runoff generation (Zhao J. et. al., 2015). Therefore, analysis of precipitation is an important source of information input for water management and agricultural production (Kidd , 2011). Farmers were very concerned about water shortages at the Koga scheme. There are poor water delivery performance, such as low adequacy and dependability (Yeshi , 2018). Moreover, the Koga scheme is found to be less resilient (Kumilachew and Hatiye , 2022). Irrigation water mainly depends on the rainfall, runoff situation and the interaction between the two. A study by Kumilachew and Hatiye (2022) used temperature and precipitation data to simulate reservoir inflow and water demand. These two climate factors found to affect streamflow and a reduction in the inflow of the reservoir when temperature rises and precipitation declines. Water security depends on the current state of the water environment, how it is changing over time, the extent it is influenced by climate and the state of water resource depends on the interactions between management and the environment in general (Maxim, 2009). The Study on the state of water resource before looking into the chains of causality, drivers and pressures that could change a state, policy alternatives, and institutions and mechanisms for policy and managerial response were supported by Derives-Pressures-State-Impact-Responses (DPSIR) framework. The methodological approach of this framework is based on the analysis of the current state. Investigating the impact and state of the system comes first, but drivers, pressures and response are investigated later to explain the causes (Bell and Morse, 2008). The framework has been criticized for its limited understanding of these causes (Svarstad et.al., 2008). Current approaches to water management primarily focus on assessing the current state of water resources and their impacts on the environment.

Many countries, particularly those suffering from the impacts of climate change, have started making projections about their own state of water resource. When evaluating irrigation systems, supply-side management options consider measures that affect water quantity and quality. In places where reservoirs are the main sources of supply, such as for example, at the Koga scheme, a supply-side management assessment should be conducted to address downstream irrigation needs. The examination of water resource conditions for irrigation agriculture is often seen as a necessary condition for policy makers and for identifying problems and taking action to improve them (Kim and Platt , 2008). In particular, hydrology is one of the relevant disciplines in the state or impact-oriented management approach. Therefore, this study does not look for chains of causality, drivers, and pressures that may alter the current climate variables. Successive steps of examining factors affecting temperature and rainfall trends were not the focus of the study.

Indicators of the state of water resources are redundant (UN CSD, 2001) or problem focused (OECD, 2003). Depending on the chosen system of description, the indicators can vary greatly from study to study (UN CSD, 2001). The water environment is mainly concerned with hydrophysical and biogeochemical changes based on information from different sources. They describe a wide range of characteristics including quantity and quality of physical (e.g. temperature), biological (e.g. fish populations) and chemical properties (e.g. atmospheric CO2 concentration) in a given area (Gabrielsen and Bosch, 2003). The study considers the physical phenomena of temperature, precipitation and hydrological data in multiple dimensions of causality as indicators of the state of water resources in Koga near or at Merawi (Koga Nr,/@ Merawi) and Gilgel Abbay near Merawi (Gilgel Abbay Nr. Merawi). This study ignores the deterministic and linear assumed casuality in the DPSIR framework. Simply assumed causal relationships cannot capture the complexity of interactions among different hydro-climatic variables (Refsgaard et.al., 2006). The relationships between categories D, P, S, I and R in DPSIR framework found to be more complex in real world. A particular impact may be caused by many other state conditions and indirectly by measures to other impacts; state conditions can be affected by different pressures, each of which can stem from a variety of driving forces each contributing to different pressures. The categories can also be turned; that depending on the method, data availability, and purpose of the analysis, the same variables can be taken as deriver, pressure, state, or response (Mysiak et.al., 2005).

Furthermore, the state or condition of the water in a multicausal system, as in the case of this study, can be influenced by various state variables within the state node. For instance, in this study, runoff is characterized as state and impact variable. The hydrological variable shows both the state of water resource and impact on water resource due to other state variables . Therefore, the study is based on a complex system of casuality between indicators of state, the analysis of their trends and relationships. When assessing water at global, regional, national and river basin levels, one of the general questions that might be asked is whether it is improving or deteriorating over time (Kristensen, 2004). Trend analysis is a preliminary tool for water resource assessment. Hydro-climatic data is an essential aspect of analyzing the state of water resources (Duwal, 2011). Examining the state and trend of water resources is required to support sustainable economic and social development while taking into account environmental quality (WMO, 2012). It is important to examine the quantity and identify the current state and impacts on the water availability for agriculture, as well as changes over time (Kristensen, 2004). The trends of water in the past and the probable future are a critical features of planning (Duwal, 2011).

3.2 Methods

3.2.1 Data types, sources and preprocessing

The Abbay river basin is divided into 16 sub basins based on the basin's major rivers. Lake Tana sub-basin is the largest fresh water lake in north of the Abbay River Basin. The Tana sub-basin has four perennial rivers: Gilgel Abbay, Megech, Ribb, and Gumera. The Gilgel

Abay and Gumara rivers contribute to roughly 70 percent of the Lake's inflow (Tigabu et al. , 2021). Koga is a tributary and nearby watershed to Gilgel Abbay. This section is a comparison study of the Koga watershed and Gilgel Abbay for hydro-climatic trends, variability, and sensitivity to climate factors.

The source of daily climate data for minimum and maximum temperatures and daily rainfall (1983-2016) was the National Meteorological Agency (NMA). From this data, other seasonal and annual data types were generated. The three seasons are: the main rainy season (June to September), the dry period (October to February), and the short rainy season (March to May) (Conway , 2000). The hydrological data types collected from the Ministry of Water, irrigation and electricity for the study include monthly and total runoff from 1959 to 2012. These data were further used to generate seasonal runoff data. The hydrological gauges are now maintained by Hydrology Department in the Ministry of Water, irrigation and electricity (Abdo, 2008). The hydrological data had gaps between 1959 and 2012. The missing data percentage for Koga Nr./@ Merawi runoff was 2 percent (13/648=2 percent) and for Gilgel Abbay Nr. Merawi was 2.5 percent (16/648=2.5 percent) over a 54-year period. Because the overall percentage of data missed was less than 5% of values in both stations, they can be ignored. However, the researcher determined that it was more important to fill them using the mean imputation method for the sake of preserving temporal patterns.

3.2.2 Estimation techniques [MK, the von Storch's pre-whitening procedure (MK-PW), the two types of Variance Correction Approaches (MK-VCA)]

Climate change and variability have various implications for agriculture, since agriculture needs abundant water relative to other sectors. In a predominantly rain fed, with a little disruption in the amount and seasonal pattern of rainfall causes significant impact on it (Deressa et. al, 2008). The common manifestations of climate change are a rising temperature and change in hydrological cycle (Lovejoy and Hannah , 2005). The mean annual temperature is used as an indicator of climate change (Mastrandrea and Schneider , 2004). An increases in average global temperature and changes in precipitation are the main characteristics of climate change (UNFCCC , 2007).

Analysis was conducted on six climate statistics to determine trends and assess the availability of water resources. These included minimum temperature, maximum temperature, average annual temperature, mean seasonal temperature, total annual rainfall, and total seasonal rainfall. Trend analysis was also performed using the two hydrological statistics - total annual runoff and total seasonal runoff - to examine the state of water resources in the two watersheds.

Mann-Kendall test, along with various modifications, was used to examine the trend in hydro-climatic variables. The tests were performed using "XLSTAT", which is an inbuilt functionality in Excel. The Mann Kendall (MK) test is preferred to other tests because it doesn't require prior assumptions on the distribution of the data sample and are less sensitive to outliers. The climate data do not have any outlier, whereas in 54 years of runoff data in Koga Nr./@ Merawi, there is only one outlier. In large datasets, a small number of outliers cannot significantly affect statistical analysis. Sometimes it's better to retain outliers as they capture valuable information, particularly when their existence doesn't diminish statistical significance. Removing them may distort variability information, especially in measures like the coefficient of variation. By doing so, you force the data to appear less variable than it is in reality. Since outlier is part of the population in runoff data, they should not be removed. The researcher cannot legitimately remove it and does not want it to distort results, so used a nonparametric estimation technique, MK. Thus, the outlier were kept as it was.

The MK requires that the observations are independent, implying that the correlation between the series with themselves must not be significant at a given lag. Autocorrelation in a series results the underestimation of variance of the S statistic (Alemu and Dioha , 2020). Therefore, the modified Mann Kendall (MK) approach was adopted after running the serial correlation test in Excel. Modified tests with full autocorrelation framework improved the accuracy of trend results (Hu et.al., 2019). These modifications have been made to the MK test to eliminate the influence of autocorrelation. XLSTAT offers two alternative methods: Hamed and Rao (1998) and Yue and Wang (2004). There is also prewhitening procedure in trend analysis. A single trend detection method cannot reflect the true trend. Consequently, the use of at least two methods to assess the presence of trends in a given dataset is recommended (G. C. Blain, 2013). The approach in the study includes four: the MK test on the original sample data, the MK test on the sample data that are subjected to the von Storch's pre-whitening procedure (MK-PW), the two types of MK test adjusted by the Variance Correction Approaches (MK-VCA) suggested in Hamed and Rao (1998) and Yue and Wang (2004).

The hydro-climatic data trends at the Koga Nr./@ Merawi for runoff trend and Merawi climate station based on the four estimation methods were compared to Gilgel Abbay Nr. Merawi runoff trend and Wetet Abbay climate station to determine if a significant change has occurred compared to Gilgel Abbay. The magnitude and sign of the MK test statistic (S) helps to understand how strong the trend is in the hydro-climatic data and whether it is increasing or decreasing in the two watersheds. A positive value of S or Kendall's tau indicates an increase trend in the time-series data.

(1) THE MK TEST

The MK test, also called the Kendall's tau test developed by Mann (1945) and Kendall (1975), is the nonparametric, rank-based test for assessing the significance of a trend. It is widely used in hydrological trend detection studies. Most of the trend studies have used the original Mann–Kendall (MK) test, assuming spatio-temporal independence of the data. The null hypothesis, H_0, states that a sample of data (X_i, i = 1, 2 . . . , n) is independently and identically distributed. The alternative hypothesis, H_1, states that there is a monotonic trend in sample data, X_i . The statistic S of Kendall's tau is defined as follows in equation 3.1 (S. Yue et.al., 2002) :

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(X_j - X_i) \tag{3.1}$$

Where, the X_j are the sequential data values, n is the length of the data set, and

$$sgn(\theta) = \begin{cases} 1 & \text{if } \theta > 0 \\ 0 & \text{if } \theta = 0 \\ -1 & \text{if } \theta < 0 \end{cases} \tag{3.2}$$

The Mann (1945) and Kendall (1975) have documented that when n $\geq$ 8, the statistic S is approximately normally distributed with the mean and the variance as follows (see equation 3.3 & equation 3.4):

$$E(S) = 0 \tag{3.3}$$

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{m=1}^{n} t_m m(m-1)(2m+5)}{18} \tag{3.4}$$

Where, t_m is the number of ties of extent m. The standardized test statistic Z is computed by equation 3.5

$$Z = \begin{cases} \frac{S-1}{\sqrt{V(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{V(S)}} & S < 0 \end{cases} \tag{3.5}$$

The standardized MK statistic Z follows the standard normal distribution with mean of zero and variance of one.

(2) von Storch's Pre-Whitening procedure (MK-PW)

Pre-whitening (PW) is another technique usually employed to remove the serial correlation in trend analysis. The technique was proposed by Von Storch (1995) and Kulkarni and von Storch (1995) for the purpose of avoiding the effect of serial correlation, such as a lag-one an autoregressive (AR(1) process, from a time series. After prewhitening procedure, the MK test applied to the serially independent residuals. Studies that have used this procedure include Douglas et al. (2000) and Zhang et al. (2001). The pre-whitening procedure is given by equation 3.6 (S. Yue et.al., 2002):

$$Y_t = X_t - r_1 X_{t-1} \tag{3.6}$$

Where, X_t, t=1,....................n are the data points of the series. If the autocorrelation is statistically significant and coefficient of correlation, r, the MK test is applied on "Pre-whitened series"or "Residual time series" as obtained by equation 3.6

(3) Hamed and Rao's MK test adjusted by the VCA (MK-VCA)

The Variance Correction Approach (VCA-adjusted) Hamed and Rao MK test (MKVCA) is one of the autocorrelation methods, an alternative method offered by XLSTAT. The sample variance of the test statistic of the MK test could be inflated due to the presence of a serial correlation. The variance correction approaches estimate the inflated variance, for which Hamed and Rao (1998) and Yue and Wang (2004) derived two different expressions. Hamed and Rao (1998) used a different method to remove the serial dependency effect by modifying the variance of the MK test statistic to compensate for this effect. This can be done using the effective sample size (ESS) to compensate for the effect of serial correlation on the variance. The method works well when there is no trend in the series (it avoids identifying a trend when it is in fact due to autocorrelation). They proposed to correct for the variance of S using an effective sample size (ESS) that reflects the effect of serial correlation on the variance of S, as presented in the previous section. The test calculates the autocorrelation between the ranks of the data after removing the apparent trend. The modified variance is given by equation 3.7 (S. Yue et.al., 2002). This correction factor to the variance is based on the correlations of ranks of the data.

$$V*(S) = V(S)\frac{n}{n*} \tag{3.7}$$

Where, V(S) is the variance of the MK statistic S for the original sample data, estimated using equation 3.4; n is the sample size; n* is the Effective Sample Size (ESS); and n/n* is the correction factor due to the existence of the serial correlation in sample data. From equation 3.5, the modified standardized MK statistic Z* is given by equation 3.8.

$$Z* = \begin{cases} \frac{S-1}{\sqrt{V*(S)}} & \text{S > 0} \\ 0 & \text{S = 0} \\ \frac{S+1}{\sqrt{V*(S)}} & \text{S < 0} \end{cases} \tag{3.8}$$

The correction factor is computed by

$$n/n* = 1 + \frac{2}{n(n-1)(n-2)} \sum_{j=1}^{n-1} (n-k)(n-k-1)(n-k-2) r_k^R \tag{3.9}$$

Where, r_k^R is the lag-k serial correlation coefficient of the ranks RX_t of the sample data X_t. r_k^R is computed by replacing the sample data X_t by their ranks RX_t in the following equation:

$$r_k = \frac{\frac{1}{n-k} \sum_{t=1}^{n-k} [X_t - E(X_t)][X_{t+k} - E(X_t)]}{\frac{1}{n} \sum_{t=1}^{n} [X_t - E(X_t)]^2} \tag{3.10}$$

$$E(X_t) = \frac{1}{n} \sum_{t=1}^{n} X_t \tag{3.11}$$

where, r_k is the lag-k serial correlation coefficient of the sample data X_t, and E(X_t) is the mean of the sample data.

(4) Yue and Wang (2004)'s MK test adjusted by the VCA (MK-VCA)

Another MK test adjusted by the VCA is suggested by Yue and Wang (2004). This method is one of the attempts to modify the MK test for serially dependent data to reduce the rejection rate when there is no trend to the assigned (nominal) significance level. The proposed correction factor for the variance in the this method is based on the correlation coefficients of the data (Yue and Wang, 2004). This autocorrelation method has the advantage that it works best when there is a trend and autocorrelation. Data are initially detrended and the effective sample size is calculated using significant serial correlation coefficients.

3.2.3 Climate Variability

A study by Pearson (1903) developed coefficient of variations measure of variation which captures the relative variability or dispersion of a dataset in relation to its mean. Hydro-climatic data variability analysis involved the use of Coefficient of Variation (CV) in formula equation 3.12:

$$CV = \frac{\sigma}{\mu} 100 \tag{3.12}$$

Where, CV is the coefficient of variation, σ is standard deviation and μ is the long-term mean annual in rainfall, temperature and runoff for climate and hydrology statistics over the period of observation. A variable with CV of less than 0.20 is less variable, CV between 0.20 and 0.30 is moderately variable and CV greater than 0.30 is highly variable (NMA , 1996). To quantitatively evaluate monthly precipitation heterogeneity throughout the year, De Luis and

Gonzalez-Hidalgo developed the precipitation concentration index (PCI) based on monthly precipitation data. The Precipitation concentration index (PCI) indicates the temporal precipitation distribution. Accordingly, a PCI value less than 10.0 represents mostly uniform precipitation distribution. A value between 11 and 15 represents moderate precipitation concentration. A value between 16 and 20 denotes irregular distribution. The values above 20 represent strong irregularity of very high concentration (Lu et al. , 2019). The values between 11 and 20 indicate high concentration (Ayalew et al. , 2012).

3.2.4 Hydo-climatic Sensitivity

The two climate factors and hydrology were considered to provide a comparative overview of the hydro-climatic sensitivity analysis in two watersheds. The elasticity estimation using non-parametric estimator proposed by Sankarasubramaniam et al. (2001) was used to examine temperature elasticity of runoff (eT) and rainfall elasticity of runoff (eR) for the two watersheds. The estimator had low bias and was as robust as, or more robust than hydrological modelling approaches. The nonparametric estimator can be expressed as equation 3.13 and equation 3.14 :

$$eT = median\frac{(Qt - Qm)}{(Tt - Tm)}\frac{Tm}{Qm} \tag{3.13}$$

$$eR = median\frac{(Qt - Qm)}{(Rt - Rm)}\frac{Rm}{Qm} \tag{3.14}$$

Where, Tm, Rm and Qm are the mean annual temperature, rainfall and runoff respectively. To estimate eT and eR, a value of in equation 3.13 and equation 3.14 were calculated for each pair of Tt and Qt, Rt and Qt in the annual time series, and the median of these values were the nonparametric estimate of eT and eR. The concept is also used to identify the dominant climate factor affecting runoff and the most sensitive watershed to climate variables. A larger magnitude of the elasticity measure indicates a larger effect of climate variables on the runoff. The major advantage of the elasticity being unit-free makes it easy to compare across different studies, data types, and watersheds.

3.3 Results and Discussion

3.3.1 Hydro-climate Change and Variability

3.3.1.1. Climate Change and Variability

Climate change adversely affects agriculture and become a challenge for sustainable development in Africa (Juana et.al., 2013). The real connection between climate change and its impact on agriculture, in particular, and sustainable development in general, have been cited in various literature. Ethiopia is one of the highly affected country in the world by climate change, seventh among countries at risk from its impact (Maplecroft , 2015).

(1) Temperature data trend analysis

The objective of this section of the study is to examine the trend and variability in temperature and rainfall patterns with a comparison of the two climate stations: Merawi station, where the Koga scheme is located, and Wetet Abbay, the nearby station. The analysis of the graph in Figure 3.1 shows the mean annual temperature and the mean seasonal temperature in Merawi and Wetet Abbay stations between 1983-2016. The Kendall's tau, MK statistics (S), Var(S) and

P-values for temperature statistics are shown in Table 3.1. The value of S and Kendall's tau in the time-series data for mean temperature are positive. The mean annual temperature showed a statistically significant rising trend in three statistical estimation techniques (i.e. original MK, Hamed and Rao (1998) and Yue and Wang (2004) in the two stations. However, there was a statistically insignificant trend (p=0.05) in the prewhitening procedure when the first lag autocorrelation correction was considered. These trend differences in temperature indicate that the way serial correlation is adjusted has significant implications for trend analysis. This, in turn, relies on the technique used for trend estimation. The positive trend result of the MK test in the mean annual temperature may not be a true trend after the pre-whitening procedure in the data set. Such difference arises due to the approach to remove serial correlation. Although the mean annual temperature showed the same pattern in both climate stations, the trend in Merawi was stronger than the trend in Wetet Abbay based on the magnitude of S statistics (see Table 3.1).

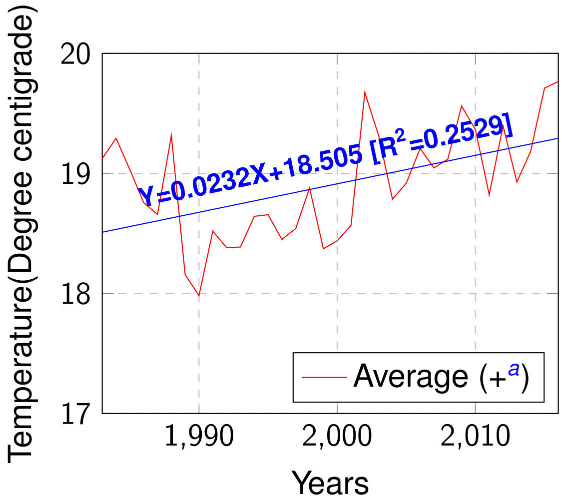
A higher value of the S statistic suggests a more significant and consistent trend in the data. It means that there is a stronger indication of a trend towards increasing values, which can be a valuable information for analyzing time series data and making predictions. In the context of the study, the trend in mean temperature means the climate has changed in Merawi and Wetet Abbay. This result is consistent with expectations and other finding both at national and local scale. The results from 42 meteorological stations showed an increase in temperature for 50 years in Ethiopia (NMSA, 2001). At the Koga scheme, upstream and downstream communities independently observed a rising temperature beginning in 1985 (Gebrehiwot et al. , 2010).

The mean temperature trend may not accurately reflect the post-dam construction scenario due to limited data availability. There was insufficient data length for a trend test, with data only available up to 2016. However, the attempt to interpret the trendline post-2005, when the construction began, suggests that the twelve-year data trendline is an optional method for examining the situation in the area, especially after the dam construction.[2] The post-dam temperature trendline reveled a rise in the mean annual temperature (see Figure 3.1c). Furthermore, in both stations, the trend lines in the mean annual temperature following the Koga dam construction and operation are steeper. The rate of change at Merawi station increased from 0.0232 to 0.0448. According to studies, dam constructions have an impact on the local climate as well as nearby stations. Typically, a reservoir's effective influencing radius is estimated to be normally 10km, and it can be between 30-40 km (Zhao et al. , 2021) and up to 100 km (Guo et al. , 2021). The scheme may have an impact on this, necessitates further research in the field. Regarding the maximum temperature, the Merawi station demonstrated a statistically stronger and increasing trend (see Figure 3.2a and 3.2c). For a stronger trend result, see the S statistics for the maximum trend in both stations in Table 3.2. Higher temperature can accelerate evaporation, leading to water shortage and affecting water availability for agriculture, and the situation may have more immediate and direct effect.

[2] According to the general information about Koga scheme provided in Appendix Two:B (see Table 5.9), the start date was 14 June 2005.

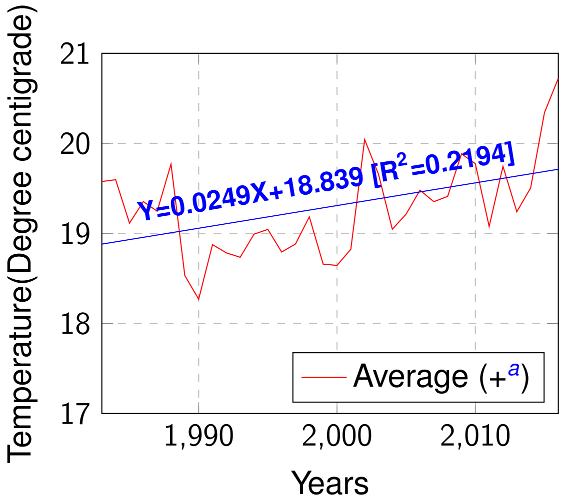
Table 3.1: Mann-Kendall trend Test results/ Average annual & mean seasonal temperature

Merawi Station	STATISTICS	MK	Von Storch (1995) Prewhitening	Hamed and Rao (1998)	(Yue and Wang, 2004)
1. Average annual temperature	Kendall's tau	0.362	0.180	0.362	0.362
	S	203.000	101.000	203.000	203.000
	Var(S)	4550.333	4550.333	7415.487	2573.693
	p-value (Two-tailed)	0.003	0.138	0.019	<0.0001
2. Mean seasonal temperature	STATISTICS	MK	Von Storch (1995) Prewhitening	Hamed and Rao (1998)	(Yue and Wang, 2004)
Main Rainy Season(MRS)	Kendall's tau	0.508	0.273	0.508	0.508
	S	285.000	153.000	285.000	285.000
	Var(S)	4550.333	4550.333	4550.333	446.821
	p-value (Two-tailed)	<0.0001	0.024	<0.0001	<0.0001
Short Rainy Season (SRS)	Kendall's tau	0.330	No serial correlation	0.330	0.330
	S	185.000		185.000	185.000
	Var(S)	4550.333		4550.333	934.838
	p-value (Two-tailed)	0.006		0.006	<0.0001
Dry Season	Kendall's tau	0.134	0.002	0.134	0.134
	S	75.000	1.000	75.000	75.000
	Var(S)	4550.333	4550.333	4550.333	3773.071
	p-value (Two-tailed)	0.273	1.000	0.273	0.228
Wetet Abbay Station	STATISTICS	MK	Von Storch (1995) Prewhitening	Hamed and Rao (1998)	(Yue and Wang, 2004)
1. Average annual temperature	Kendall's tau	0.308	0.187	0.308	0.308
	S	173.000	105.000	173.000	173.000
	Var(S)	4550.333	4550.333	4550.333	2569.990
	p-value (Two-tailed)	0.011	0.123	0.011	0.001
2. Mean seasonal temperature	STATISTICS	MK	Von Storch (1995) Prewhitening	Hamed and Rao (1998)	(Yue and Wang, 2004)
Main Rainy Season(MRS)	Kendall's tau	0.497	0.316	0.497	0.497
	S	279.000	177.000	279.000	279.000
	Var(S)	4550.333	4550.333	4550.333	861.563
	p-value (Two-tailed)	<0.0001	0.009	<0.0001	<0.0001
Short Rainy Season (SRS)	Kendall's tau	0.219	No serial correlation	0.219	0.219
	S	123.000		123.000	123.000
	Var(S)	4550.333		4550.333	940.923
	p-value (Two-tailed)	0.071		0.071	<0.0001
Dry Season	Kendall's tau	0.134	0.037	0.134	0.134
	S	75.000	21.000	75.000	75.000
	Var(S)	4550.333	4550.333	7993.441	4168.657
	p-value (Two-tailed)	0.273	0.767	0.408	0.252



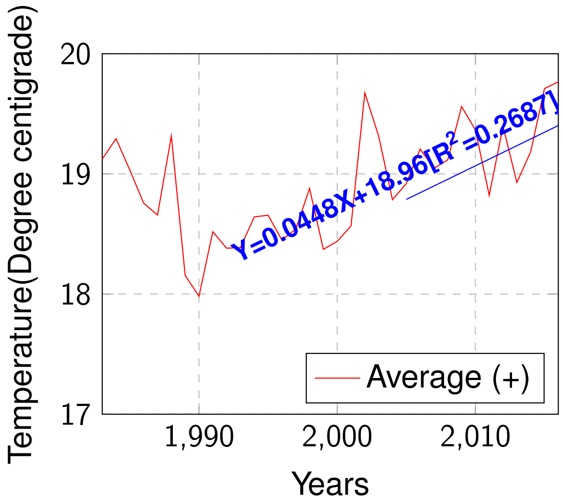
(a) Average annual temperature in Merawi

[a]Statistically significant increasing trend is detected except the Prewhitening procedure

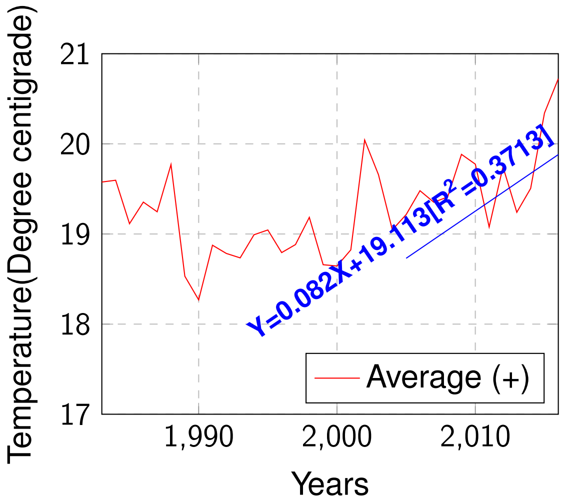


(b) Average annual temperature in Wetet Abbay

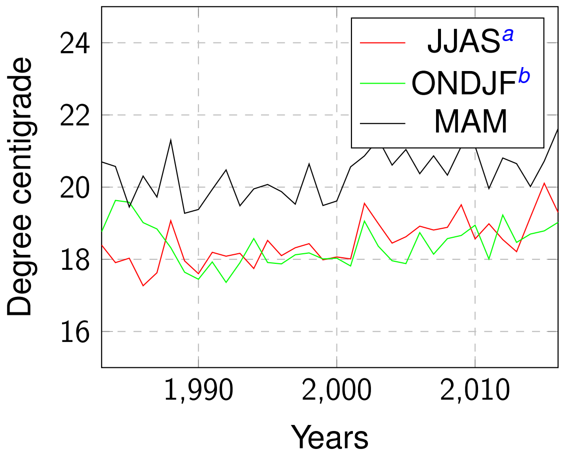
[a]Statistically significant increasing trend is detected except the Prewhitening procedure



(c) Temperature trendline after Koga dam construction and operation in Merawi



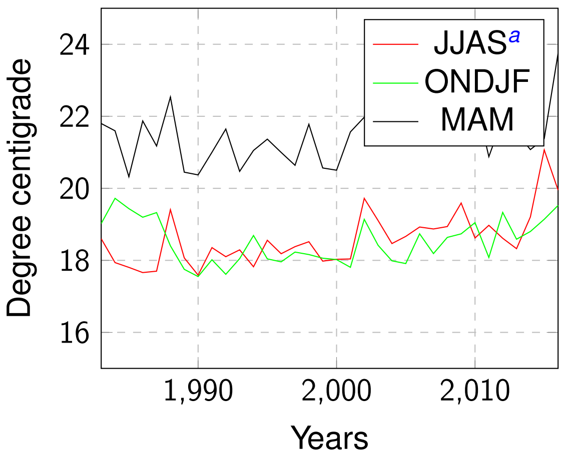
(d) Temperature trendline after Koga dam construction and operation in Wetet Abbay



(e) Mean seasonal temperature in Merawi

[a]The main rainy season that lasts from June to September, the dry season from October to February, and the short rainy season from March to May (Conway , 2000)

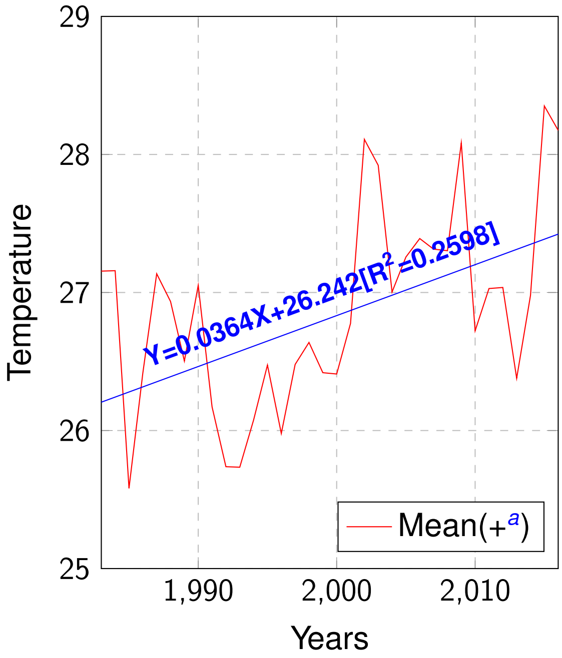
[b]There were statistically significant increasing trends except the dry season



(f) Mean seasonal temperature in Wetet Abbay

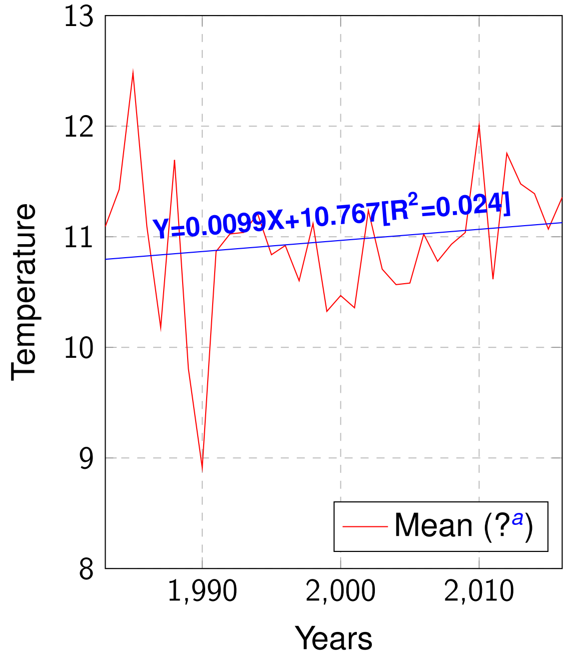
[a]There were statistically significant increasing trends except the dry season

Figure 3.1: Average temperature data trend analysis in Merawi and Wetet Abbay



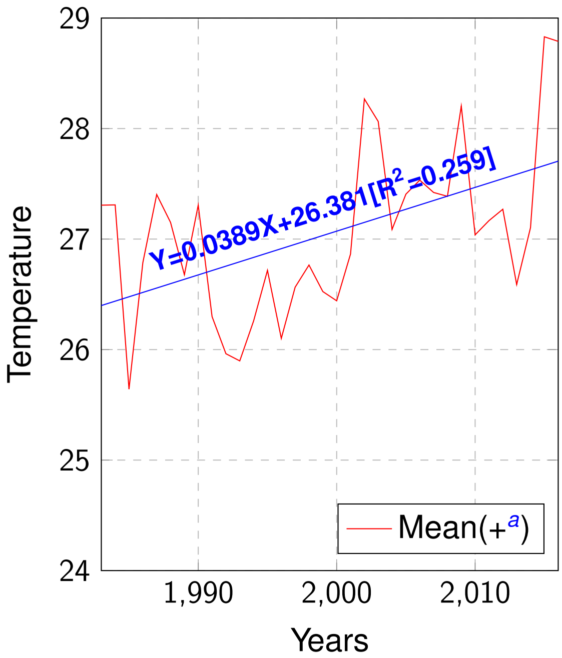
(a) Daily maximum temperature in Merawi

[a]Statistically significant increasing trend is detected in four statistical estimation tools



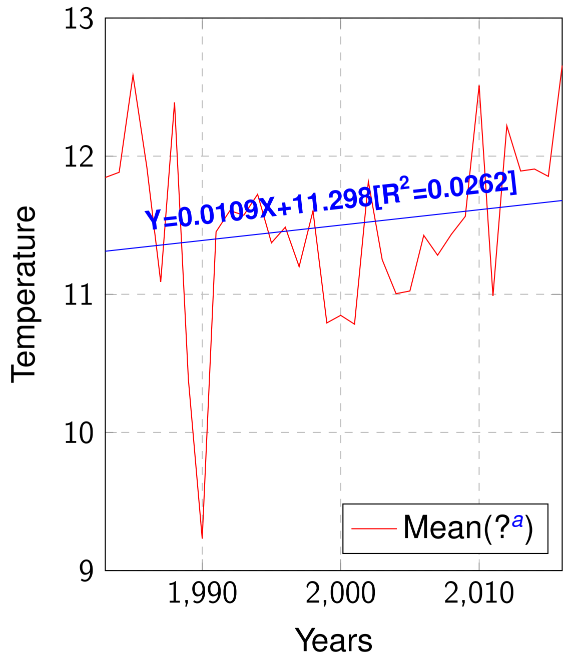
(b) Daily minimum temperature in Merawi

[a]Increasing trend but statistically insignificant(p=0.05) in different statistical estimation tools



(c) Daily maximum temperature in Wetet Abbay

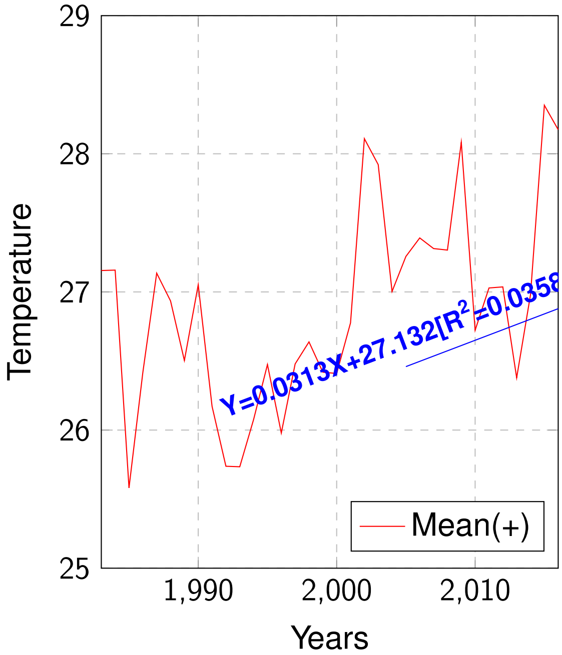
[a]Statistically significant increasing trend is detected in four statistical estimation tools



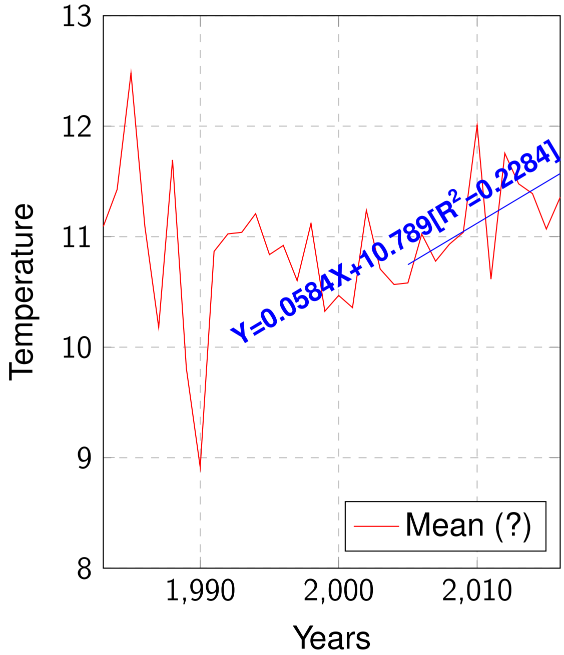
(d) Daily minimum temperature in Wetet Abbay

[a]Increasing trend but statistically insignificant(p=0.05) in diffrent authocorrelation methods

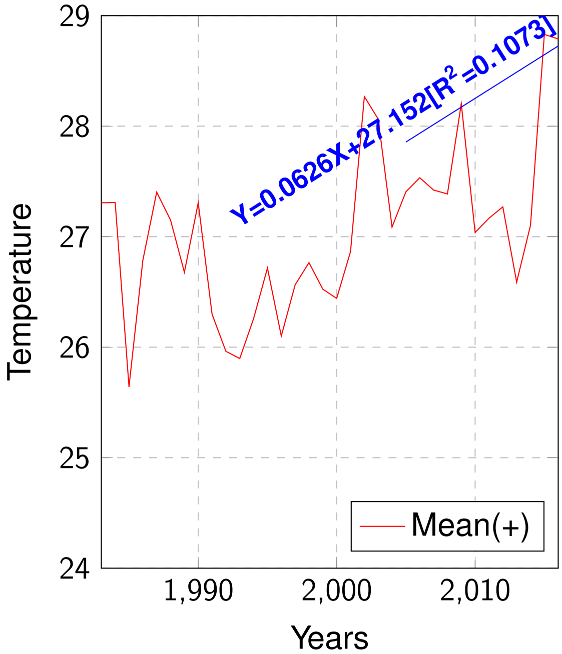
Figure 3.2: Daily minimum and maximum temperature data trend analysis in both stations



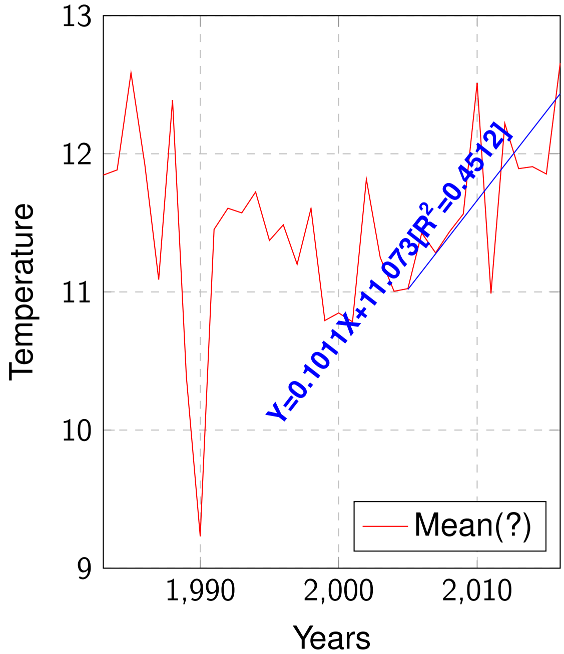
(a) Daily maximum temperature trendline after Koga dam construction and operation in Merawi



(b) Daily minimum temperature trendline after Koga dam construction and operation in Merawi



(c) Daily maximum temperature trendline after Koga dam construction and operation in Wetet Abbay



(d) Daily minimum temperature trendline after Koga dam construction and operation in Wetet Abbay

Figure 3.3: Daily minimum and maximum temperature data trend line after Koga dam construction and operation

Table 3.2: Mann-Kendall trend Test results/Mean daily minimum, maximum temperature in both stations

Merawi Station	STATISTICS	MK	Prewhitening	Hamed and Rao	Yue and Wang
1. Mean daily maximum temperature	Kendall's tau	0.308	0.244	0.308	0.308
	S	173.000	137.000	173.000	173.000
	Var(S)	4550.333	4550.333	5432.148	1421.610
	p-value (Two-tailed)	0.011	0.044	0.020	<0.0001
2. Mean daily minimum temperature	Kendall's tau	0.105	No serial autocorrelation	0.105	0.105
	S	59.000		59.000	59.000
	Var(S)	4550.333		4550.333	1427.801
	p-value (Two-tailed)	0.390		0.390	0.125
Wetet Abbay Station	**STATISTICS**	**MK**	**Prewhitening**	**Hamed and Rao**	**Yue and Wang**
1. Mean daily maximum temperature	Kendall's tau	0.305	0.340	0.305	0.305
	S	171.000	191.000	171.000	171.000
	Var(S)	4550.333	4550.333	6566.417	1512.683
	p-value (Two-tailed)	0.012	0.005	0.036	<0.0001
2. Mean daily minimum temperature	Kendall's tau	0.066	No serial autocorrelation	0.066	0.066
	S	37.000		37.000	37.000
	Var(S)	4550.333		4550.333	1913.203
	p-value (Two-tailed)	0.594		0.594	0.410

At a seasonal level, a rising trend in temperature is found in the four statistical estimation techniques during the main rainy season at the two stations (see Figure 3.1). This trend was similar when the results of different techniques were taken into account. Consequently, the trend reflects the most reliable true trend. Seasonal trend during main rainy season is stronger at Merawi station, whose S statistic is higher except the prewhitening procedure (see Table 3.1). During the short rainy season, a rising trend in temperature was found at Merawi station when the Original MK, Hamed and Rao (1998) and Yue and Wang (2004) autocorrelation methods were considered. At Wetet Abbay station, there was a significant (increasing) trend only when Yue and Wang (2004) autocorrelation method was considered. The trend at Merawi station during short rainy season was also stronger than the Wetet Abbay station when considering S statistics of the Yue and Wang (2004) method of autocorrelation. However, an increasing trends during Dry season were statistically insignificant in both stations.

Freshwater availability for agriculture is also quantified in terms of river runoff (Damkjaer and Taylor , 2017), with precipitation as the primary driver of runoff generation (Zhao J. et. al., 2015). In Ethiopia rain typically occurs between June to September. During this period, the majority of the country's agricultural activities take place, as the rainfall provides the necessary water for crop growth and development. However, a rise in temperature during the this season can lead to increased evapotranspiration rates, which in turn reduces the availability of water (through its impact on reservoir) for agriculture to use during other seasons when rainfall is low. This can have significant implications for the sustainability of agriculture in Ethiopia, as it may lead to water scarcity and reduced crop yields in the dry seasons. As a result, not only temperature affects demand, but it also affects the water supply availability for irrigation during long dry seasons.

Climate change is a complex and multifaceted issue, with increasing temperatures being a key indicator. As temperatures continue to rise, the demand for water increases for various purposes, including agriculture. Dams can store water in reservoirs, ensuring a steady supply during periods of drought or high demand. However, if temperatures continue to rise, as indicated in post-dam trends suggest, it could threaten water availability by increasing water demand and decreasing supply. The primary importance of studying climate change lies in comprehending these implications and devising strategies to manage and adapt to the impacts resulted from climate change.

(2) Rainfall data trend analysis

Precipitation patterns also indicate the overall understanding of changes in climate. The graphs of rainfall data that includes total annual and seasonal rainfall for Merawi and Wetet Abbay station are shown in Figure 3.4, 3.5 and 3.8. The rainfall data were free from lag one serial correlation problem. Therefore, the trends in rainfall data were estimated using three techniques : Original MK, Hamed and Rao (1998) and Yue and Wang (2004), that the researcher didn't apply the prewhitening procedure in the time series. The trends in the total annual rainfall data were statistically significant increasing trend only when the Yue and Wang (2004) autocorrelation method was considered at Merawi station (See Figure 3.4). There was no sufficient evidence to conclude the rising trend in total rainfall in Merawi station, as a single trend detection method cannot reflect the true trend. There was also a statistically insignificant rainfall trend during the three seasons. There was not enough evidence to conclude that the observed increase rainfall trend is significant, implying unclear and inconsistent pattern of increasing rainfall over time. More data is required for future research to determine if there is a real trend occurring. However, the comparison of the total rainfall trendlines before and after the dam revealed a declining trend after the Koga dam in both stations. Furthermore, the rate of change

Table 3.3: Rainfall distribution in the three seasons (1983-2016)

Stations	Main Rainy Season	Short Rainy Season	Dry Season	Wettest month
Merawi	1092.3(85.5%)	106.7(8.4%)	77.8(6.1%)	July 372.2(29.2%)
Wetet Abbay	1217.2(83.5%)	144.4(9.9%)	96.9(6.6%)	July 386.1(26.5%)

at the Merawi station was -21.381 (See Figure 3.6 and Figure 3.7).

(3) Rainfall distribution

In the context of rainfall distribution in both stations, the distribution or pattern of rainfall has only one peak or mode, implying only a single season during which rainfall is most concentrated. A unimodal rainfall distribution found to be the feature of both stations. The rain usually begins in April then gradually rises until it reaches its peak in July (Figure 3.9 and Figure 3.10). The rainfall distribution is characterized by highly concentrated rainfall in Merawi and Wetet Abbay stations from June to September, which contribute approximately 85.5 percent and 83.5 percent of total rainfall, respectively, with July taking the largest share. July alone accounts for 29.2 percent in Merawi station and 26.5 percent in Wetet Abbay station (Table 3.3). The implication such a unimodal rainfall distribution is more reliance on the main rainy season, that water availability can be more variable during other seasons.

Another measure, usually using index number, of distribution of rainfall is the precipitation concentration index (PCI). During the study period, the PCI in Merawi exceeded 16 in all years. The data revealed an irregular distribution of rainfall and it is highly concentrated. Most years (67.6 percent) showed a strong irregularity in Merawi station. In Wetet Abbay station, irregular rainfall distribution occurred more than 97 percent of the time. More than 47 percent of the years had strong irregularity in Merawi station. Furthermore, rainfall at Merawi station was more concentrated than at Wetet Abay station, in which the PCI graph for Merawi station mostly lies above. However, using trendline results for Merawi station, PCI was decreasing with a rate of -0.0373. In contrast, PCI rose after the Koga scheme during post-dam period, with a rate of 0.0852 (see Figure 3.11). A rise in the index typically represents an increase in the variability of rainfall distribution of the post-dam period, implying a greater chance of occurring extreme weather events and more precipitation is falling in few and more fewer periods.

The rainfall distribution and precipitation concentration results demonstrate how rainfall is concentrated in the Koga scheme command areas. A greater concentration of rainfall results in a lengthier dry season. The dam's ability in resolving these consequences is determined by its ability to supply enough water for use in irrigation agriculture. The dam can offer a consistent water supply for agriculture. A dam can be an effective method to handle water shortages, as long as it can store enough water. Climate considerations have a substantial implications on irrigation water supply and demand sides, as well as availability. Rising temperatures and statistically insignificant rainfall trend will worsen the water scarcity, rendering it unsuitable for future usage. The situation may be exacerbated by a more steeper rise in temperature and a declining trend in total rainfall during post-dam period. The rising temperature could affect water demand by increasing water requirements for plan growth while insignificant trend in rainfall making the supply of water uncertain. These situation in Koga scheme have the tendency to increase the existing water shortage in the area. The physical availability of water, as well as, poor water management in the area makes things more complicated as far as water availability for irrigation agriculture is concerned.

Table 3.4: Mann-Kendall trend Test results/ Total annual & total seasonal rainfall

Merawi Station	STATISTICS	MK	Von Storch (1995) Prewhitening	Hamed and Rao (1998)	(Yue and Wang, 2004)
1. Total annual rainfall	Kendall's tau	0.178	No serial correlation	0.178	0.178
	S	100.000		100.000	100.000
	Var(S)	4549.333		6524.769	468.493
	p-value (Two-tailed)	0.142		0.220	<0.0001
2. Total seasonal rainfall	STATISTICS	MK	Von Storch (1995) Prewhitening	Hamed and Rao (1998)	(Yue and Wang, 2004)
Main Rainy Season(MRS)rainfall	Kendall's tau	0.121	No serial correlation	0.121	0.121
	S	68.000		68.000	68.000
	Var(S)	4549.333		4549.333	1228.504
	p-value (Two-tailed)	0.321		0.321	0.056
Short Rainy Season(SRS)rainfall	Kendall's tau	0.063	No serial correlation	0.063	0.063
	S	35.000		35.000	35.000
	Var(S)	4546.333		4546.333	899.232
	p-value (Two-tailed)	0.614		0.614	0.257
Dry Season rainfall	Kendall's tau	0.072	No serial correlation	0.072	0.072
	S	40.000		40.000	40.000
	Var(S)	4545.333		4545.333	1339.120
	p-value (Two-tailed)	0.563		0.563	0.287
Wetet Abbay Station	STATISTICS	MK	Von Storch (1995) Prewhitening	Hamed and Rao (1998)	(Yue and Wang, 2004)
1. Total annual rainfall	Kendall's tau	0.064	No serial correlation	0.064	0.064
	S	36.000		36.000	36.000
	Var(S)	4549.333		6265.011	780.809
	p-value (Two-tailed)	0.604		0.658	0.210
2. Total seasonal rainfall	STATISTICS	MK	Von Storch (1995) Prewhitening	Hamed and Rao (1998)	(Yue and Wang, 2004)
Main Rainy Season(MRS)rainfall	Kendall's tau	-0.007	No serial correlation	-0.007	-0.007
	S	-4.000		-4.000	-4.000
	Var(S)	4549.333		3586.525	2007.283
	p-value (Two-tailed)	0.965		0.960	0.947
Short Rainy Season(SRS) rainfall	Kendall's tau	0.115	No serial correlation	0.115	0.115
	S	64.000		64.000	64.000
	Var(S)	4545.333		4545.333	697.614
	p-value (Two-tailed)	0.350		0.350	0.017
Dry Season rainfall	Kendall's tau	0.050	No serial correlation	0.050	0.050
	S	28.000		28.000	28.000
	Var(S)	4544.667		4544.667	1597.725
	p-value (Two-tailed)	0.689		0.689	0.499

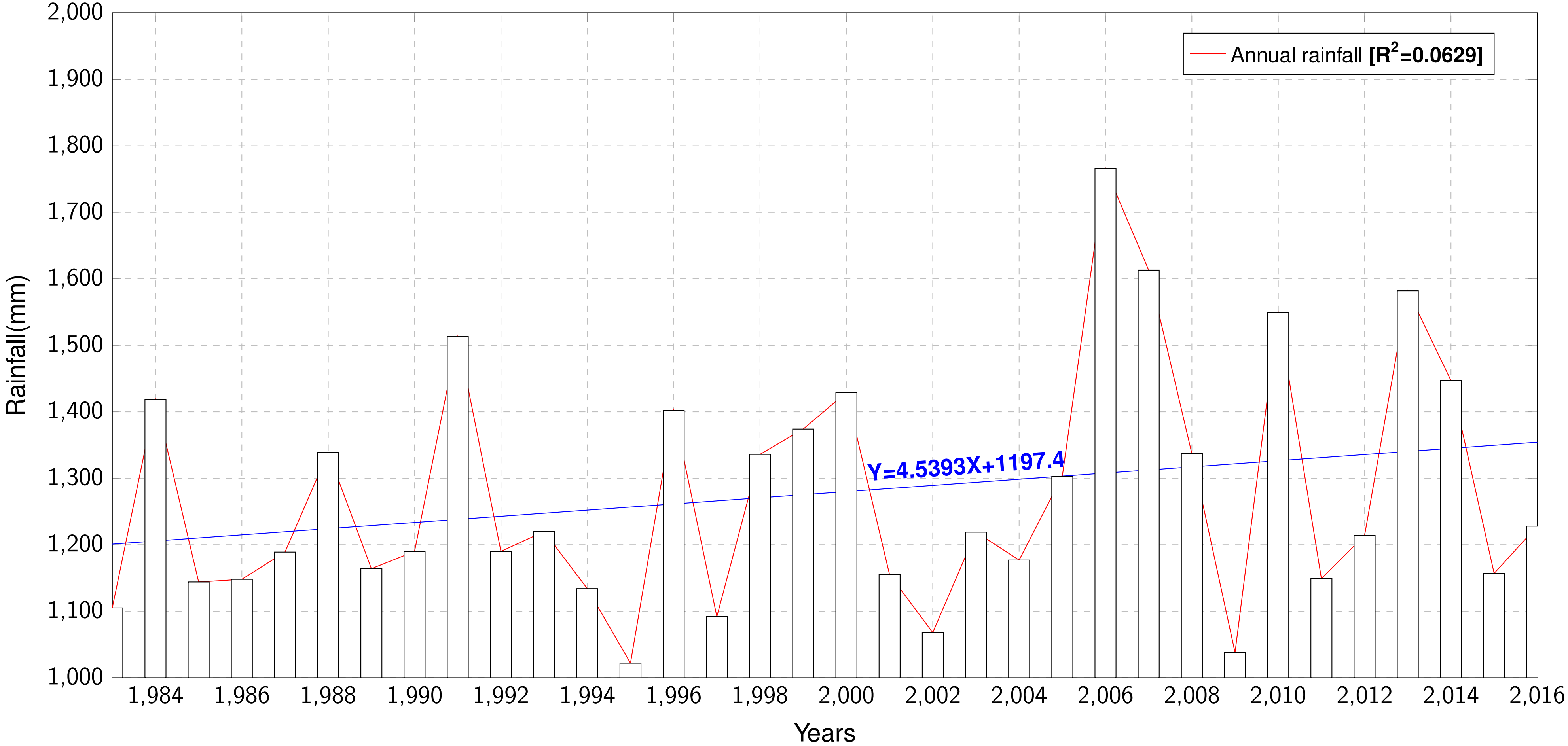


Figure 3.4: Total annual rainfall in Merawi

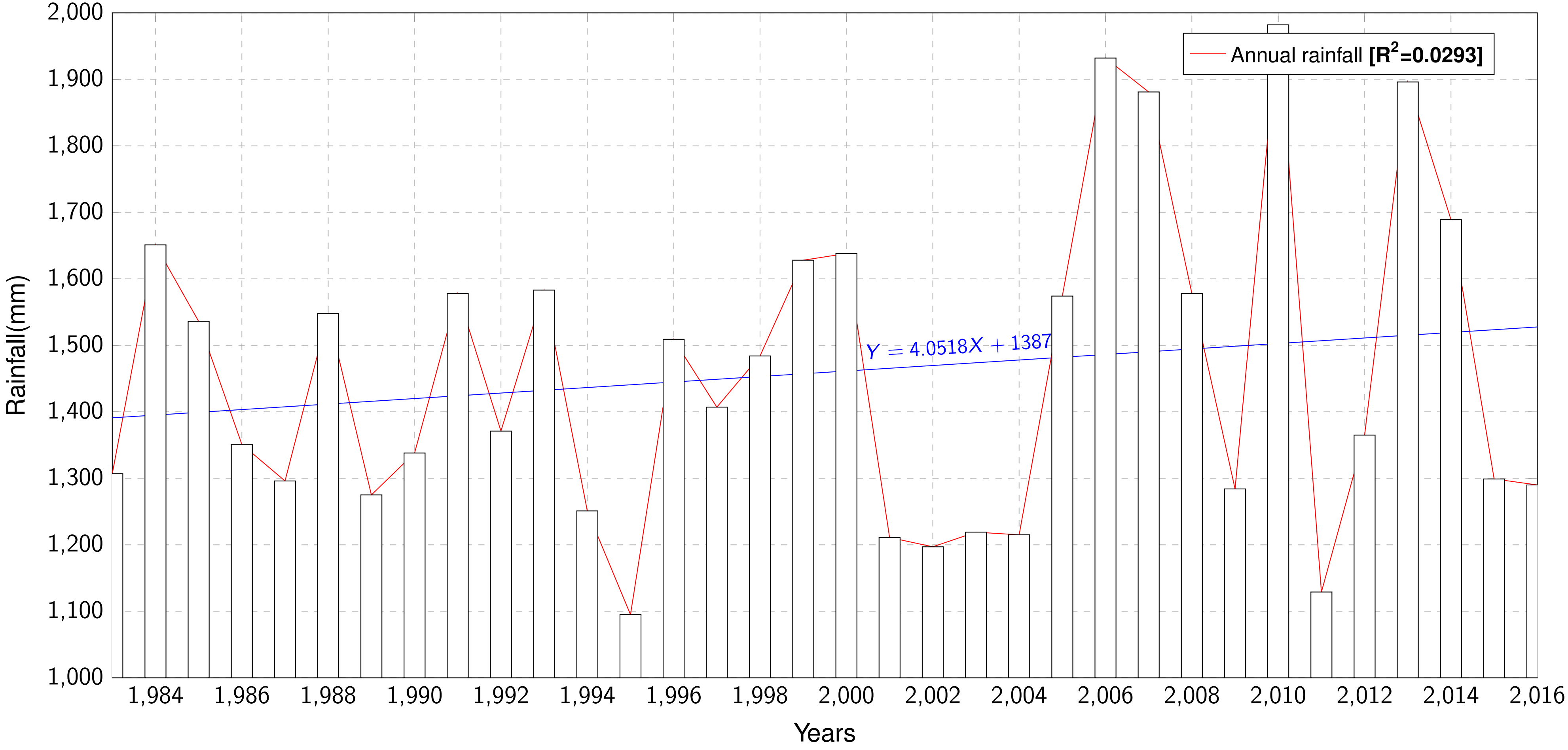


Figure 3.5: Total annual rainfall in Wetet Abbay

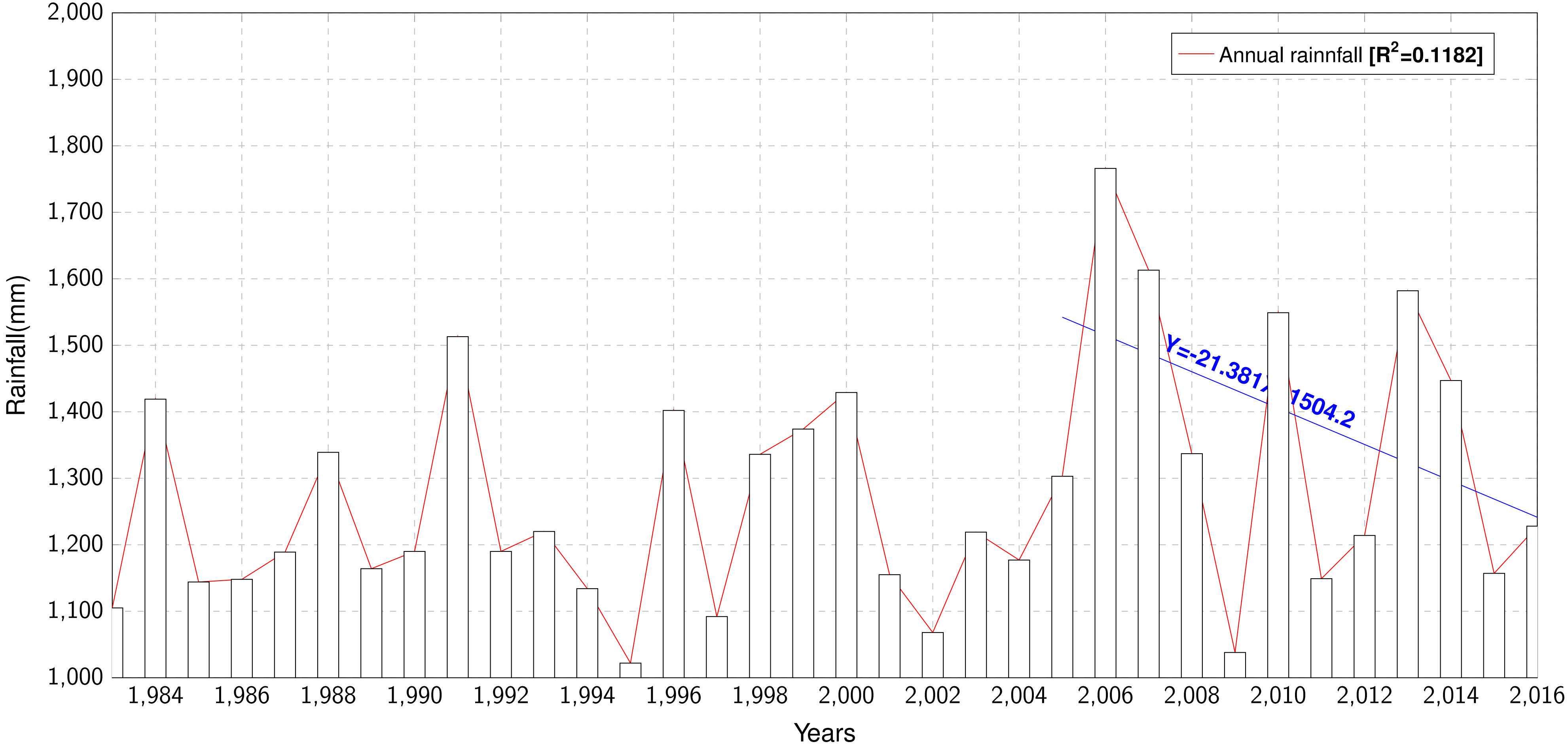


Figure 3.6: Total annual rainfall trend after Koga Dam construction and operation in Merawi

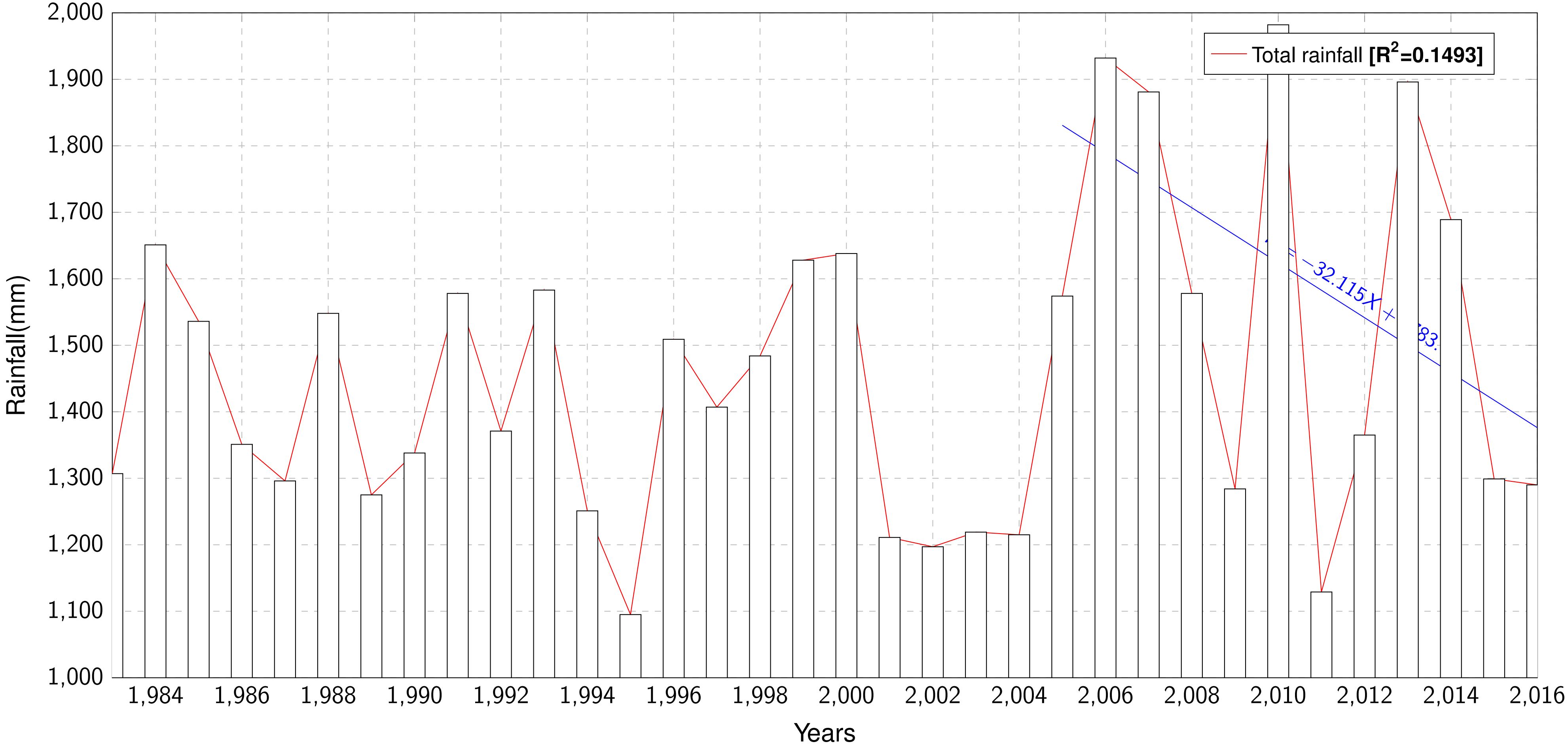


Figure 3.7: Total annual rainfall trend after Koga Dam construction and operation in Wetet Abbay

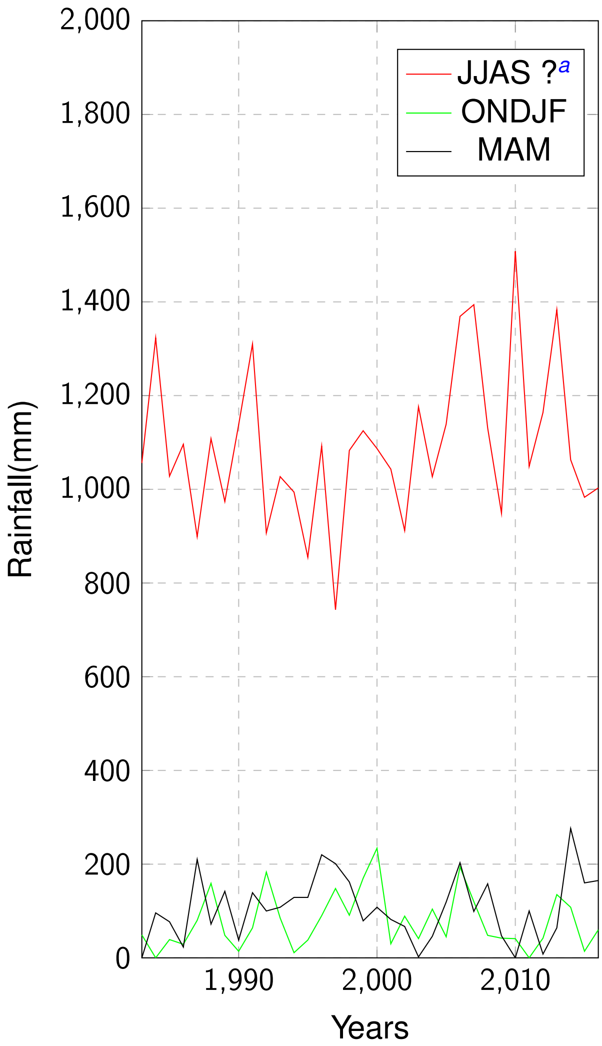
Table 3.5: Rainfall and temperature coefficient of variations (1983-2016)

Data	Annual	Main Rainy Season	Short Rainy Season	Dry Season
Temperature	Mean(SD)CV	Mean(SD)CV	Mean(SD)CV	Mean(SD)CV
Merawi	18.9(0.46)2.4%	18.5(0.63)3.4%	20.3(0.64)3.1%	18.4(0.57)3.1%
Wetet Abbay	19.3(0.53)2.7%	18.6(0.74)4%	21.5(0.75)3.5%	18.5(0.61)3.3%
Rainfall	Mean(SD)CV	Mean(SD)CV	Mean(SD)CV	Mean(SD)CV
Merawi	1276.8(180.3)14.1%	1092.3(166.1)15.2%	106.7(68.6)64.3%	77.8(59.8)76.9%
Wetet Abbay	1458.4(235.9)16.2%	1217.2(208.5)17%	144.4(77.7)53.8%	96.9(65)67%

(4) Climate variability

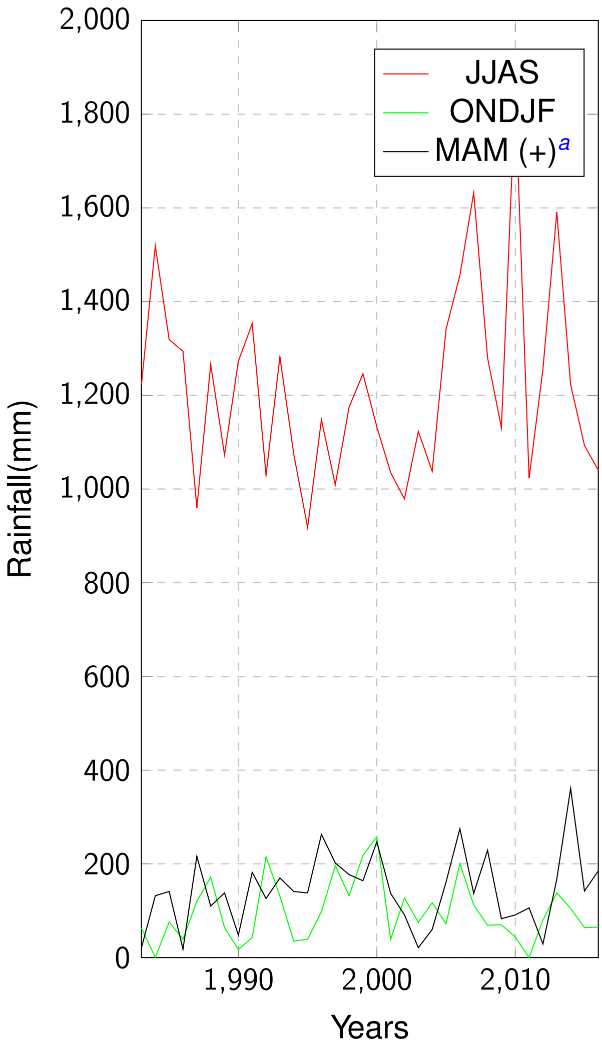
Climate variability in rainfall is another important climatic factor which influences agriculture. The amount and temporal distribution of rainfall is one of the most crucial factor for national crop production levels in Ethiopia (Mulat et.al , 2004). Climate variability, most importantly rainfall variability, affects crop production. For instance, a ten percent decline in seasonal rainfall from the long-term average caused a 4.4 percent decline in food production (Von Braun , 1991).

The study used the coefficient of variation in major climate variables, such as temperature and rainfall to examine the climate variability. As of the table in Table 3.5, less variability in the average annual temperature and in all the three seasons were observed in both stations. The temperature variability in the two stations, based on CV, was <20%. Moreover, variability in the average annual temperature (CV =2.4 %), the Main Rainy Season (CV =3.4 %), Short Rainy Season (CV =3.1 %) and Dry Season (CV =3.1%) were lower in the Merawi station than in Wetet Abbay station. These results indicate a more consistent and predictable temperature pattern. Rainfall variability was also found to be less in terms of total annual rainfall in the two stations. The total annual rainfall variability was 14.1% at Merawi and 16.2% at Wetet Abbay station. However, there was an inter-annual variability in seasonal rainfall in the two stations. High rainfall variability was found in Short Rainy Season (SRS)(CV=64.3%) and Dry Season (CV=76.9%), whereas less variability in Main Rainy Season (MRS) (CV=15.2%) in Merawi station. More variability in Short Rainy Season and Dry Season rainfall than the Main Rainy Season rainfall in both stations was disclosed. The implications of the coefficient of variation result in Merawi station mean rainfall is less reliable, inconsistent and unpredictable during the short rainy and dry season while much more reliable in main rainy season.



(a) Total seasonal rainfall in Merawi

[a]Statistically insignificant increasing trend is detected in diffrent statistical estimation techniques



(b) Total seasonal rainfall in Wetet Abbay

[a]A statisticallly siginficant trend is detected only during Short Rainy Season (SRS) when (Yue and Wang, 2004) autocorrelation method was considered

Figure 3.8: Seasonal rainfall data trend analysis in Merawi and Wetet Abbay

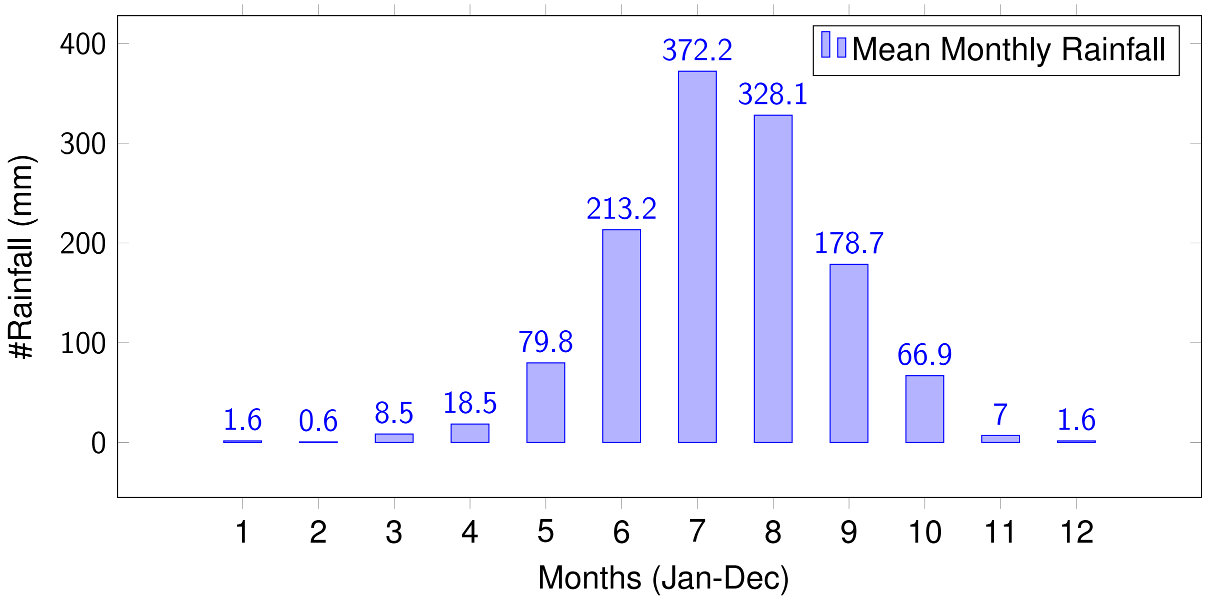


Figure 3.9: Rainfall Distribution in Merawi Station

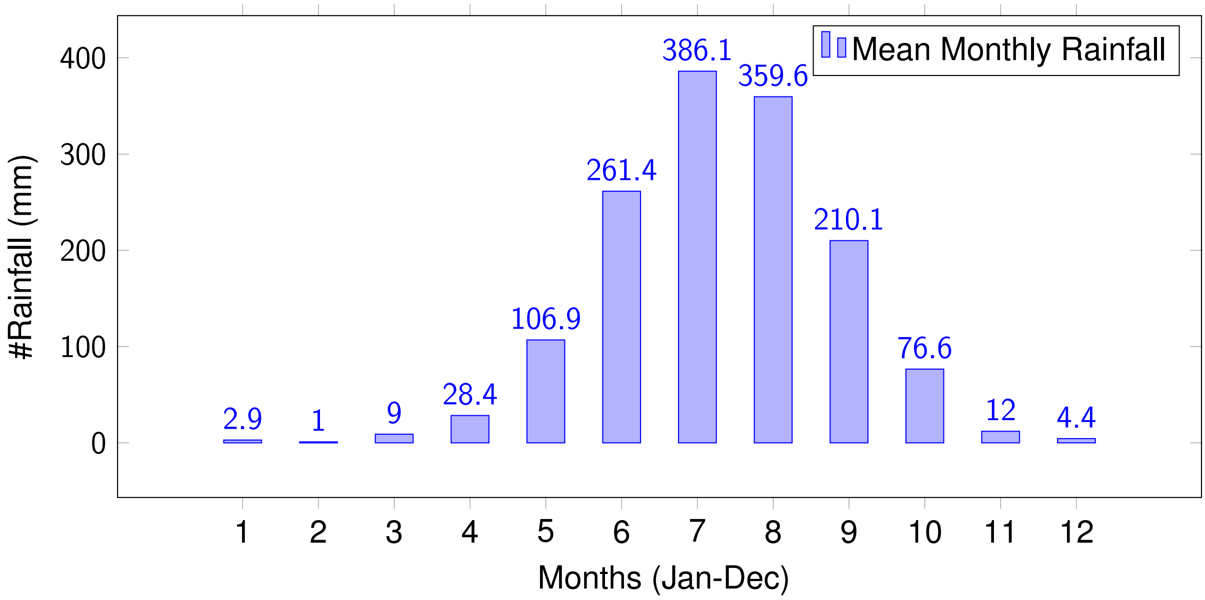


Figure 3.10: Rainfall Distribution in Wetet Abbay Station

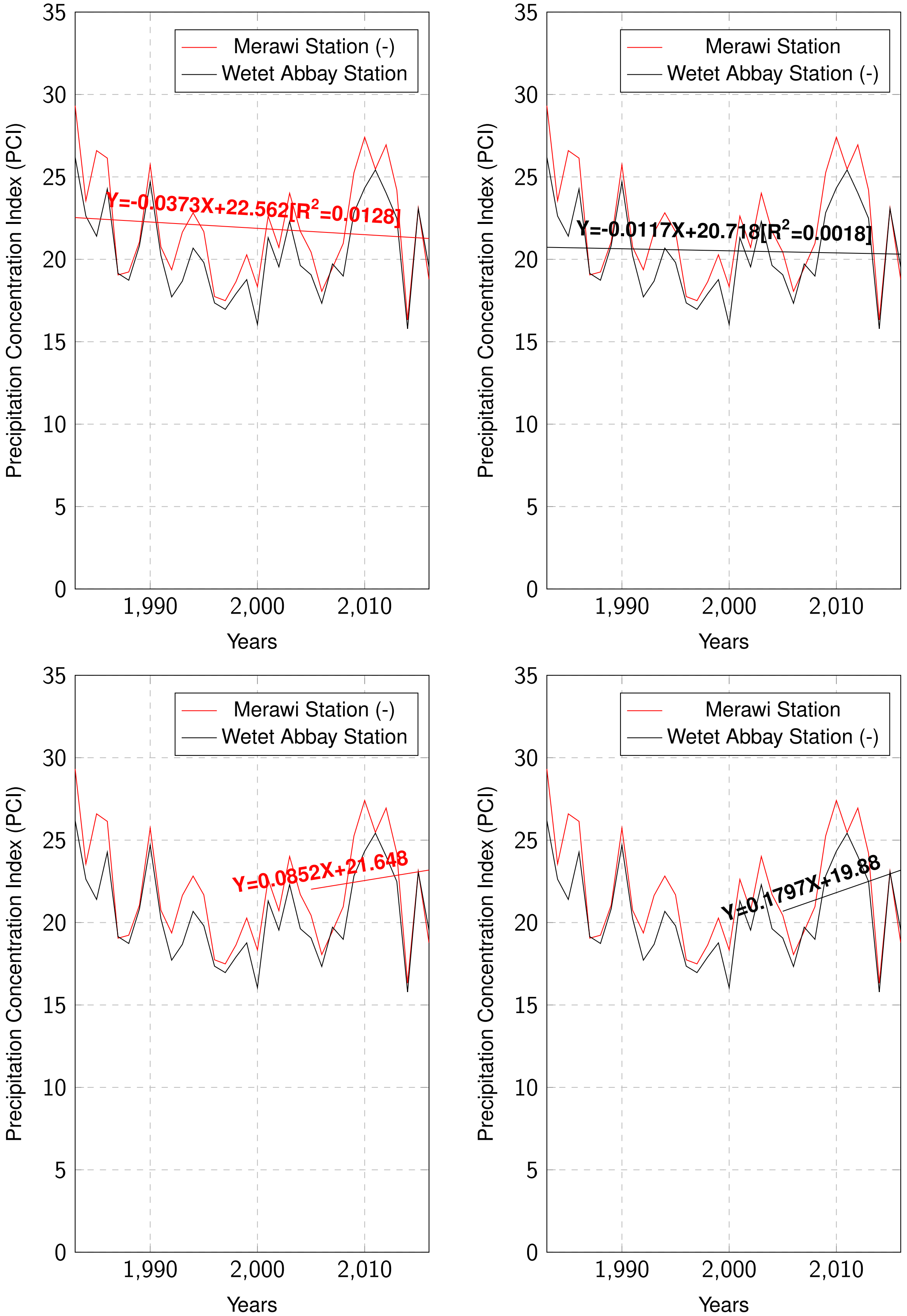


Figure 3.11: PCI in the two Stations

Table 3.6: Runoff coefficient of variations (1959-2012)

Data	Annual	Main Rainy Season	Short Rainy Season	Dry Season
Total runoff (*millionm*^{3})	Mean(SD)CV	Mean(SD)CV	Mean(SD)CV	Mean(SD)CV
Koga Nr./@ Merawi	157(73.2)46.6%	114.3(60.8)53%	7.3(2.5)34%	35.4(15.4)43.5%
Gilgel Abbay Nr. Merawi	1723.4(225.7)13.1%	1398.5(180.4)12.9%	44.5(36.8)82.7%	280.5(97.9)34.9%

3.3.1.2. Hydrological data trend analysis

Runoff is a measure of the amount of water that flows over the land surface and into rivers. The graph of total annual runoff and seasonal runoff at Koga Nr./@ Merawi and Gilgel Abbay Nr. Merawi is shown in Figure 3.12 and their respective Kendall's tau, MK statistics (S), Var(S) & p-values for runoff statistics are given in Table 3.7. The total runoff data were free from serial correlation problem in the two watersheds. The total runoff, runoff trends in the Main Rainy Season and Dry Season showed a statistically insignificant trends when considering the different autocorrelation methods. During Short Rainy Season, a rising trend was observed only when Yue and Wang (2004) autocorrelation method at Koga Nr./@ Merawi and when the Original MK at Gilgel Abbay Nr. Merawi were used. The Short Rainy Season runoff trend in the Koga Nr./@ Merawi was less stronger than Gilgel Abbay trend (See S statistics in Table 3.7). The Short Rainy Season trend result test using the original MK at Gilgel Abbay Nr. Merawi can not be a true trend. There was no significant trend after the Prewhitening procedure; when the autocorrelation methods of Hamed and Rao (1998) and Yue and Wang (2004) were taken into account.

The comparison of trend lines for runoff before and after the scheme reveals a decline in runoff after the dam in Koga watershed over an eight-year period, while runoff in Gilgel Abbay was rising. Each year, the change was -12.2 rate in Koga watershed during post-dam period (See Figure 3.12c and 3.12d). The main rainy season is the major source of runoff in Koga river, accounted to be 72% of the annual runoff. So that, the Koga dam has to accumulate enough water during this time for a use in dry seasons (ADF , 2001). However, the trend during main rainy season was statistically insignificant. There was no sufficient data to believe an increase in rainfall and runoff during this season to discharge it in the dry season. The rainfall and runoff trends during the dry season by itself are also statistically insignificant.

The runoff concentration within few months, most importantly during main rainy season, coupled with high runoff variability in Koga scheme make things complicated. It endangers future water demand and supply balance for irrigation activities. Runoff is highly variable in Koga Nr/@. Merawi both at annual and seasonal levels. It was highly variable exceeding 30%. The runoff variability at Koga Nr/@. Merawi were mostly higher than at Gilgel Abbay Nr. Merawi. (See Table 3.6). The inter-annual variability of runoff is an important constraint on reservoir yield and storage size for water resource management in Koga watershed. Improving our understanding of the extent of inter-annual runoff variability, as well as how this may change in the future, is critical to achieving long-term robust water and watershed management.

Table 3.7: Mann-Kendall trend Test results/ Total annual & total seasonal runoff

Koga Nr./@ Merawi Station	STATISTICS	MK	Von Storch (1995) Prewhitening	Hamed and Rao (1998)	(Yue and Wang, 2004)
1. Total annual runoff	Kendall's tau	0.034	No serial correlation	0.034	0.034
	S	49.000		49.000	49.000
	Var(S)	17967.000		3616.840	4088.872
	p-value (Two-tailed)	0.720		0.425	0.453
2. Total seasonal runoff	STATISTICS	MK	Von Storch (1995) Prewhitening	Hamed and Rao (1998)	(Yue and Wang, 2004)
Main Rainy Season	Kendall's tau	0.027	No serial correlation	0.027	0.027
	S	39.000		39.000	39.000
	Var(S)	17967.000		4689.912	3018.560
	p-value (Two-tailed)	0.777		0.579	0.489
Short Rainy Season	Kendall's tau	0.156	No serial correlation	0.156	0.156
	S	223.000		223.000	223.000
	Var(S)	17967.000		13964.307	5073.240
	p-value (Two-tailed)	0.098		0.060	0.002
Dry Season	Kendall's tau	-0.055	-0.087	-0.055	-0.055
	S	-79.000	-125.000	-79.000	-79.000
	Var(S)	17967.000	17967.000	45747.522	11200.758
	p-value (Two-tailed)	0.561	0.355	0.715	0.461

Gilgel Abbay Nr. Merawi Station	STATISTICS	MK	Von Storch (1995) Prewhitening	Hamed and Rao (1998)	(Yue and Wang, 2004)
1. Total annual runoff	Kendall's tau	0.033	No serial correlation	0.033	0.033
	S	47.000		47.000	47.000
	Var(S)	17967.000		17967.000	1245.021
	p-value (Two-tailed)	0.731		0.731	0.192
2. Total seasonal runoff	STATISTICS	MK	Von Storch (1995) Prewhitening	Hamed and Rao (1998)	(Yue and Wang, 2004)
Main Rainy Season	Kendall's tau	-0.069	No serial correlation	-0.069	-0.069
	S	-99.000		-99.000	-99.000
	Var(S)	17967.000		17967.000	3208.905
	p-value (Two-tailed)	0.465		0.465	0.084
Short Rainy Season	Kendall's tau	0.205	0.017	0.205	0.205
	S	293.000	25.000	293.000	293.000
	Var(S)	17967.000	17967.000	32303.339	35874.259
	p-value (Two-tailed)	0.029	0.858	0.104	0.123
Dry Season	Kendall's tau	0.023	0.024	0.023	0.023
	S	33.000	35.000	33.000	33.000
	Var(S)	17967.000	17967.000	28971.960	9452.644
	p-value (Two-tailed)	0.811	0.800	0.851	0.742

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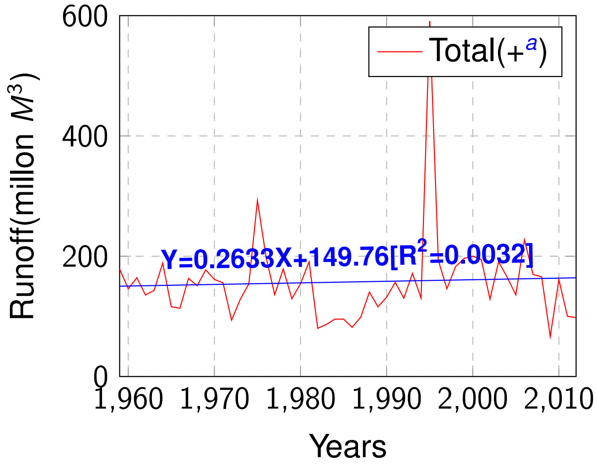
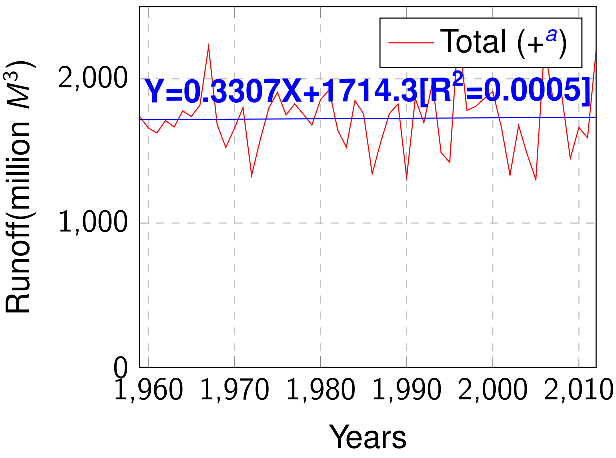


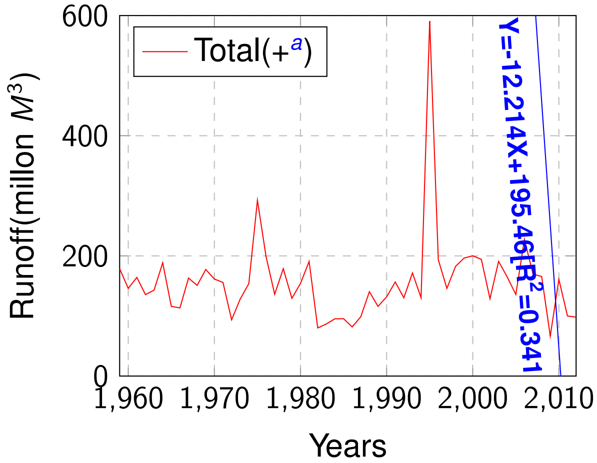
(a) Total annual runoff in Koga Nr./ @ Merawi

[a]Statistically significant increasing trend is detected when Yue and Wang (2004) autocorrelation method was considered



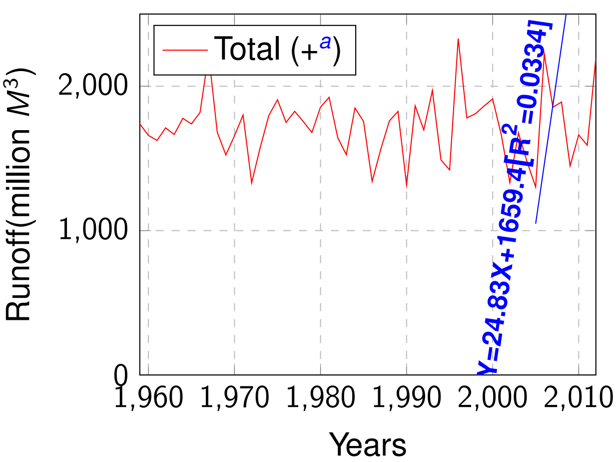
(b) Total annual runoff in Gilgel Abbay Nr. Merawi

[a]Statistically insignificant increasing trend is detected in diffrent statistical estimation techniques



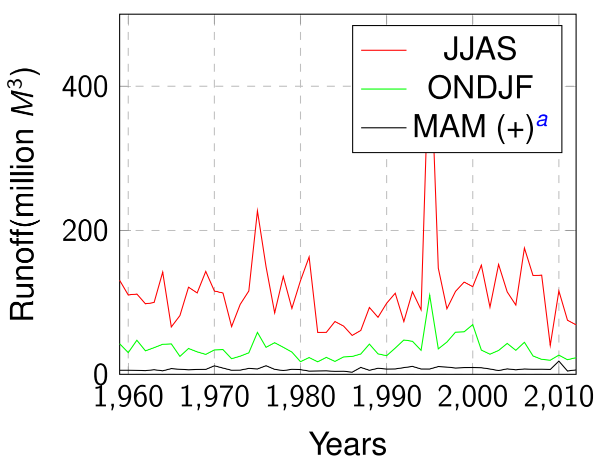
(c) Trend line after Koga dam in Koga Nr./ @ Merawi

[a]Statistically significant increasing trend is detected when Yue and Wang (2004) autocorrelation method was considered



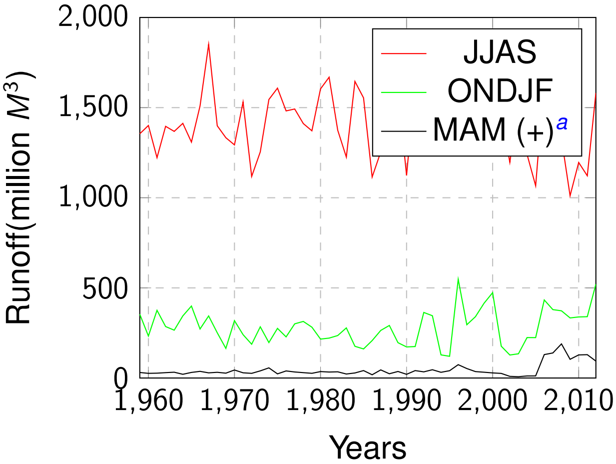
(d) Trend line after Koga dam in Gilgel Abbay Nr. Merawi

[a]Statistically insignificant increasing trend is detected in diffrent statistical estimation techniques



(e) Total seasonal runoff in Koga Nr./@ Merawi

[a]Statistically significant increasing trend is detected when Yue and Wang (2004) is considered



(f) Total seasonal runoff in Gilgel Abbay Nr. Merawi

[a]Statistically significant increasing trend is detected when the Orgional MK is considered

Figure 3.12: Runoff data trend analysis in Koga Nr./@ Merawi and Gilgel Abbay Nr. Merawi

3.3.2 Hydro-climatic sensitivity analysis

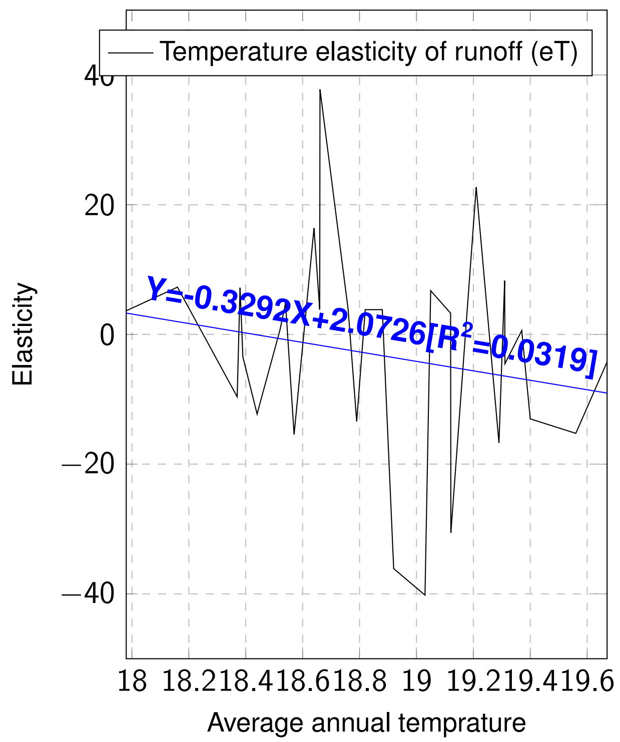
Temperature and precipitation trend affect the availability of water in irrigation agriculture by affecting both demand and supply of water for plant growth. The degree of responsiveness of runoff, a measure of water availability for agriculture, to climate variables, such as temperature and precipitation is one area of focus for water resource managers, researchers, and stakeholders. Various studies analyzed the sensitivity of hydrological variables to climatic variables and land use changes. However, research how forest cover affects runoff still in progress (Andreassian, 2004); the complex and multifaceted nature of the response of watersheds to forest cover changes (Calder, 2005) and it is difficult to assess the impact of change of the forest cover (Bloschl et.al., 2007). There was no changes in the flow regime between 1960 and 2002 in Koga watershed, despite the reduction in forest area. This was consistent with the perception of farmers (Gebrehiwot et al. , 2010). Therefore, the study examines the degree of sensitivity of runoff to changes in two climate factors : temperature and rainfall. A small long-term changes in these climate factors can have significant impacts on the hydrological cycle, particularly at the basin level. The elasticity measures show how sensitive the total annual runoff are to a 1 % change in total annual rainfall at constant average annual temperature or average annual temperature at constant total annual rainfall (see Figure 3.13].

The Hydrologic sensitivity to temperature and rainfall in Koga watershed is shown in Figure 3.13a and Figure 3.13b, while in Gilgel Abbay watershed, it is shown in 3.13c and Figure 3.13d. Temperature elasticity of runoff (eT) ranges from 0.602976 to -40.193 in Koga watershed. The nonparametric estimate of eT is -1.43367 in Koga while -1.44365 in Gilgel Abbay watershed. Temperature had adverse effect on the runoff water availability for agriculture during the study period. A 1 percent increase in temperature leads to, an average, a 1.43367 percent decline in runoff. The implication is that when temperature increases, the rate of evaporation from the open water surface of the reservoir also increases and this may result in the reservoir not being able to supply enough water due to the decrease in the active storage volume. The trend line result shows a decline elasticity as temperature rises. For each 1 unit increase in temperature, elasticity declines by 0.3292 in Koga while by 0.0054 in Gilgel Abbay watersheds. While rainfall elasticity of runoff (eR) ranges from -0.05476 to -14.1574, the nonparametric estimate of eR is 1.438282 in Koga while 0.769782 in Gilgel Abbay. A 1 percent change in rainfall leads to a 1.438282 percent change in runoff. The trend line of eR, however, showed a decline elasticity as rainfall rises. For each 1 unit increase in rainfall elasticity declines by 0.0019 in Koga watershed. This is consistent to the finding in arid and semiarid regions of United States, that the sensitivity of runoff to precipitation is greater for a decrease in precipitation than for an increase in precipitation (Tang et al. , 2019). The soil's ability to absorb water plays a significant role in this sensitivity. When precipitation decreases, the soil has less capacity to retain moisture, resulting in a greater proportion of water becoming runoff. However, when precipitation increases, the soil can absorb more water first, which decreases the immediate increase in runoff. This argument needs more research in the area considering the soil type and other determining variables.

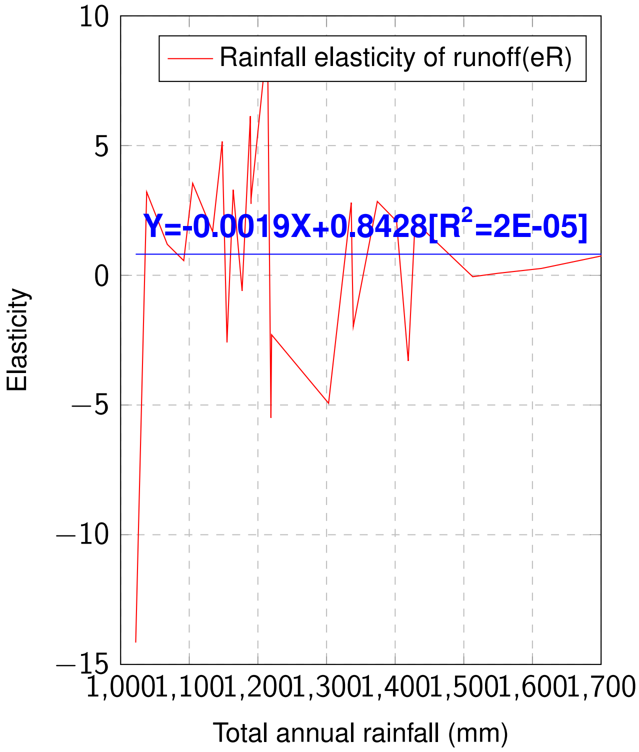
The runoff hydrological data was influenced by the two climatic variables. However, which climate factor is the dominant one is the interest of decision makers. The graphical analysis of the dominant climate factor, along with the trend line before and after the Koga dam construction and operation in runoff elasticities, is shown in Figure 3.14 (see Figure 3.14c, 3.14d, 3.14a and 3.14b). The temperature elasticities of runoff (eT) lie mostly above (with positive elasticities) and below (with negative elasticities) the rainfall elasticities of runoff (eR) in the two watersheds [See Figure 3.14 and Figure 3.15 for more comparison between two watersheds]. The result confirms that temperature is the most influential climate factor affecting runoff than rainfall. It was the dominant factor affecting runoff. The tend lines for the two elasticities also confirmed that each year eT increased by 0.0718 while eR decreased by 0.0045. Moreover, the trend lines after Koga dam construction and operation is more steeper with the rate of change of 0.3594 and 1.3658 for eT and eR respectively. A similar result was also found that watersheds such as Anger, Beles, Birr, Guder, Neshi, Muger are more sensitive to rainfall changes compared to the other watersheds, and Chacha, Koga, Sechi, Teme are more sensitive to potential evapotranspiration (Haileyesus , 2011). Potential evapotranspiration, in turn directly linked to a temperature increase. In contrast to the findings of this study, Abdo (2008) found that Gilgel Abbay watershed was more sensitive to rainfall than to temperature changes .

The comparison study also focused on identifying the more sensitive watershed to climate factors from the two watersheds. The Koga watershed is more sensitive than the Gilgel Abbay watershed on two elasticity measures i.e. temperature elasticity of runoff and rainfall elasticity of runoff (See Figure 3.16). The temperature and rainfall elasticities of runoff (eT and eR) in Koga watershed lie mostly above (with positive elasticities) and below (with negative elasticities) the elasticities in Gilgel Abbay watershed. Other research also found that the Koga watershed is more sensitive than the Gilgel Abbay watershed (Haileyesus , 2011). The paper ranked the ten most sensitive river watersheds down to the least sensitive such as Chacha, Teme, Neshi, Muger, Koga, Birr, Gilgel, Belese, Guder, Little Anger and Sechi. The Koga and Gilgel Abbay watersheds ranked fifth and seventh, respectively.

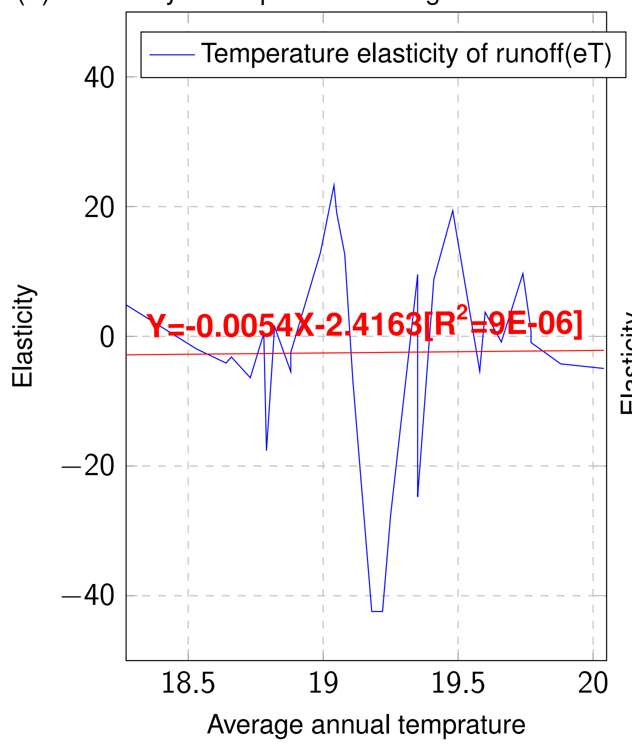
The situation in the Koga watershed is determined by looking at the trends and variabilities in temperature and rainfall, hydroclimatic conditions such as hydro-climatic sensitivities, along with trendline results before and after Koga dam. A rise in annual temperature at the Merawi station, a negative temperature elasticity of runoff with a more than proportionate effect, lack of sufficient evidence to believe that rainfall and runoff have a positive trends, high variability in runoff, and a more sensitive watershed than the nearby watershed, all of these situations and the hydroclimatic conditions, combined with management inefficiency, make the sustainability of the Kog watershed difficult. All of these forces put the reservoir's ability to supply water for irrigation demand during the dry season at risk.



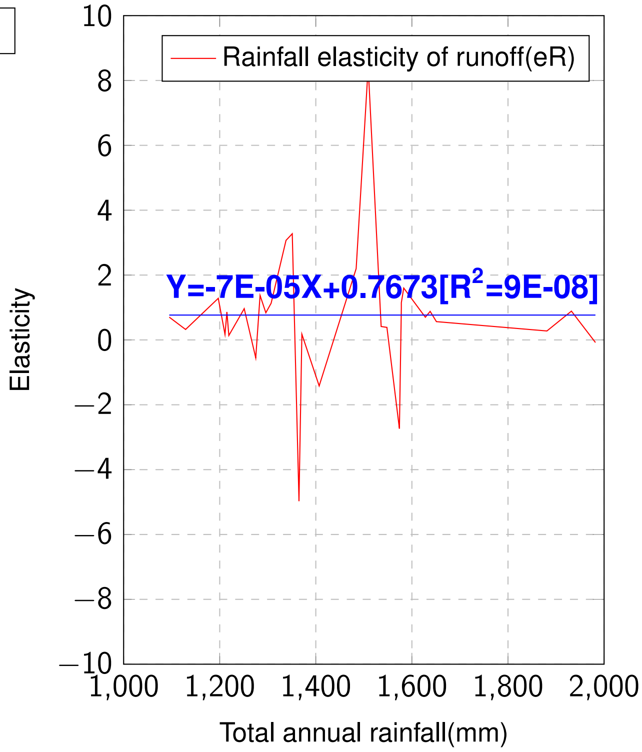
(a) Sensitivity to temperature in Koga Watershed



(b) Sensitivity to rainfall in Koga Watershed

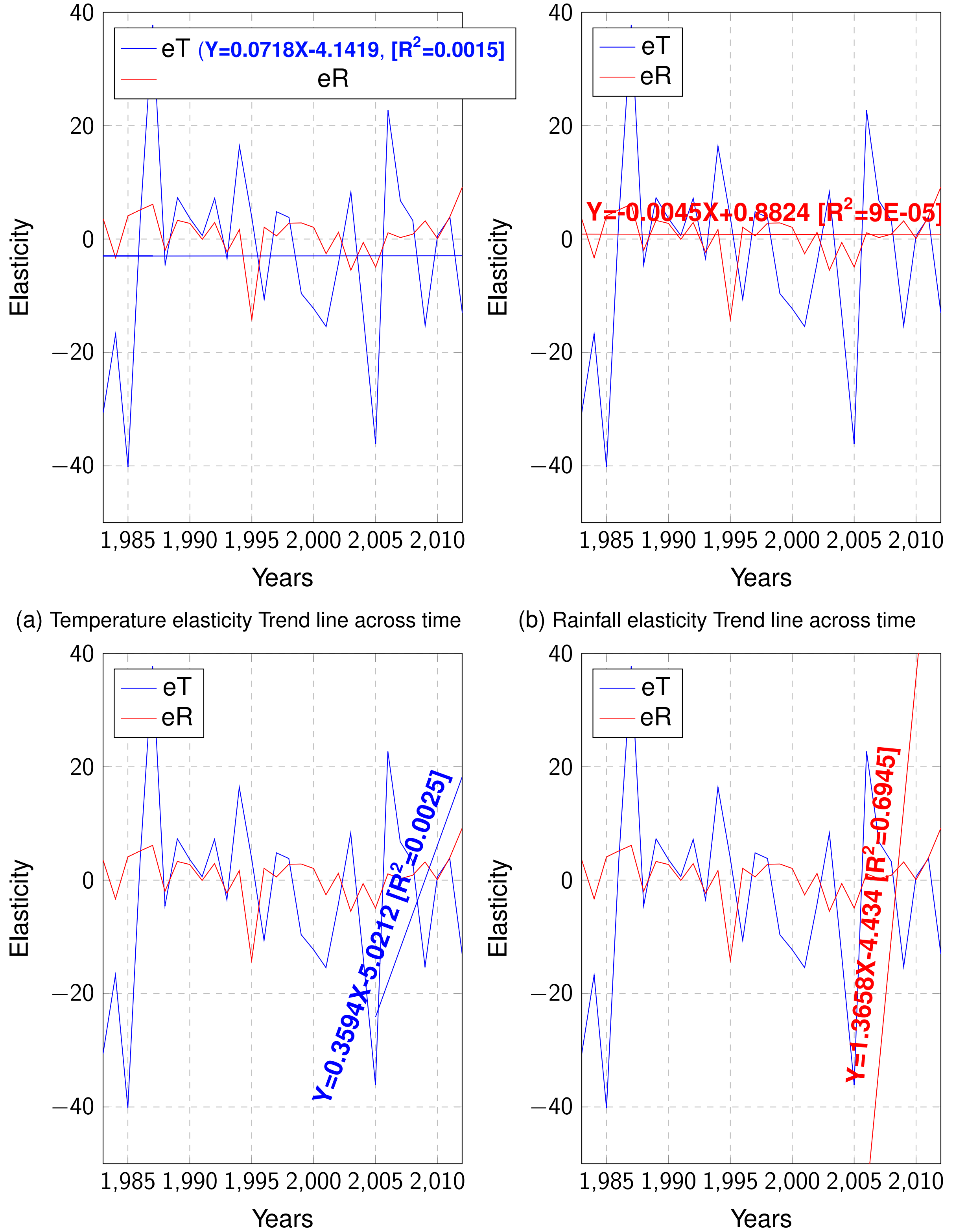


(c) Sensitivity to temperature in Gilgel Abbay Watershed



(d) Sensitivity to rainfall in Gilgel Abbay Watershed

Figure 3.13: Hydrologic sensitivity to climate factors in two Watersheds



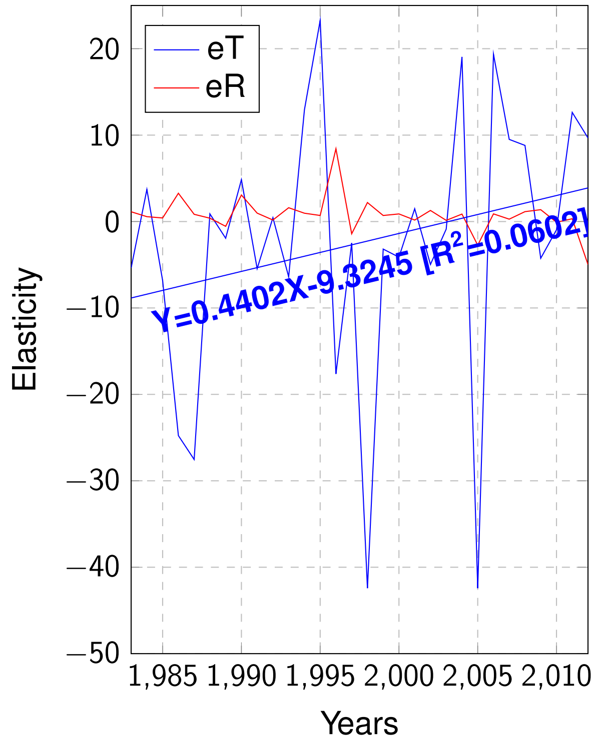
(a) Temperature elasticity Trend line across time

(b) Rainfall elasticity Trend line across time

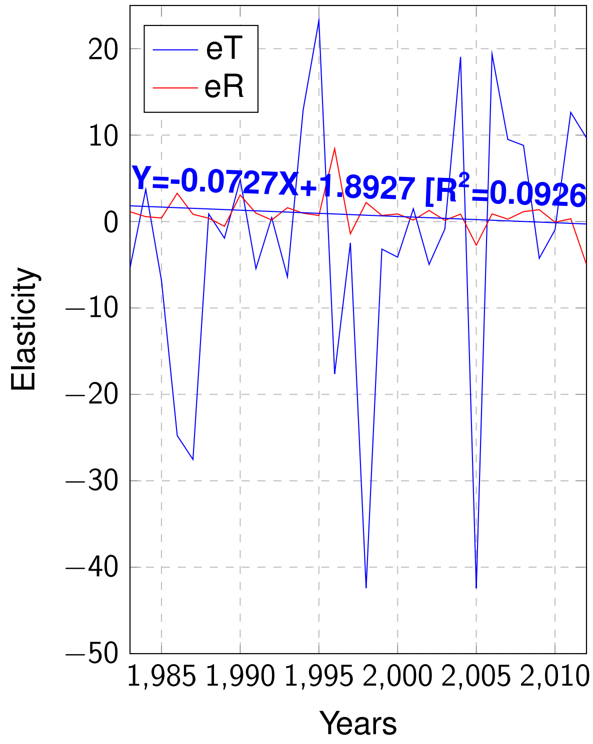
(c) Temperature elasticity trend line after dam construction and operation

(d) Rainfall elasticity trend line after dam construction and operation

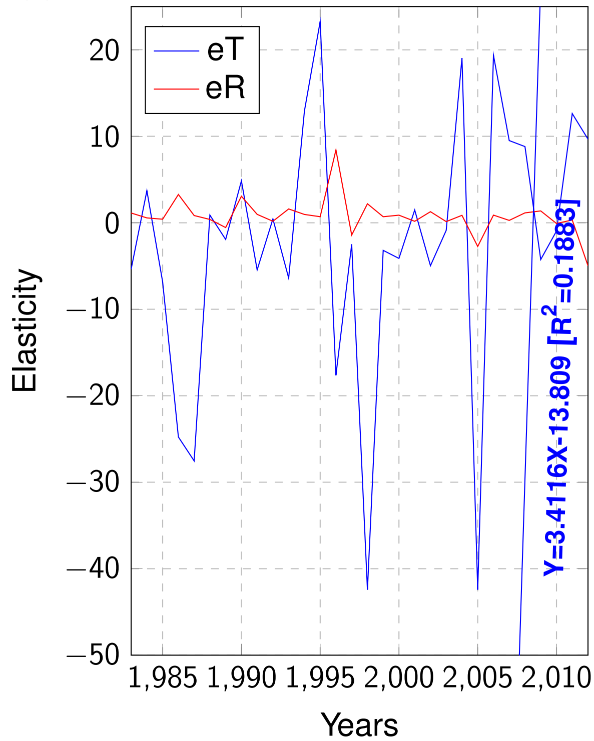
Figure 3.14: Dominant factor affecting runoff in Koga Watershed



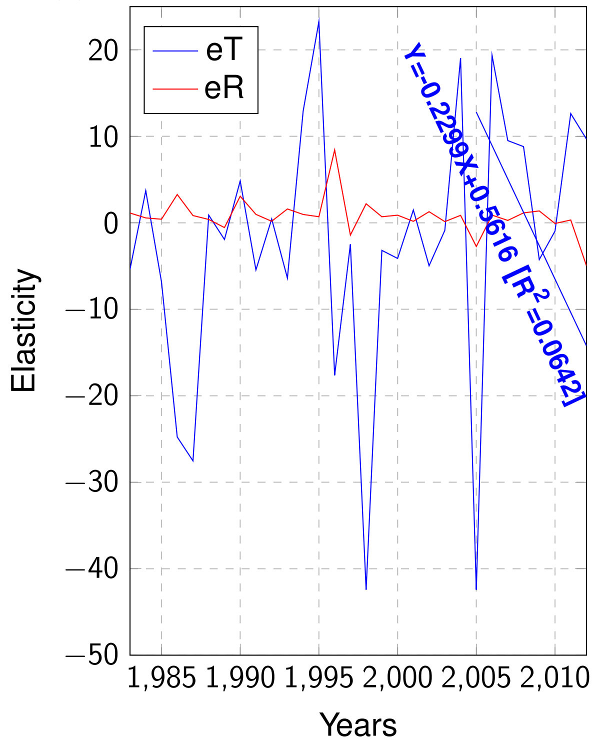
(a) Temperature elasticity Trend line across time



(b) Rainfall elasticity trend line across time

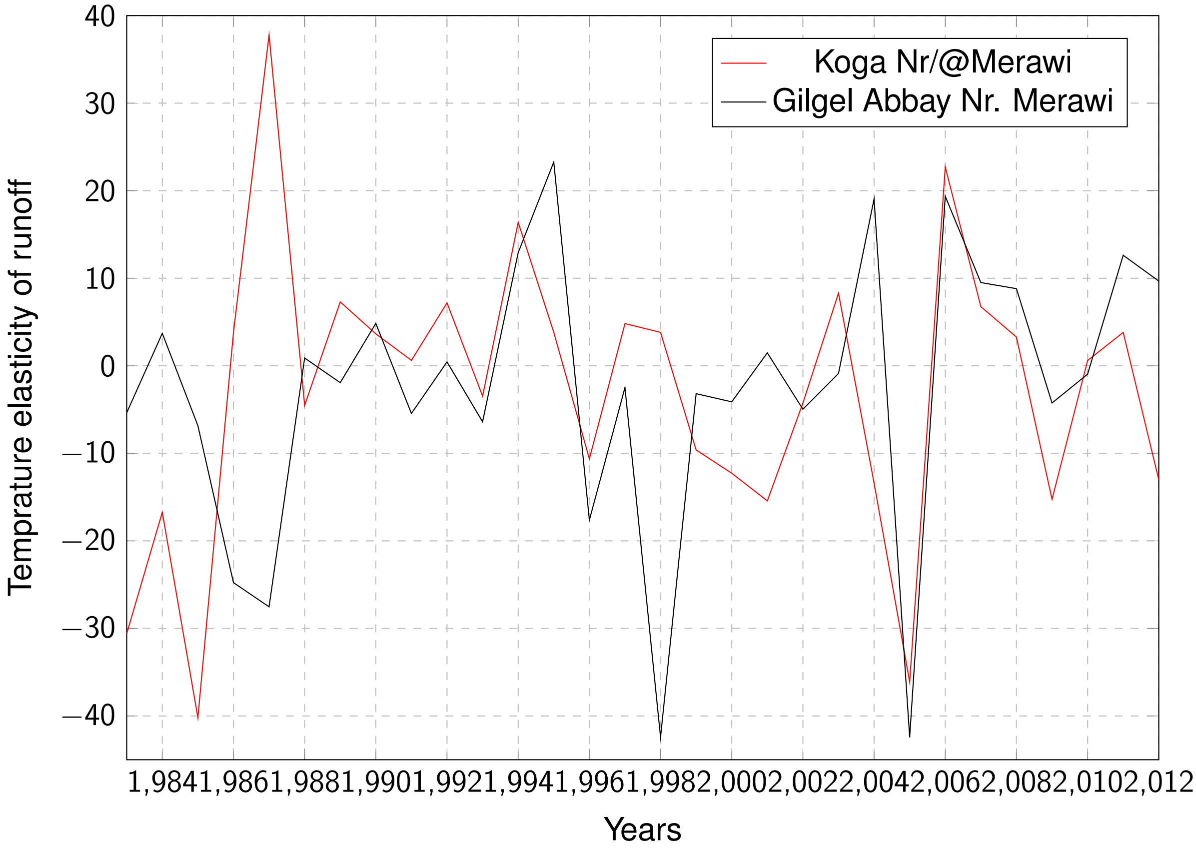


(c) Temperature elasticity trend line after dam construction and operation

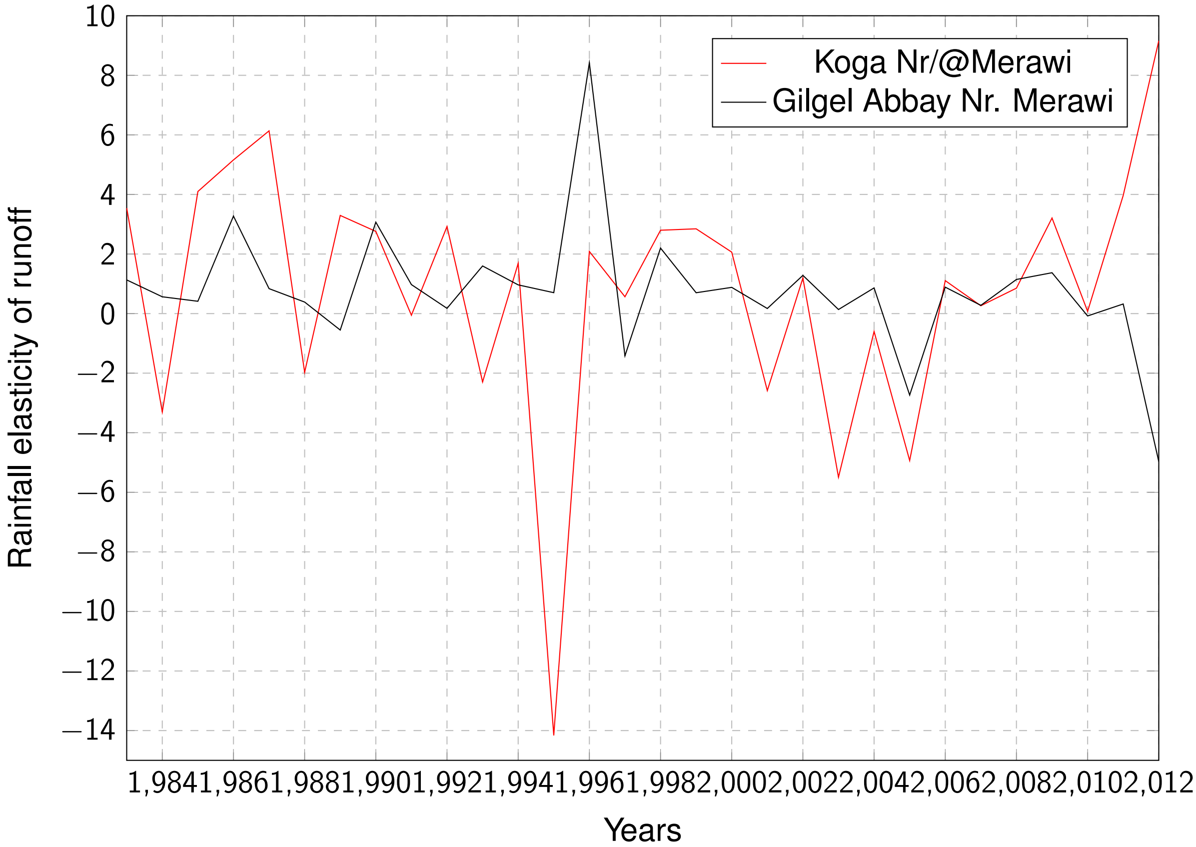


(d) Rainfall elasticity trend line after dam construction and operation

Figure 3.15: Dominant factor affecting runoff Gilgel Abbay Watershed



(a) Runoff sensitivity to temperature



(b) Runoff sensitivity to rainfall

Figure 3.16: Comparison of runoff sensitivity to climate of two watersheds

3.4 Conclusion and policy implication

The study investigated the hydro-climatic trend, variability, and sensitivity of runoff to climate influences, with a particular emphasis on the water availability for agriculture. Temperature trends in Merawi station were consistent with climate change trends and patterns in Wetet Abbay station. Both stations showed an increase trend pattern in temperature at annual scale and seasonal levels. In Merawi, where the Koga scheme is located, the trend was just as strong compared to Wetet Abbay. The rainfall distribution at both stations was a unimodal pattern. Rainfall was highly concentrated in main rainy season (June- September), which accounts more than 80% in the two stations. The study highlights high runoff variability exceeding 30% in Koga watershed, and in most cases it is highly variable than the Gilgel Abbay Nr. Merawi. The sensitivity analysis confirmed that the runoff hydrological data was influenced by the two climatic variables. Temperature was the most influential factor affecting runoff, being dominant factor affecting runoff than rainfall in most cases. The Koga watershed is more sensitive than the Gilgel Abbay in both elasticities measures. The situation in the Koga Watershed is determined by examining temperature, rainfall and runoff trends, whether the majority of hydro-climatic elasticities were positive or negative along with trendlines in elasticities during the pre-dam and post-dam period. A rise in annual temperature at the Merawi station, temperature elasticity of runoff that is mostly negative in Koga Nr./@ Merawi, temperature is dominant, while insignificant trend in total rainfall and total runoff, all of these situations and hydroclimatic conditions, make the Koga watershed's sustainability difficult. All of these factors jeopardize the reservoir's ability to meet irrigation demand during the dry season. The study provides evidence that climate trends can have undesired negative effects on water availability. It is crucial for farmers, especially those in highly dependent groups, to be aware of these potential consequences and to take steps to manage the water.

CHAPTER 4

SUSTAINABILITY ANALYSIS OF WATER MANAGEMENT, WITH EMPHASIS ON INTEGRATED WATER RESOURCE MANAGEMENT (IWRM) AND ENVIRONMENTAL MANAGEMENT PLAN (EMP)

Abstract

The study focused on investigating how Integrated Water Resource Management (IWRM) and Environmental Impact Analysis (EIA) recommended measures are supporting sustainable development. A five-member analysis group was established to ensure objectivity and consensus in addressing the Sustainable Development Analysis Grid (GADD), containing 166 goals divided into 40 themes and six dimensions, and the Multi-Criteria Analysis (MCA) through mDSS software. The GADD is designed to analyze the current condition and future priority areas of IWRM in terms of its support to sustainable development. Even though most IWRM principles were implemented with some verifiable indicators, the majority of sustainable development themes (26 out of 40) were poorly considered. More than seventy-one percent of goals were identified for improvements, casting doubt on IWRM's success in sustainable development. Most sustainable development goals must be handled promptly, if not immediately, so that the office and stakeholders should take corrective actions. Based on the MCA, the EIA-recommended measures suggested in EMP are likely to succeed in sustainable development when synergy in sustainable development was taken in to account, but balancing the three sustainability pillars remains a challenge. The most favored adaptation and mitigation measures are training and extension courses, and planting forest seedlings, while training and cooperative organization striking a good balance of the three pillars. However, planting forest seedlings doesn't fully comprehend as a sustainable solution because of the negative consequences of eucalyptus plantations on environment and a threat to food security, as it is being planted in fertile lands. The academia should match trade off and synergy issues with both immediate and long-term goals, and determine the suitable sustainable development framework of whether a triple bottom line or wedding cake framework should be adopted given the current environmental situations.

Keywords

mDSS; Sustainability; Multi Criteria Analysis; Triple bottom line and Wedding cake framework

4.1 Introduction

A country's policies, strategies, programs or projects and plan are crucial in achieving sustainable development. There are several policies and programs in place to maintain sustainability, such as Integrated Water Resource Management (IWRM) and Environmental Management Plan (EMP). These plans are the key tool for ensuring sustainable development and minimizing environmental risk. Every country devised its plans in order to accomplish its desired development objectives. To achieve these objectives, proper execution of these plans is required to achieve various needs in water sector. Water scarcity issues are becoming more common as a result of increased conflicts over water. Measures based on IWRM are frequently targeted to address these issues (Adey et al. , 2018). A watershed is commonly mentioned as a key for IWRM implementation and as the natural water resource management unit (Giordano and Shah , 2014). It is the system of systems for sustainable development (M. El-Kady and F. El-Shibini , 2004) and an ideal solution for basin sustainable development (Yericho and Mulugeta , 2019). This plan addresses the key shortcomings in water sector development in ways that balance efficiency, social equity, and ecological sustainability, fulfilling the SDGs and the Millennium Development Goals (MDG) (Aung , 2021). The UN emphasized implementation competence as a prerequisite for sustainability. The UN's emphasis on monitoring implementation through institutional indicators hinders our knowledge of effectiveness and ignores linkages to other SDGs. Furthermore, due of its sectoral cross-cutting nature, IWRM has the ability to promote the attainment of acknowledging the importance of water resources to broader sustainable development (Benson et al. , 2019).

The majority of papers assessed the extent of IWRM implementation while ignoring links to SDGs in Ethiopia. Kidanemariam (2009) explored the issue of the IWRM from changes to the existing system, a sense of ownership amongst all stakeholders, gaining political support at various levels and multi-stakeholder platforms perspectives for its success. Similarly Tamiru (2011) examined the practices of IWRM based on integration of all stakeholders for the catchment management, budget constraints and whether management was confined to buffer zone. The goal of this study is to re-conceptualize IWRM in order to objectively measure the progress of the social dimension, ecological dimension, economic dimension, cultural dimension, ethical dimension, and governance dimension. It is now widely recognized as a guiding principle for the sustainable development and management of water resources in Ethiopia. Ethiopia's national water resources management policy aims to strengthen and support efforts toward the efficient, equitable, and optimal use of available water resources, as well as to contribute to the country's socioeconomic development throughout time. The policy environment is highly supportive of IWRM approaches. This water management plan is widely understood and accepted in the country (Yonas and Deleje , 2008). Ethiopia has embraced the IWRM principles and approaches, and has already implemented relevant policies and strategies. According to Alamirew (2018), the average level of IWRM implementation was 31 percent, with the enabling environment (the status of policies, laws, and plans to support IWRM at all levels) (40/100), institutions and participation (37.5/100), management instruments (27.8/100), and Financing (20/100) as the determinants. The lesson from Ethiopia's IWRM pilot exercise revealed low level of integration and decentralization without empowering capacity at the local level (Jembere , 2009).

Despite the fact that IWRM is strongly associated with sustainability (MoWR , 1999), the evaluation of IWRM plans against sustainability themes is rare. The purpose sets out to investigate the degree of implementation of IWRM in terms of water management, as well as to evaluate against predefined sustainable goals. The IWRM plan should be evaluated in light of the evolution of global knowledge, practices, and consensus on sustainable development.

As a result, this study aimed to examine the extent to which the IWRM plan promotes human welfare through real-world activity. It enables those who use it to place themselves and propose ways to improve the plan, with the goal of continuous improvement. The analysis can also be used to create goals, identify indicators, make more informed decisions, and find compromises that improve the plan's acceptance.

The other regulatory process for managing and protecting natural resources, notably water and the environment, is the Environmental Impact Assessment (EIA). It is critical in the framework of activities aimed at developing a comprehensive water resource management strategy. Prior to the approval of investment proposals, an assessment of potential environmental consequences ensure the core elements of sustainable development are considered. The EIA highlights the project's potential desirable and undesirable impacts in advance. Possible paths and mitigation procedures for those detrimental consequences on the natural and socioeconomic environment were identified in advance. This enables the project to be ecological friendly and acceptable to the surrounding community by avoiding or minimizing impacts. The assessment is a method of appraisal and decision-making for sustainable development, and its success influenced by various factors, one of which is the implementation of EIA recommendations. It is now widely acknowledged that the environment and social aspects must be considered within the scope of the project itself by including EIA into the design and implementation processes.

In Ethiopia, EIA practice has only recently begun and is not yet sufficiently developed to assist in accomplishing environmental protection and sustainability goals. Among the elements thought to be influencing the efficiency of EIA in Ethiopia are the quality of implementation and the follow-up of EIA recommendations (Arebo , 2005). This situation necessitates a comprehensive examination of the Environmental Management Plan (EMP) in order to provide accurate information that can be utilized to develop strategies to improve the quality of these elements. However, the current EIA approach in Ethiopian water resource development projects is insufficient to play the overarching function of sustainable development, nor to evaluate how each mitigation measure is faring at the sustainability pillars. According to Noble and Storey (2004), environmental management actions specified in the EIA report were not adequately translated into action plans, and measures were not evaluated using the three pillars of sustainability. Sustainable analysis of each action is also required for successful implementation of EIA recommendations. Environmental Management Plans serve as a vital link between the expected consequences and mitigation actions outlined in the EIA report and implementation and operation activities. The effect of the construction phase are mostly short-term, limited to the plot area, and not expected on a larger scale. The environmental impacts throughout the operating phase are caused by the project's continuous operation; thus, the priority in the EMP is to minimize such impacts. As a result, this component of the study concentrated on the sustainability analysis of mostly EIA-recommended and other adaptation and mitigation measures in the Koga scheme. The current study primarily ascertains the extent to which a particular course of action in EMP contributes to sustainable development, as well as striking a balance of pillars.

4.2 Methods

4.2.1 Data types and sources

A five-member analysis group was developed with the objective of offering greater objectivity and answering the pairwise comparison questionnaire and the Sustainable Development Analysis Grid (GADD), an excel spreadsheet, by consensus, majority vote, or average. Within the Network Analysis – Creative System Modelling – Decision support (NetSyMoD) approach, the task force group familiar with specific expertise of relevance who can provide more objectivity, as well as fresh perspectives, mitigating the potential biases was formed from two departments in the project office of Koga scheme: irrigation and watershed management offices. One facilitator was then needed to support the group, averaging, facilitating majority voting,and helping the group to reach a common consensus and analyse the outcomes of the brainstorming exercise. The facilitator's role is crucial for providing a correct and effective management of participation. During the pairwise comparison, the facilitator checked the consistency on a regular basis. When the group was experiencing high inconsistency in pairs, he reopened the discussion to achieve a new agreement. Although some research suggests to include up to ten people, it is recommended that the analysis be kept under small amount for the benefit of efficiency in meeting management within even in the NetSyMod approach, with a minimum of four members (Giupponi et al. , 2008).

Using the snowball sampling technique, data were collected from experts with varied backgrounds working at the Koga scheme in Merawi. The snowball sampling process begins with identifying the "seeds", a relatively small number of experts who are the first to be involved in the process. These seeds are then asked to name other task force group members. Since the population of interest was difficult to access, experts who are familiar with EIA, IWRM and Sustainable development, it was found to be more important to make snowball sampling. It establishes trust as it relies on referrals, and it is also recommended in NetSyMoD approach.

4.2.2 The Sustainable Development Analysis Grid (GADD)

This section assessed the level of Integrated Water Resources Management (IWRM) support in the Koga scheme with regards to promoting sustainable development. Before the examination of IWRM's support to sustainable development, the following pre-defined principles were employed to determine whether current management practices are in line with IWRM principles. Therefore, the study utilized principles, such as participation, integration, decentralization (elements derived from IWRM literature, most notably the Dublin principles), transparency and openness, rule of law and enforcement, accountability and integrity, and responsiveness from governance decision-making processes, as suggested by De Stefano et al. (2014). Survey data from households were obtained to achieve this purpose. Furthermore, a set of dimensions, themes, and goals, known as GADD, has been developed to assess the sustainability assessment of IWRM plan and implementation. The GADD is an Excel spreadsheet that contains a set of 166 goals divided into 40 themes and six dimensions (see Table 4.1) (Villeneuve et al. , 2016).[1]

4.2.2.1. Method of Analysis

The detail analysis involves weighting, an assessment based on planned or already implemented actions, and the identification of opportunities for improvement and makes it possible

[1] The goals are listed in appendix section (Table 5.18 - 5.24).

Table 4.1: Sustainable Development Dimensions and Themes

Dimension	Themes
SOCIAL DIMENSION: Seeks to address social needs, individual and collective aspirations, health and well-being needs, and quality of life needs.	
Social	Poverty reduction
	Water
	Food
	Health
	Safety
	Education
	Community and Involvement
	Human Settlements
	Gender
ECOLOGICAL DIMENSION: Seeks to address the need for a quality natural environment and for sustainable resources, and to redefine the relationship between humans and nature.	
Ecological	Ecosystems
	Biodiversity
	Resources
	Output
	Land Use
	Climate Change
ECONOMIC DIMENSION: Seeks to address the material needs and financial empowerment of individuals and communities.	
Economic	Responsible Production
	Responsible Consumption
	Economic Viability
	Work
	Wealth and Prosperity
	Energy
	Enterprenurship
	Economic Models
CULTURAL DIMENSION: Seeks to address the need to affirm, express, protect and promote the diversity of cultural traits.	
Cultural	Transmission of Cultural heritages
	Cultural and Artistic Practices
	Cultural Diversity
	Contribution of Culture to Development
ETHICAL DIMENSION: Seeks to address equity needs, consistency needs and the need to identify with common values.	
Ethical	Responsibility
	Peace
	Benevolence
	Sharing
	Ethical Process
GOVERNANCE DIMENSION: Seeks to address Participation and citizenship, democracy and transparency needs, and the need for effective institutions.	
Governance	Insititutions
	Tools and Processes
	Participation and Citezenship
	Subsidary
	Local Integration
	Information
	Innovation
	Risk Management and Resilience

to prioritize the actions to take in a process of continuous improvement. The detail analysis enables to conduct more in-depth investigations, set priorities, and inform stakeholders about issues related to sustainable development. The analysis method aids in the prioritization of improvements based on the importance and performance of each goal.

(1) Weighting goals and goal assessment

The 166 goals are weighted and quantitatively evaluated. The weighting is determined by the importance and relevance of each goal to the IWRM plan and implementation. The weighted values were determined by consensus and averaging. For each goal, the following questions were asked: Is achieving a goal essential, necessary, or desirable for the success of IWRM? The importance is determined by numerical values ranging from 1 to 3.

1. Desirable goal: achieving a goal is not deemed important, or is not a priority;

2. Important goal: achieving a goal is important, but is not one of the immediate priorities related to the needs targeted by the IWRM;

3. Indispensable goal: achieving this goal is important and is an immediate priority. It is deemed indispensable to the success and delivery of the IWRM.

Following weighting, each goal is evaluated by answering the following question: How does the IWRM achieve its goals?. The numerical values and their interpretations are provided in Table 4.2. The assessments are justified by planned and implemented actions. Based on their discussions, analysts averaged their respective assessments or agreed on a common score. The goal assessment was based on Ethiopia's IWRM plan document, as well as practices executed and planned at the Merawi project office.

(2) Interpreting Analysis Results

The main goal is to identify the goals that should be prioritized in order to improve the IWRM's performance in terms of sustainable development, as well as to highlight the IWRM's strengths. The interpretation is presented using the following tools: radar chart, prioritization, and priority issue.

(I) Radar Charts

Using a radar chart, the performance results of the IWRM plan and implementations were automatically generated as a percentage for each of the six dimensions. The study evaluated the overall performance of the IWRM plan, the balance of the sustainable development dimensions, and the performance of each dimension and theme using these charts. The score is a performance indicator that has no scientific significance, but it is used to compare the performance of dimensions, themes, or similar plans. Table 4.3 provides a qualitative assessment of scores for a dimension or theme.

(II) Prioritization Index

The prioritization index seeks to identify the goals that should be prioritized in order to improve IWRM performance in terms of sustainable development. The higher the weighted value of the goal and the lower the performance (low assessment score), the greater the urgency to implement improvement measures (opportunities for improvement) for this goal. The prioritizing goal mechanism is shown in Table 4.4 and 4.5.

Table 4.2: Goal Assessment Scale and Interpretation

Percentages	Interpretation
0-9	The IWRM plan has significant negative impacts on a goal
10-19	The IWRM has moderate negative impacts on this goal
20-29	The IWRM has minimal negative impacts on this goal
30-39	The goal is not taken into account by the IWRM, but
	the IWRM has no impact on the goal
40-49	The goal is not taken into account by the IWRM, but
	the IWRM has indirect positive impacts on the goal
50-59	The goal is slightly taken into account, with no
	concrete actions and measures, and minimal positive impacts are expected
60-69	The goal is moderately taken into account, with
	planned actions, but with no innovative elements compared to similar Plans
70-79	The goal is taken into account, with concrete actions
	and some innovative elements; positive impacts are expected
80-89	The goal is well taken into account, with innovations and
	concrete measures, significant positive impacts are expected
90-100	The goal is strongly taken into account, the IWRM is exemplary

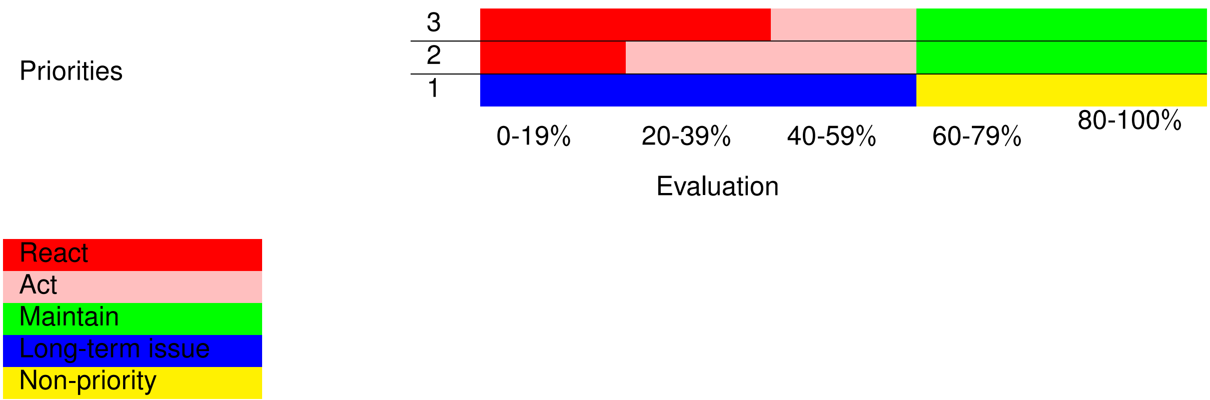
Table 4.3: The performance results of the IWRM plan Interpretation [Radar Charts]

Percentages	Interpretation
Less than 20	Critical situation: The dimension or theme is negatively affected by the IWRM
Between 20 and 39	Problematic situation: The dimension or theme is insufficiently considered in the IWRM
Between 40 and 59	Improvable situation: The dimension or theme is poorly considered in the IWRM
Between 60 and 79	Satisfactory situation: The dimension or theme is considered in the IWRM
Between 80 and 100	Excellent situation: The dimension or theme is strongly considered in the IWRM

Table 4.4: The Prioritization Index and Interpretation

Priorities	Interpretation
The "React" priority	Indispensable goals (weighted 3) with an assessment $<$ 40 and Necessary goals (weighted 2) with an assessment score $<$ 20;
The "Act" priority	Indispensable goals with an assessment score between 40 and 59 and Necessary goals with an assessment score between 20 and 59;
The "Maintain" priority	Indispensable and necessary goals with an assessment score $\geq$ 60;
The "Long-term issue" priority	Desirable goals (weighted 1) with an assessment score $<$ 60;
"Non-priority"	It applies to desirable goals with an assessment score $\geq$ 60.

Table 4.5: Prioritization Index



(III) Priority Issues

The analysis also included the weighted goals associated with each theme to aid in identifying the most important goals, as well as an IWRM theme. A high weighted value average indicates that the majority of goals associated with a theme were deemed important or indispensable. Priority issues are those with associated weighted goals whose average is equal to or greater than 2.5.

(3) Sustainability assessment of IWRM plan

The sustainability assessment of IWRM plan is expressed using a Radar chart of the balance of poles. The plan meant to be part of a sustainable development should reach a minimum threshold of 60 percent in all six dimensions of the GADD that cover as many sustainable development issues drawn from science and practice as possible. A score of less than 60 percent is unlikely to succeed in the field of sustainable development. As a result, it should be revised or increase IWRM implementations.

4.2.3 NetSyMoD methodological framework and the mDSS tool

The NetSyMoD approach, where NetSyMoD stands for Network Analysis – Creative System Modelling – Decision Support, represents the outcome of several years of research in the field of natural resources management, environmental evaluation and decision-making, within the Natural Resources Management Research Programme. NetSyMoD is a flexible and comprehensive methodological framework aimed at facilitating the involvement of stakeholders or experts in policy- or decision-making processes. The various applications of NetSyMoD share the same approach for problem analysis and communication within the group of actors, based upon the the formalisation of human-environment relationships through the Drivers-Pressures-State-Impacts-Responses (DPSIR) framework, and the use of Multi-Criteria Analysis (MCA) through the DSS software (Giupponi et al. , 2008).

4.2.4 Basic steps of Multicriteria Decision Analysis

The basic steps of Multicriteria Decision Analysis, as implemented in the MULINO (MULti-sectoral, INtegrated and Operational Decision Support System for Sustainable Use of Water Resources at the Catchment Scale) (mDSS), include the decision process starts with problem structuring during which the problem to be solved is explored and available information is collected. The possible options – responses in terms of the DPSIR framework – are defined and criteria aiming at evaluation of their performance are identified. In the next step, the performances of the options in terms of the criteria scores are modelled. As a result a matrix – called analysis matrix – is constructed. The analysis matrix contains the raw options' performance with different criteria. Since the main aim of a multicriteria decision analysis is to reduce option of each performances into a single value to facilitate the ranking process, the heart piece of any MCA decision rule is an aggregation procedure. There is no single method that is universally suitable for any kind of decision problem, the decision maker has to choose the method which best corresponds with the purpose. However, the use of more than one methods increase the robustness of results since findings can be strengthened through triangulation. Finally, a sensitivity analysis examines how robust the final choice is to even a small change in the preferences expressed by the expert group.

4.2.5 Problem Structuring

For the analysis, eight adaptation and mitigation measures, as well as three criteria useful for the evaluation of their performance in terms of sustainable development, were identified. The measures are composed of mostly from EIA recommended measures, and based on recommendations obtained from Koga Irrigation Development Office, Merawi. The EIA-recommended measures includs public health, training and extension courses for farmers, settlement and compensation payment, planting forest seedlings, and livestock development. Additionally, irrigation agronomic practices, marketing activities, and cooperative organization are also evaluated as additional measures. These measures were analyzed in terms of social, economic, and environmental sustainability. Table 4.6 shows the selection procedure and justifications for the inclusion or exclusion of adaptation and mitigation measures for the analysis. The EIA recommended measures in Table 4.6 are based on Abebe et al. (2007), and the others 9 are neither listed in their paper nor reported or activity done.

4.2.6 Generating Analysis Matrix

The analysis matrix (M X N: M options/measures and N criteria/pillars of sustainability) was built from the indicators identified in problem structuring. The cells of the matrix relate to the option-criterion pairs and contain the outcomes or consequences for a set of options and a set of evaluation criteria.

4.2.7 Modelling Criteria Weights

Decision problems involve criteria of varying importance to decision maker. The same holds true for the relative importance of the three pillars of sustainability in literature. There are different ways of thinking that prioritize all three equally, and others that consider the environment as base. The criterion weights usually provide the information about the relative importance of the considered criterion. The Pair-Wise Comparison (PWC) method developed by Saaty (1980) was used for assessing the criterion weights i.e. the relative importance of each pillar of sustainability to sustainable development. The method involves pairwise comparisons to create a ratio matrix with values, from 1 to 9, to describe the relative preferences for two criteria. That way, the order of layers in wedding cake framework was determined along with their weights. Furthermore, it aids in validating the criticisms made by Bill Scott regarding the ordering of layers. The PWC method also used to evaluate the relative importance of measures to each pillar, and generating scores in the analysis matrix. The scale of the pairwise comparisons and their interpretation are listed below (as in Table 4.7).

Table 4.6: The adaptation /mitigation measures selection procedure

		20 EMP EIA-Recommended measures	
	1.	Control of liquid and solid pollution from labor camps	Not reported
	2.	Restoration plan for quarry sites;	Not reported
	3.	Aquatic weed control;	Not reported
	4.	Public health;	Reported but poor performance
	5.	Training and extension courses for farmers;	Reported
	6.	Sustenance of riverine fishery;	No report/activity
	7.	Watershed management;	Reported but its broad concept
	8.	Settlement and compensation payment,	Reported but poor
	9.	Control of air pollution	No report/activity
	10.	Planting forest seedlings	Reported and satisfactory
	11.	Livestock development	Reported and satisfactory
		Others 9 either not reported or no activity done	
Measures	1.	Irrigation agronomic practices	
(Others)	2.	Marketing activities	
	3.	Cooperative organization	

Table 4.7: Scale for pairwise comparison [Saaty (1980)]

Scales	Interpretation
1	equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	may be used for interpolation between them/intermediate values

The following equations show the steps to generate criteria weights implemented in the mDSS software. Using the pairwise comparison matrix A $\in \mathbf{R}^{n \times n}$ the weights w_j may be determined as below:

1. Estimate the maximum eignvalue λ_{max} of the comparison matrix, which fulfil the following formula
$$det(A - \lambda \times I) = 0 \tag{4.1}$$

2. Determine the solution $\tilde{w}$ as in the following formula
$$(A - \lambda \times I) \times \tilde{w} = 0 \tag{4.2}$$
$$\tilde{w}_i \geq 0 \tag{4.3}$$

3. Normalize the $\tilde{W}$ by following formula
$$w_j = \frac{\tilde{w}_j}{\sum_{i=1}^{n} \tilde{w}_i} \tag{4.4}$$

After the weights have been determined, the consistency of pairwise comparison must be evaluated. Unfortunately, the decision maker is often not able to express consistent preferences in the case of multiple indicators as in the case of the relative importance each eight EIA recommended adaption and mitigation measures to each pillar of sustainability. Saaty (1980) method measures the inconsistency of the pairwise comparison matrix and sets a consistency threshold which should not be exceeded. Given the consistence ratio (CR) less than or equal to 0.1, the pairwise comparison matrix is considered to be consistent enough. Otherwise, the comparison matrix should be improved.

4.2.8 Decision Rules

Decision rules aggregate partial preferences describing individual criterion into a global preference and then rank the EIA-recommended measures towards sustainable development. The decision rules chosen for implementation in the mDSS in this study include (i) Simple Additive Weighting (SAW), (ii) Order Weighting Average (OWA), and (iii) Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)/ideal point method. The use of these three methods increase the robustness of results, since the findings can be strengthened through triangulation.

1. SAW is one of the most popular decision method because of its simplicity. It assumes additive aggregation of decision outcomes, which is controlled by weights expressing the importance of criteria.

2. The OWA is being used because of its potential to control the trade-of level between criteria and to consider the risk-behaviour of the decision makers.

3. Ideal point methods like TOPSIS order a set of options on the basis of their separation from the ideal solutions. The option that is closest to the ideal positive solution and furthest from the negative ideal solution is the best one.

(1) Simple Additive Weighting (SAW)

Simple additive weighting is a popular decision rule because of its simplicity. It uses the additive aggregation of the criteria outcomes (see equation 4.5).

$$\Phi_{SAW}(a_i) = \sum_{j=1}^{n} W_j \times U_{ij} \tag{4.5}$$

where W_j..criteria weights

(2) Order Weighting Average (OWA)

$$\Phi_{OWA}(a_i) = \sum_{k=1}^{n} OW_k \times b_k \tag{4.6}$$

Where, b_k..denotes the k-th lowest score of the options i (u_{ij}). The criteria are weighted on the basis of their rank order rather than their inherent qualities. By so doing the weights – called order weights - are applied to the criteria according to the rank order across their scores. For a given option, the order weight ow_1 is assigned to the criterion with the lowest score, order weight ow_2 to the criterion with next higher-ranked scores, and so on. Consequently, an order weight ow_i may be assigned to different criteria by two options a_1 and a_2, depending on the rank order of their scores.

(3) Ideal Point Method (TOPSIS)

Ideal point method orders a set of adaptation and mitigation measures on the basis of their separation from the ideal solution. The ideal solution represents an option, though not achievable and thus only hypothetical, that consists in the most desirable level of each criterion across the options under consideration. The option that is closest to the ideal point is the best one. The measurement of separation requires distance metrics. The ideal negative solution may be defined in the same way: the best option in this case is characterised by the maximum distance from it. The equations 4.7 and 4.8 show the generalised definition of distance metrics.

$$[S_{i+} = \left[\sum_{j=1}^{n} W_j^p (U_{ij} - U_{+j})^p \right]^{\frac{1}{p}}] \tag{4.7}$$

- S_{i+}...separation of the ith option from the ideal point
- W_j...weight assigned to the criterion j
- U_{+j}...ideal value for the jth criterion
- P...power parameter ranking from 1 to ∞

$$[S_{i-} = \left[\sum_{j=1}^{n} W_j^p (U_{ij} - U_{-j})^p \right]^{\frac{1}{p}}] \tag{4.8}$$

- S_{i-}...separation of the ith option from the negative ideal point
- U_{i-}...negative ideal value for the jth criterion

TOPSIS defines the best option as the one that is closest to the ideal option and farthest away from the negative ideal point. The distance from the ideal/negative ideal point is calculated as in equation 4.9 and 4.10.

$$[S_{i+} = \left[\sum_{j=1}^{n}(U_{ij} - U_{+j})^2\right]^{0.5}] \tag{4.9}$$

$$[S_{i-} = \left[\sum_{j=1}^{n}(U_{ij} - U_{-j})^2\right]^{0.5}] \tag{4.10}$$

For p = 2, the Euclidian distance is obtained. Euclidian distance is named after the ancient Greek mathematician Euclid, who is often referred to as the "father of geometry." The Euclidean distance is the straight-line distance between two points in Euclidean space, which is often represented as the shortest path and more accurate representation actual distance of between two points. The relative closeness to the solution (C_{i+}), which will be used for the ranking of options, is calculated as in equation 4.11.

$$C_{i+} = \frac{S_{i-}}{S_{i+} + S_{i-}} \tag{4.11}$$

4.3 Results and Discussion

4.3.1 The extent of IWRM existence and some verifiable indicators

Prior to the sustainability assessment of IWRM plan, the perspectives of farmers in the command area were explored to ascertain the extent of IWRM implementation using seven principles including participation, integration, decentralization, transparency and openness, rule of law and enforcement, responsiveness, and accountability and integrity. Principles are inextricably linked. Active participation of stakeholders, particularly those at the basin level is a foundation for IWRM implementation. Promoting beneficiary participation is a key project component.

The household survey results show that farmers and local farmer institutions, such as Water Users' Associations (WUAs), took part and were given the opportunity to comment on the outcomes of planning and working processes that directly affect them. Despite varying degrees of agreement, 70.5 percent of survey households believed that farmers participate in many things that impact them, while 25.5 percent did not (shown in stacked bar chart Figure 4.1). Land redistribution mechanisms and compensation, as well as participatory means of relocation were some objectively verifiable indicators of participation in Koga scheme. Such participation began during the project's pre-preparation in late 1999 and 2000, which included a stakeholders' dialogue with both men and women in the command communities. Participatory management was also fostered by enabling the formation of water users associations to involve farmer in command management. Beneficiaries were expected to have a sense of ownership as a result of the participatory approach employed throughout the project's design and implementation (ADF , 2001).

Households were primarily involved in regulating and controlling collective actions to manage the irrigation scheme, owing to a combination of socio-economic and institutional factors. Participation in irrigation management operations is widespread and a different aspect of

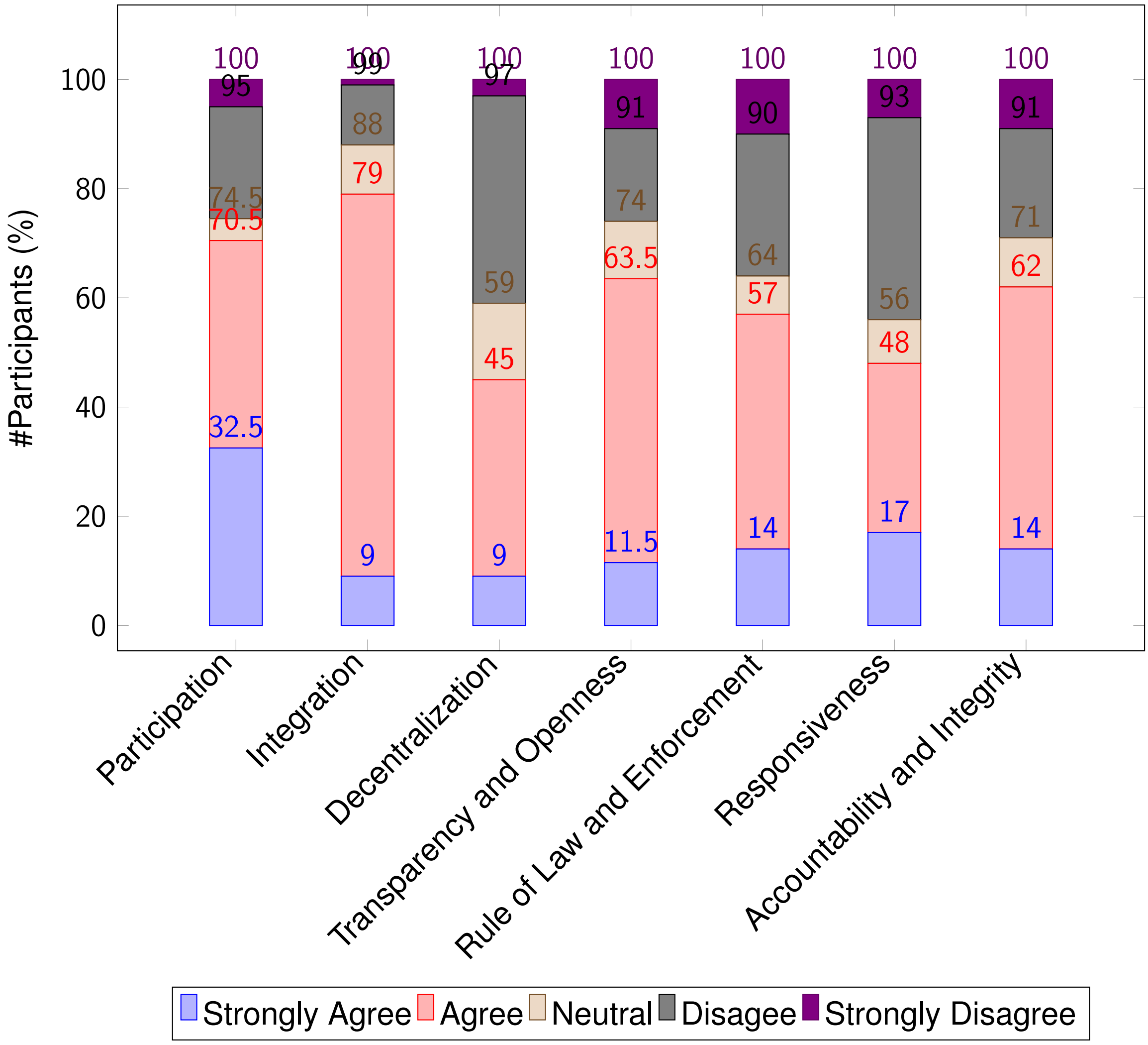


Figure 4.1: The extent of IWRM as per the Principles

participation indicator in terms of labor, decision making and regulation. There were labor participation in the form of canal repair and maintenance; decision making participation in the form of contributing ideas in meeting and training; as well as regulation and control participation that includes reporting illegal water use, reporting and controlling theft of irrigation infrastructure, and reporting and controlling water leakages or runoff. It is claimed that water users have a low degree of participation in management operations, and the project has not met its objectives. Farmers took part in a few activities with varied levels of participation. They were more participated in regulation and control duties (Kassie , 2019). Similarly Yilak (2013) found unsatisfactory participation in the management activities, operation duties, and maintenance of the scheme. Moreover, according to experts group analysis, in order to promote involvement, the project office has built demonstration centers and facilitated meetings. Some other verifiable indicators of participation include the presence of a general assembly, farmers' holidays, and irrigation campaigns to engage farmers in a common vision.

The participation of different stakeholders is dependent on other principles such as decentralization. By expanding citizen engagement in decision-making, IWRM promotes also water resource decentralization as a management activity. For this management strategy to function, all stakeholders must be involved. It seeks to promote collaboration while avoiding marginalization of water users and groups. Change and the formation of institutions as well as sharing responsibilities, from the federal to the local and community, are the greatest ways to understand decentralization principle of IWRM. According to the significant number of households (45 percent), there was decentralization in the sense that control of an activity or organization was given to several local offices or authorities rather than a single one (see Figure 4.1). The Koga Irrigation Development Project Office also hoped to handover responsibilities to the surrounding farmers (ANRS , 2011).

Similar to the household survey results, the water sector has seen changes in terms of decentralization. Some verifiable indicators include that the Federal Government is responsible for policy formation (Wube et.al , 2009), as well as providing technical support to regional water offices (MoWE , 2010). The promotion and monitoring IWRM responsibilities were given to River Basin Organizations (RBO), Abbay Basin, often known as the Blue Nile Basin is the first RBO formed (GoE , 2007). As part of the decentralisation movement, regional water offices also handed authority for a wide range of services such as, for WUAs. The establishment and operation of WUAs as a specific and new type of legal entity in Ethiopia in general. WUAs, which are sometimes regarded as the lowest unit in the IWRM structure. One sign of decentralization in Koga scheme is the formation and establishment of WUAs. The implication is that they have a say and major responsibility on the scheme that benefits and affects them through farmer representation in the overall management of the command. According to its mandate, WUAs have duties and responsibilities in operating and maintaining irrigation infrastructures as well as managing or protecting watersheds. Decentralization is one of the sustainable methods for managing watersheds (Sthapit , 2005). For effective decentralization, community organizations need to be given more resources and duties. An unambiguous institutional framework with clear obligations for farmers and their associations; decentralized government services; and agencies and private operators all play a role in the project.

Transfer of irrigation management from government agencies to farmer organizations or WUAs can result in better irrigation water management and service delivery, as there is better cooperation between the water users. As a result, an integrated approach includes crucial institutional elements that can help to avoid water management conflicts. Water scarcity related conflicts need the use of integration IWRM techniques. One of the project's success conditions is an integrated approach in various aspects, such as, productivity and income, agricultural extension, input provision, market access, and supporting private sectors. Reports show that many organisations work independently. However, there were institutions that work with good cooperation with each other.

The verifiable indicators as far as integration is concerned is that the then Amhara Credit and Savings Institution (ACSI) worked good with kebele administration, farmers' training centre, cooperatives and police. The farmers' training centre, kebele administration, community water committee and church had good integration (Tafere et al. , 2014). The Commission for Sustainable Agriculture and Environmental Rehabilitation in Amhara Region (COSAERAR) collaborates with the Bureau of Agriculture (BOA) to provide farmer assistance services. The livestock and natural resource development activities were expected to be carried out as part of the regular duties of the Woreda Agriculture Development Office (ANRS , 2011). It also works closely with the Kebele Administration at the grassroots level, acting as important links between peasants and the government. Another type of integration is collaboration with credit and donor intervention (ADF , 2001). As a result of integration, additional forestry programs are required to support the crop sector in rural development. The expert group also noted the Integration of educational, agricultural and fishing institutions to promote inclusiveness of institutions. The study also confirmed that the majority (79 percent) of survey respondents believed there was synergy among various institutions working in the command area. The results of the survey show that multiple stakeholders worked together to develop and manage various resources to achieve the project's economic, social, and environmental benefits. The project was expected to integrate the irrigation and watershed management sub-sectors through coordination with various institutions. However, according to Yonas and Deleje (2008), overlapping roles and responsibilities of various water institutes is identified a major failure in the area.

Because of the lack of an integrated strategy among departments with overlapping responsibilities, there is a general lack of accountability and a poor flow of information between institutions. In terms of accountability and integrity, most farmers agreed that institutions at various levels were accountable for what they did and could provide a satisfactory explanation for it. Farmers believed that actors and institutions should adhere to the concepts of openness, accountability, and involvement in water governance, which are based on basic values of honesty, equity, and professionalism. The experts also corroborated this by saying to act with integrity and transparency, and owing to the urgency, they usually work on weekends.

Involving farmers in management and decision-making can boost water productivity while also increasing transparency and responsibility in water management. Transparency and openness are the initial rungs on the public participation ladder because they imply that farmers and other stakeholders, such as WUAs need to have timely information as far as informed decisions are concerned. The survey findings demonstrated the availability of transparency and public access to information, allowing farmers to better be informed the decision making environment that affects them and to be aware of the standards to expect from stakeholders. The stakeholders were aware of the broad intentions of the project, resettlement procedures, and had reached consensus regarding compensations (ADF , 2001). The resettlement procedure and redistribution of land were based on transparent criteria, enabled to protect the rights of females and the poor. Moreover, the management of the water resource was developed with full informed participation of the principal stakeholders for the project's overall success. One of the project's area of responsibility is accountability and transparent management of water resource and irrigation infrastructures. This will be done through supporting credible mechanisms for enforcement of agreed irrigation management rules, empowerment of WUAs and monitoring and evaluation of service delivery (PID , 2007). According to the survey, there are enforcing mechanisms in place in Koga scheme. To establish monitoring and evaluation measures, a team led by the manager submits a report every Friday. Yet there are no incentive based enforcement mechanisms than punishing for inappropriate uses or activities (Haileslassie et al. , 2013). When it comes to responsiveness, or the ability to respond quickly and favorably, significant number farmers also agreed.

In terms of the IWRM principles degree of implementation, most farmers were generally in favor of the majority of the principles. They contend that practically almost all of the principles were put into practice, indicating that IWRM was implemented in the Koga scheme (see the proportions of households who strongly agree and agree for each principle in Figure 4.1). Particularly, the principles participation, integration and decentralization were being implemented with some verifiable indicators. The rest principles of IWRM have little or no indicators identified to make triangulation with the farming households' perception regarding their existence in the area. Implementing IWRM principles in Koga scheme has several implications for sustainable development, as IWRM is a holistic approach to water management that aims to achieve different aspects of sustainable development by considering the social issues, economic gains, and environmental issues in managing water resources. According to Woldemichael and Belay (2015), implementing IWRM in the Blue Nile Basin, which includes the Koga Project, can be viable solution for productivity, livelihoods and promote sustainable development. Implementing IWRM in the Koga scheme could contribute to the area's ecological health by safeguarding the region's unique biodiversity and preserving the natural resources that rely on it (UNEP , 2009).

4.3.2 Sustainability Assessment of Integrated Water Resource Management (IWRM) plan

The previous section discussed whether there is IWRM implementation based on predefined principles. The question of whether IWRM principles support sustainable development remains debatable. It is unclear if it truly meets the primary goal of sustainable development. A more detailed assessment to follow based on the sustainable development assessment grid (GADD).

4.3.2.1. Dimensions' and themes' current situation

The GADD has six dimensions and 40 themes, and the interpretation of the current situation is explained using radar charts to follow. The Radar charts (shown in Figure 4.2a to 4.2f) provided the graphical presentation of the scores for each dimension and themes of sustainable development based on planed and implemented actions. The qualitative analysis of the results for dimensions and themes that indicate the current condition are provided in Tables 4.8 to 4.13. The majority of themes fall within the 40-60 percent score range. The score serves as a measure of the performance of IWRM plan with respect to sustainable development dimension or theme. As a result, the majority of the themes (26 out of 40) are in an improvable state where the themes are poorly considered in the IWRM plan and implementations. There are, however, only a few typical sustainable development objectives where the project is some how progressing (shown in Table 4.14 to 4.17). While some 9 themes, including land use, water, economic viability, work, entrepreneurship, peace, institutions, participation and citizenship, and information, are in a satisfactory state and are taken into account in the plan, a few 5 themes, including risk management and resilience, transmission of cultural heritage, energy, food, and safety, are in a problematic state and are not sufficiently taken into account. No dimensions or themes can be categorized as critical situations that the IWRM plan negatively

Table 4.8: Interpreting the situation of ECOLOGICAL dimension and themes

	Dimensions/Themes	Current situation
1.	ECOLOGICAL	Improvable situation
1.1.	Biodiversity	Improvable situation
1.2.	Ecosystems	Improvable situation
1.3.	Climate change	Improvable situation
1.4.	Resources	Improvable situation
1.5.	Output	Improvable situation
1.6.	Land use	Satisfactory situation

Table 4.9: Interpreting the situation of SOCIAL dimension and themes

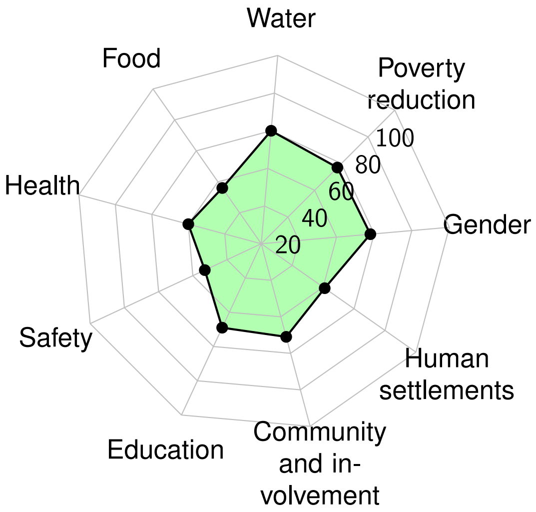
	Dimensions/Themes	Current situation
2.	SOCIAL	Improvable situation
2.1.	Water	Satisfactory situation
2.2.	Poverty reduction	Improvable situation
2.3.	Gender	Improvable situation
2.4.	Human settlements	Improvable situation
2.5.	Community and involvement	Improvable situation
2.6.	Education	Improvable situation
2.7.	Safety	Problematic situation
2.8.	Health	Improvable situation
2.9.	Food	Problematic situation

impacted and excellent situations that the plan carefully considered.

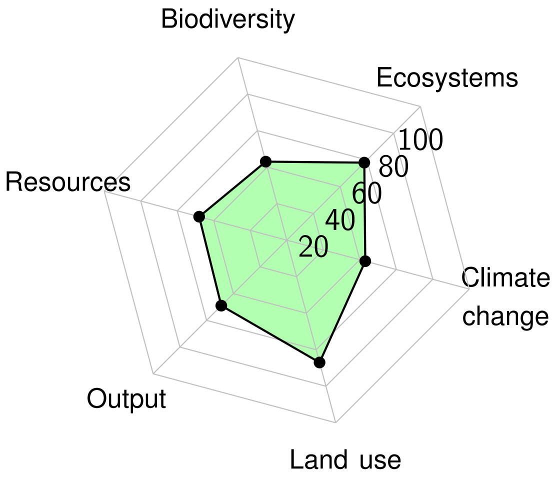
4.3.2.2. Prioritization Index for Goals

The index helped to prioritize goals for better execution in the area of sustainable development. The office may not be able devise improvement mechanisms for all goals. By prioritizing, it could list out those which needs immediate attention and those with long term priority to enhance the performance of IWRM plan and its implementation in terms of sustainable development. The priority is based on how a goal is important for IWRM and the extent of planned and implemented activities to achieve a goal. The analysis found that the greater the importance of the goal for IWRM and the poorer the performance, the greater the urgency of implementing measures for this goal. According to the index, 12 percent of the 166 goals specified in the grid receive the react index, 59.6 percent received act, and 26.5 percent received maintain, with the remainder being long-term concerns. There is no such thing as a non-priority objective. Twenty goals are classified as react index, suggesting that they must be addressed immediately, so that the office and other stakeholders should reply automatically. Ninety-nine goals necessitate less immediate action. While attempting to keep the forty-four goals performance, stakeholders are required to identify improvements for react and act priority indexed goals, which account for 71.6 percent of the goals.

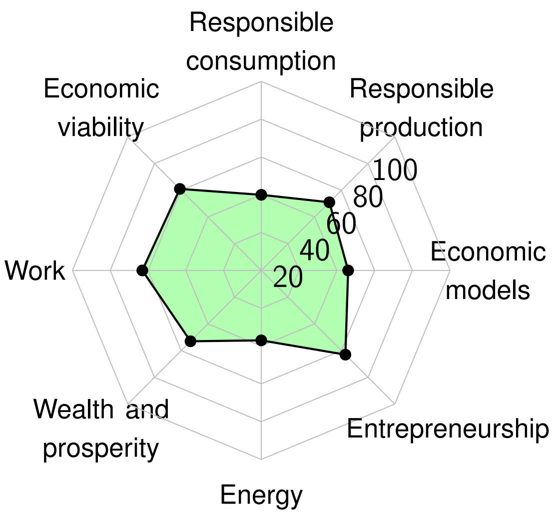
Out of the 40 themes listed in the grid, 35 (87.5 percent) were deemed to be the primary focus of IWRM. The analysis reveals that the majority of goals were regarded so



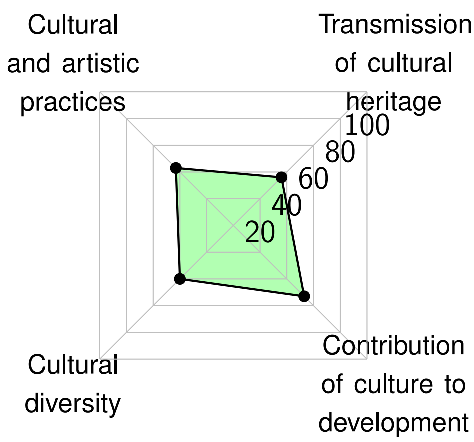
(a) Social dimension's themes



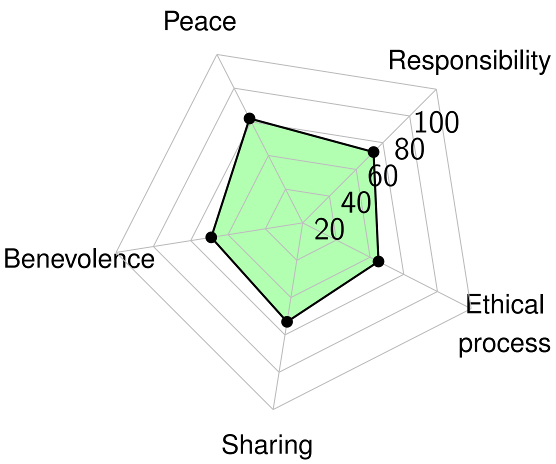
(b) Ecological dimension's themes



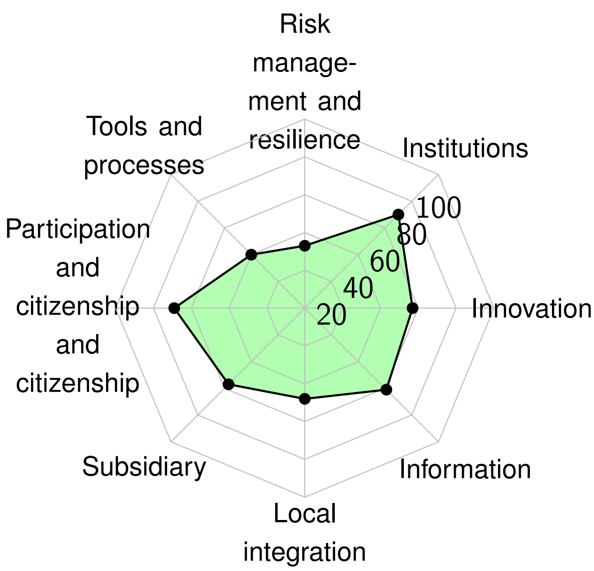
(c) Economical dimension's themes



(d) Cultural dimension's themes



(e) Ethical dimension's themes



(f) Governance dimension's themes

Figure 4.2: Performance of dimensions and themes

Table 4.10: Interpreting the situation of ECONOMICAL dimension and themes

	Dimensions/Themes	Current situation
3.	ECONOMICAL	Improvable situation
3.1.	Responsible production	Improvable situation
3.2.	Responsible consumption	Improvable situation
3.3.	Economic viability	Satisfactory situation
3.4.	Work	Satisfactory situation
3.5.	Wealth and prosperity	Improvable situation
3.6.	Energy	Problematic situation
3.7.	Entrepreneurship	Satisfactory situation
3.8.	Economic models	Improvable situation

Table 4.11: Interpreting the situation of CULTURAL dimension and themes

	Dimensions/Themes	Current situation
4.	CULTURAL	Improvable situation
4.1.	Transmission of cultural heritage	Problematic situation
4.2.	Cultural and artistic practices	Improvable situation
4.3.	Cultural diversity	Improvable situation
4.4.	Contribution of culture to development	Improvable situation

Table 4.12: Interpreting the situation of ETHICAL dimension and themes

	Dimensions/Themes	Current situation
5.	ETHICAL	Improvable situation
5.1.	Responsibility	Improvable situation
5.2.	Peace	Satisfactory situation
5.3.	Benevolence	Improvable situation
5.4.	Sharing	Improvable situation
5.5.	Ethical process	Improvable situation

Table 4.13: Interpreting the situation of GOVERNANCE dimension and themes

	Dimensions/Themes	Current situation
6.	GOVERNANCE	Improvable situation
6.1.	Institutions	Satisfactory situation
6.2.	Tools and processes	Improvable situation
6.3.	Participation and citizenship	Satisfactory situation
6.4.	Subsidiary	Improvable situation
6.5.	Local integration	Improvable situation
6.6.	Information	Satisfactory situation
6.7.	Innovation	Improvable situation
6.8.	Risk management and resilience	Problematic situation

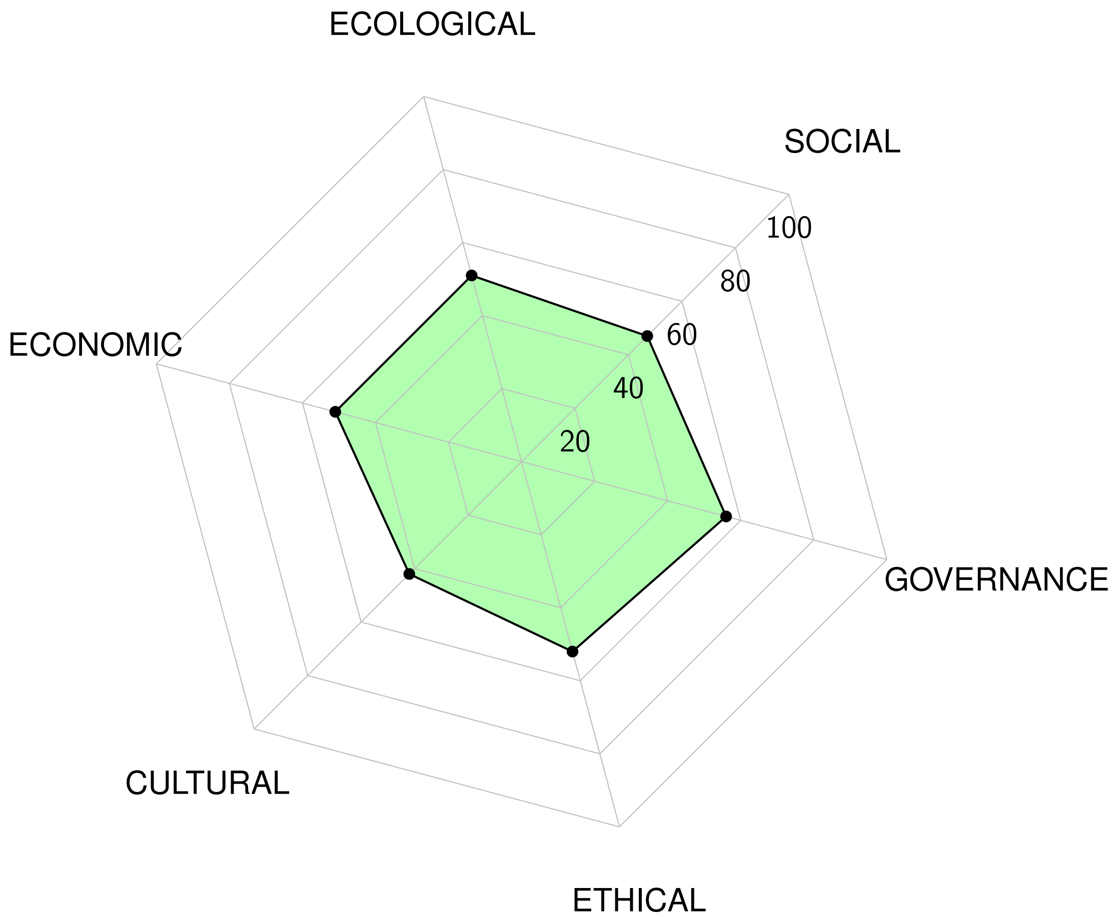


Figure 4.3: Performance of the sustainable development dimensions

significant. As a result, the themes and goals indicate a major concern related with the IWRM plan and implementation. Priority concerns are ones that affect practically all themes. Further information on react, act, maintain and long-term issues indexed goals are given Appendix Seven : G (shown in Table 5.18-5.24).

4.3.2.3. Sustainability Assessment of IWRM Plan

In order to examine how and to what extent IWRM plan and execution support sustainable development, the score of each dimension is essential. Accordingly, it should score a minimum of 60 percent on all six GADD dimensions. The decision rule inherently balances the six pillars of sustainability, with no room for compensatory effects. It is more focused on finding a balance among dimensions. If compensatory effects were allowed, the chances of succeeding in sustainable development would be low, as all dimensions would be poorly considered simultaneously.

The IWRM plan and its implementation in Koga scheme were not supporting much in all areas of sustainable development. Since the finding revealed the scheme scored less than 60 percent in all dimensions, indicating that they have got low chnaces to succeed in the field of sustainable development (see Figure 4.3). As a result, it should be revised or increase its implementation. Indeed, the existence of IWRM principles does not guarantee the achievement of sustainable development. The implication is that their success depends on various factors beyond the principles themselves. These factors include the effectiveness of implementation, the context in which the principles are applied, and the way farmers understand and perceive the principles. To ensure that IWRM contributes to sustainable development, it is crucial to have proper implementation, political will, and strong institutions in place. Additionally, understanding and addressing the issues and extent of true participation, integration, and decentralization matter a lot.

Table 4.14: Some planned and implemented activities related to various goals of sustainable development

	DIMENSIONS/Themes	Planned and implemented activities
	SOCIAL/Poverty reduction	
1.	Put in place measures to support the most disadvantaged and most vulnerable within local communities	Fruit production helped both females and youth Organizing poor without land in each block to get land Engaging youth in loading and unloading products
	SOCIAL/Water	
1.	Ensure a potable water supply for everyone	Building hand pumps bring drinking water Develop more streams as a source of water Information on dam water should not be used as drinking
2.	Ensure adequate quality of water supply according to its uses	Providing water on payment basis for various uses Providing plastic pump for different uses Utilizing potential source of hand pumping areas
3.	Increase the population's participation in mastering water and improving its management	Strengthen water team leader and committees Providing training on water distribution Developing water schedule and queue Efforts to develop sense of ownership
	SOCIAL/Food	
1.	Ensure access to food	Each farmer intends to grow wheat
2.	Ensure the nutritional quality of food	Training on crop protection packages Training farmers to use recommended chemicals
3.	Enhance food sovereignty	Guidance on selection of crop Training on nutritional value of crops
	SOCIAL/Health	
1.	Improve and maintain the health of populations	Advising farmers to use fruits and vegetables for food Advise to wear recommended chemical-resistant materials
2.	Ensure access to health care	Planned to work with health centers
	SOCIAL/Education	
1.	Ensure access to a quality educational system	Supporting schools with chairs and desks in the locality Provide irrigation land to local schools

Table 4.15: Some planned and implemented activities related to various goals of sustainable development...continued

	DIMENSIONS/Themes	Planned and implemented activities
	SOCIAL/Community and involvement	
1.	Promote involvement	Building demonstration centers Facilitate meetings Crop evaluation at each monthly meeting
	SOCIAL/Human settlements	
1.	Build sustainable infrastructures	Road construction in each block Providing electricity service for investors
	SOCIAL/Gender	
1.	Seek to implement equal rights without gender distinctions	Women engaged in development activities
	ECOLOGICAL/Biodiversity	
1.	Encourage biodiversity protection	Avoid overgrazing Planting fruit along canals
	ECOLOGICAL/Resources	
1.	Preserve the resources needed to sustain life in ecosystems	Awareness creation for various stakeholders Mass Avocado plantations
	ECOLOGICAL/Output	
1.	Manage hazardous waste properly	Develop reservoir for hazardous waste during summer Keep cleaning the canals continusouly
	ECOLOGICAL/Land use	
1.	Limit usage conflicts	Land plot map was prepared Integrated with wereda level land adminstration Value estimation was done on crops
	ECOLOGICAL/Climate change	
1.	Plan for adaptation measures to respond to the new climate reality	Planting climate-friendly fruits Plant byproducts should not be burned
	ECONOMICAL/Responsible production	
1.	Producing quality goods and services	Instruction on how and when to farm The right chemical use at the right time

Table 4.16: Some planned and implemented activities related to various goals of sustainable development...continued

	DIMENSIONS/Themes	Planned and implemented activities
	ECONOMICAL/Responsible production	
1.	Ensure adequation between needs and the goods and services produced	Working on crop calender basis Use of cluster based farming Collaboration with cooperatives in quality matters
	ECONOMICAL/Economic viability	
1.	To ensure economic viability	Do feasibility study at demo-centers
	ECONOMICAL/Work	
1.	To promote access to an occupation	Organizing youths in fruit production Investors employed 100-150 laborers
	ECONOMICAL/Weath and prosperity	
1.	To aim for wealth growth	Farmers purchased homes in Merawi town Some purchased an electric mill machine They have a better living standard
	ECONOMICAL/Enterprenurship	
1.	To develop an entrepreneurial culture	The feasibility study Offering examples of successful entrepreneurs
	CULTURAL/Transmission of cultural heritage	
1.	To promote individual expression, freedom and pluralism of beliefs, opinions and identities	Irrigation is possible even during holidays Work culture has improved
	CULTURAL/Contribution of culture to development	
1.	To make explicit the links between culture, development, employment and economic prosperity	Continuous capacity building
	ETHICAL/Responsibilty	
1.	To act with integrity and transparently	Due of the urgency, experts frequently work on weekends
	ETHICAL/Peace	
1.	To promote a culture of peace and non-violence	Conflict resolution process at the kebele level
2.	To foster a sense of justice	Fair use of water Water users' associations established

Table 4.17: Some planned and implemented activities related to various goals of sustainable development...continued

	DIMENSIONS/Themes	Planned and implemented activities
	ETHICAL/Benevolence	
1.	To develop community spirit and solidarity	Meetings every two weeks Canal cleaning in groups
	GOVERNANCE/Institutions	
1.	To improve the effectiveness, accountability and inclusiveness of institutions	Integration with educational, agricultural , and fishing institutions
	GOVERNANCE/Participation and citizenship	
1.	To promote engagement and mobilization around a common vision	There is a general assemby There are farmers' holidays There are irrigation campaigns
	GOVERNANCE/Information	
1.	To establish monitoring and evaluation measures	Every Friday, a team led by the manager submit a report
	GOVERNANCE/Innovation	
1.	To promote research and development	Bahir Dar University has been awarded 60.5 hec Adet agricultural research center awarded 5.75 hec The region's plant protection office awarded 4 hec Study area, both at the Masters and PhD level students

4.3.3 Sustainability Analysis of EIA-recommended adaptation and mitigation measures

Despite the fact that the preparation and details of follow-up programs should be defined at the pre-decision phases of EIA. Following up on the results of impact assessment activities is critical. Follow-up allows for learning from experience by incorporating input into the EIA process. Evaluation of EIA recommended measures should be done any time to make sure EIA is not a merely formality. Monitoring and evaluating EIA activities, on a micro-scale, is closely related to mitigation and environmental management plan. The evaluation ensures whether the project and environment are managed in an appropriate manner with respect to the notion of sustainable development?. Evaluations of sustainable development are inspired in part by the increased emphasis on accountability in governance and strategic actions, including the voluntary use of certain guidelines to report the economic, environmental, and social components of their activities.

This section examines adaptation and mitigation measures at the Koga scheme in relation to the three pillars of sustainability, using two sustainable frameworks: the triple bottom line and the wedding cake frameworks, which can then be used as an input feedback measure for the subsequent follow-up stage of implementing various EIA-recommended actions. It examined at how and to what extent the Environmental Management Plan (EMP) EIA-recommended measures performed in terms of sustainable development across the two frameworks, and how did EMP fare in terms of balancing the pillars.

4.3.3.1. Framework for criteria weighting

The explanation of sustainability in the literature employs numerous interrelated pillars, dimensions, components, stool legs, aspects, and perspectives as described in the models of sustainable development part of literature review. There are multiple-dimensional models, however, the three-pillar model of sustainability has come to dominate the literature, and they remain the most common paradigm for evaluating and understanding sustainable development today. The popular three pillars was also validated by the expert group, who believed that the three sustainability pillars are sufficient to grasp sustainable development. However, there are some debate about whether these three criteria should be viewed as pillars or as a trilemma. Given challenges in striking balancing, some believe the three pillars have become a trilemma (Martine and Alves , 2015). Whereas, the analysis of this study reveals that the group of experts sees the three dimensions as pillars. The understanding of the three dimensions of sustainability as pillars or trilemma by decision makers has a significant impact on water management in particular for decision makers and sustainable development at large. However, decision-makers must maintain ongoing awareness of the linkages, complementarities, trade-offs, and relative importance between these pillars in order to ensure responsible human behavior and actions.

In addition to identifying dimensions, sustainability models define the relative importance of pillars in their frameworks. The three-pillar model of sustainable development, typically represented as three intersecting rings with overall sustainability at the center, has come to dominate the literature in the Triple Bottom Line (TBL) Framework. However, the environmental aspect is the most important, according a number of sources. The SDGs were divided into three categories by Swedish scholar Carl Folke and his team[2]: environmental at the bottom, social in the middle, and economic at the top. Each circle/layer does not have equal size, but rather gets smaller as it goes higher, like a wedding cake. The idea behind the reduction was to show how each layer's size reflected its relative importance. An innovative paradigm for gauging development is offered by this framework. Setting this environmental objective as a top priority would also create the groundwork for accomplishing other social and economic objectives (Aubrecht , 2022). So, while the Wedding Cake Framework recognizes a hierarchy, the Triple Bottom Line (TBL) Framework struggles to prioritize the three. The graphic with three layered ellipses is also one technique to demonstrate the distinctive status of the environmental dimension. The nested ellipses diagram for the SDGs is similar to the Wedding Cake Framework, in which the environmental dimension or system serves as the foundation for the other two dimensions. The expert group in the current study also confirms that the environmental dimension is the most significant to overall sustainability when weighing the criteria in the pairwise comparison.

The analysis group employed the definition of sustainable development, three pillars, and significant indicators/themes indicated in Table 4.19. When making pairwise comparisons to generate the criteria weighing and analysis matrix, the group kept these concepts and major themes in mind at all times. Appendix Eight : H provided the detail information on pairwise comparisons in criteria weighting to develop weights of pillars in the wedding cake framework and the relative importance of measures for each pillar of sustainable development (See Table 5.25, 5.26 and 5.27). The study's approach for weighing the criteria demonstrates how important each pillar is in relation to sustainability. The pairwise comparison of criteria results from expert group suggest that environmental sustainability is moderately more important than economic sustainability, but it is extremely important when compared to social sustainability. The is also a strong importance on achieving economic sustainability over social sustainability. Table 4.18 shows how the criteria were rated against each other. Looking at the bottom row, environmental pillar scored a 9 above social and a 3 above economic pillars, while economic pillar scored a 5 above social pillar, by utilizing Saaty (1980) scales. This pairwise

[2]Prof. Johan Rockström, Executive Director of the Stockholm Resilience Centre and Chairman of the EAT Foundation's Advisory Board, is often credited with developing the wedding cake framework

comparisons result gives social 6.3 percent, economic 26.5 percent of the criteria priority, and with the most important criteria being environment, at 67.2 percent. While the Wedding Cake Framework undoubtedly offers a fresh perspective on sustainable development. The Wedding Cake Framework was criticized for arranging that hierarchy. The economy exists to service society, not the other way around, hence the economy should be the middle tier while environmental concerns go at the bottom (Aubrecht , 2022). As demonstrated by the criteria weighting results, the current study analysis is based on the Wedding Cake Framework, with the economy serving as the intermediary. The sustainable development model is in favor of Bill Scott's idea. The economic pillar came in the middle layer of the wedding cake framework.

Environmental objectives are the most essential criterion since they have the highest priority vector. For a growing number of people, sustainable development most commonly depends on direct attention being paid to environmental issues. In contrast less attention is paid to environmental sustainability, according to farmers' perception (see Figure 4.13a). In addition, a significant number of households (36%) believe that economic sustainability is very important to overall sustainability. Because of its relative importance, they prefer to achieve economic sustainability over other pillars to achieve overall sustainability (Figure 4.4). The relative attention of farmers in the study area to environmental sustainability compared to economic sustainability is minimal. Only 12% of respondents choose environmental sustainability over other pillars to achieve overall sustainability.

Table 4.18: Pairwise comparison of criteria for overall sustainability

Resulting weights	Criteria to be aggregated	Social sustanability	Economic sustanability	Environmental sustanability
0.063	Social sustanability	1	0.2	0.111
0.265	Economic sustanability	5.	1	0.333
0.672	Environmental sustanability	9.	3.	1

Consistency index is: 0.024 (consistent enough) Cancel OK

Table 4.19: Definition of sustainability, three pillars, and major indicators / themes

	Sustainability
	An ‘economically viable, environmentally sound and socially acceptable development that meets the needs of the present without compromising the ability of future generations to meet their own needs’
Sustainability and its pillars	1. Social sustainability
	The ability of the social system, such as community, to function at a defined level of social wellbeing and harmony indefinitely. Problems like was, endemic poverty, widespread injustice, and low education rates are symptoms a system in socially unsustainable.
	2. Economic sustainability
	The ability of an economy to support a defined level of production indefinitely
	3. Environmental sustainability
	The ability of the environment to support a defined level of environmental quality and natural resource extraction rates indefinitely
Pillars	Indicators/themes
Environmental sustainability	Protect, sustain, and restore the health of natural habitats and biodiversity maintenance; water pollution; land degradation
Economic sustainability	Profitability, marketability, input access, liquidity, stability, production and productivity. Strengthen and maintain current and future jobs. Liquidity measures the availability of cash to meet immediate and short-term obligations
Social sustainability	Autonomy in input access, Freedom in crop selection, Resource security;Aligned with community interests; Psychological well-being (education, health gender equality, infrastructures) Multifunctionality (quality of rural areas, contribution to employment and environment), Acceptable agricultural practices (animal welfare), and quality of products Equity /Fairness; Intergenerational continuity in agriculture, Sense of community and place attachment; Safety: protection and secure when experiencing environmental vulnerability. The concept of Eco-prosumption (model of consuming producing) refers to modes of producing and gaining values in socially and environmentally responsible ways. Integration of newcomers and connectedness; Cultural acceptability, indigenous knowledge

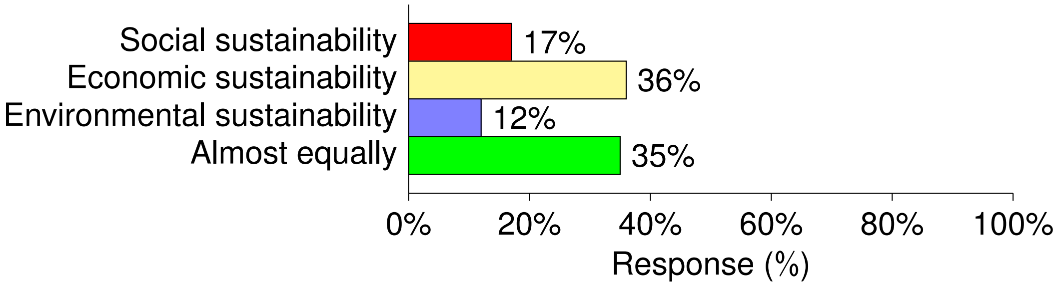


Figure 4.4: Relative importance of pillar for overall sustainability

4.3.3.2. Analysis Matrix

Sustainable development measures are expected to ensure achievement of social, economic gain, and environmental benefits, while trade-offs may emerge at times. These trade-offs appear to be particularly obvious in the short term, as long-term synergy among the pillars of sustainable development appears to be prominent. It becomes clear that some measure are better suited to social objectives, while still some other may be suited to economic gain or environmental benefits. The analysis matrix's option values indicate the relative importance of EIA-recommended adaptation and mitigation options. The adaptation and mitigation measures recommended in Environmental Management Plan (EMP) and other measures (see measures listed in Table 4.21) are not equally suited to achieving the three pillars of sustainability (see the option values in Table 4.22). The analysis matrix option values show how each alternative measures fared for each pillar of sustainability as a decision criterion. According to the results of the pairwise comparison in analysis matrix in Table 4.20, public health is best suited to the achievement of social sustainability (its score is 0.377, 0.03 and 0.028 for social, economic and environmental pillars), whereas planting forest seedlings is the least. Irrigation agronomic practices are the best for economic sustainability, whereas settlement and compensation are the least important contributors. Planting forest seedlings is the best alternative for environmental goals, while marketing activities are the worst. Unequal adaptability of measures can best explain the potential tradeoff in sustainable development.

Furthermore, half of the eight adaptation and mitigation measures investigated in this study are most suited to social objectives. These include public health measures, farmer training and extension programs, settlement and compensation, and cooperative organization. Whereas three of the eight measures are best suited to the economic pillar (including livestock development, irrigation agronomic practices, and marketing activities), only one (planting forest seedlings) is best suited to the environmental pillar (see the scores in Table 4.20). The bulk of adaptation and mitigation measures, according to the analysis, were related to social sustainability pillar and unrelated to environmental objectives. Although 87.5 percent of the measures (7 out of 8) are better suited to accomplishing economic or social pillars, these pillars have both direct and indirect desirable and undesirable negative impacts on the environmental goal, indicating long run synergy in sustainable development. Economic

Table 4.20: Analysis Matrix

	INDICATORS	Constraint	1	2	3	4	5	6	7	8
1	Social sustainability		0.377	0.212	0.075	0.029	0.065	0.044	0.156	0.042
2	Economic sustainability		0.03	0.184	0.027	0.046	0.243	0.246	0.071	0.153
3	Environmental sustainability		0.028	0.135	0.03	0.481	0.095	0.111	0.095	0.025

activity is required to ensure environmental sustainability. Measures that increase technical

Table 4.21: List of EIA-recommended and other measures for the analysis

Code	Adaptation and mitigation measures
1	Public health
2	Training and extension service for farmers
3	Settlement and compensation payment
4	Planting forest seedlings
5	Livestock development
6	Irrigation agronomic practices
7	Cooperative organization
8	Marketing activities

efficiency are an important toolset for decoupling economic growth from environmental costs of deterioration while increasing production and productivity. Improvements in technical efficiency enable not just economic progress and wealth, but also reduce waste and resource depletion. Beyond economic gain, enhancing technical efficiency can be considered in terms of environmental sustainability. Among other key social factors, social sustainability encompasses environmental justice, human health, resource security, and education. Efforts that enhances social sustainability should also achieve improvements in economic gains and environmental benefits.

Table 4.22: Pairwise comparisons of option for each pillar of sustainability

Pairwise comparation

The left-hand side (criterion) is compared with the top (criterion)

Social sustanability	Options	1	2	3	4	5	6	7	8
0.377	1	1	5	3	9	3	7	3	9
0.212	2	0.2	1	3	5	3	5	3	7
0.075	3	0.333	0.333	1	3	1	1	0.333	3
0.029	4	0.111	0.2	0.333	1	0.333	1	.2	0.333
0.065	5	0.333	0.333	1.	3.	1	1	0.333	1
0.044	6	0.143	0.2	1.	1.	1.	1	0.2	1
0.156	7	0.333	0.333	3.	5.	3.	5.	1	5
0.042	8	0.111	0.143	0.333	3.	1.	1.	0.2	1

Pairwise comparation

The left-hand side (criterion) is compared with the top (criterion)

Economic sustanability	Options	1	2	3	4	5	6	7	8
0.030	1	1	0.2	1	1	0.143	0.2	0.333	0.111
0.184	2	5.	1	5	3	1	0.333	3	3
0.027	3	1.	0.2	1	0.333	0.143	0.2	0.333	0.111
0.046	4	1.	0.333	3.	1	0.2	0.333	0.333	0.2
0.243	5	7.	1.	7.	5.	1	1	5	3
0.246	6	5.	3.	5.	3.	1.	1	3	3
0.071	7	3.	0.333	3.	3.	0.2	0.333	1	0.333
0.153	8	9.	0.333	9.	5.	0.333	0.333	3.	1

Pairwise comparation

The left-hand side (criterion) is compared with the top (criterion)

Environmen sustanability	Options	1	2	3	4	5	6	7	8
0.028	1	1	0.111	1	0.111	0.333	0.2	0.333	1
0.135	2	9.	1	7	0.143	1	1	1	7
0.030	3	1.	0.143	1	0.111	0.333	.333	0.333	1
0.481	4	9.	7.	9.	1	7	5	7	9
0.095	5	3.	1.	3.	0.143	1	1	1	5
0.111	6	5.	1.	3.003	0.2	1.	1	1	7
0.095	7	3.	1.	3.	0.143	1.	1.	1	5
0.025	8	1.	0.143	1.	0.111	0.2	0.143	0.2	1

4.3.3.3. Multi-Criteria Analysis (MCA) Evaluation

The analysis matrix results show how each measure performs with respect to each sustainable development pillar/criterion. It shows only the score of measures for individual pillar, not the aggregate score. It does not tell us the overall aggregate performance of measures. Therefore, the most important procedure in Multi Criteria Analysis is that we need to convert the partial scores performance of each measure for each single criterion into overall score to make ranking in terms of sustainable development. Decision rules in this study refers to the way we aggregate individual preferences for individual criterion into a overall preference and then make ranking of measures. The decision rules chosen for implementation in the this study include (i) Simple Additive Weighting (SAW), (ii) Order Weighting Average (OWA), and (iii) Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). The use of these three methods increase the robustness of results since findings can be strengthened through triangulation. The ranking of adaptation and mitigation measures is based on the following two criteria weighting frameworks:

1. As stated in the EMP document and based on the TBL framework with the interpretation of sustainability that places equal priority on environmental, social, and economic aspects in decision-making, each pillar is equally important and

2. Based on Wedding Cake Framework, but weights generated from the pairwise comparison result. The DPSIR framework, on the other hand, has been criticized for favoring the

environmental aspect of sustainability.

I. Simple Additive Weighting (SAW) Decision Rule

The Triple Bottom Line (TBL) Framework, where criteria are intended to be seen as equally essential, and based on the criteria weighting results utilizing the Wedding Cake Framework, are the foundations for the Simple Additive Weighting (SAW) responses in Figure 4.5 (see Figure 4.5a and 4.5b under Triple bottom line and Wedding cake frameworks respectively). According to the triple bottom line sustainability framework, farmer training and extension courses have the best sustainability score (0.4967), whereas settlement and compensation payments have the lowest score (0.0467). The Livestock development measure has a score of 0.413 (83% relative to the score of training and extension courses), however the settlement and compensation payment measure has a score of just 9% relative to the training and extension courses. In the wedding cake framework, planting forest seedlings has the maximum value (0.6959), while settlement and compensation payments receive the lowest score (0.0149), amounting to only 2% relative to the maximum value. Irrigation agronomic practices receive the second highest grade, accounting for around 56 % in comparison to forest seedling plantings.

In the context of sustainability analysis of various measures, farmer training and extension courses are found to be the best adaptation and mitigation measure to achieve sustainability. These measures are the most preferred from the standpoint of sustainability, according to the SAW decision rule in triple bottom line framework. The second most preferred measure is livestock development activities, while settlement and compensation payment are the least preferred (see Figure 4.5a). However according the wedding cake framework, when pairwise comparisons (PWC) of criteria weights are taken into consideration in Table 4.18, planting forest seedlings is the most preferred measure, followed by irrigation agronomic practices (see Figure 4.5b). The findings suggest that the performance of different EIA recommended measures in promoting sustainable development depends on the assumption of whether the three pillars (economic, social, and environmental) have equal relative importance or not. For example, when considering the environment as a foundation for the other pillars, the score for planting forest seedlings outperforms other measures, creating a wider relative performance gap in terms of sustainability score. The implication of these findings is that measures other than planting forest seedlings perform relatively poorly as far as sustainable development is concerned. If the area fail to show good progress towards planting, it is equivalent to a failure in sustainable development arena. It seems that there are limited ways to achieve sustainability other than planting forests for sustainability. The degree of substitutability for these measures is low. The Koga scheme office, due to its limited options for achieving sustainable development, seems primarily relies on planting forest seedlings.

The discussion of some livestock contributions is worth mentioning because the researcher thought it was an unexpected finding and intended to provide possible explanations on this. Livestock development for sustainable development is supported through its contribution to social, economic, and environmental goals in various literature, mostly positive, with a few negative interactions and trade-offs (Schneider and Tarawali , 2021). The livestock sector is an important contributor for agricultural GDP in least developed countries, like Ethiopia, and this figure is rising. Livestock usually serve as primarily insurance and financing. In the poorest countries, livestock dung accounts for more than 70 percent of soil fertility additions, and approximately 90 percent of animal products are produced and consumed in the same country or region, with vital nutrients (ILRI , 2017). Livestock is important to rural livelihoods for producers and others involved in the value chain because it has a high value, especially when compared to crops, elevating one's social standing. The richest people in rural poor in various African countries associated with livestock holdings, as well as non-farm sources (Herrero et al. , 2012). According to Capper (2017), however, the livestock sub-sector failed to find a balance economic gains, environmental benefits, and social acceptance. Whereas, the sector has relatively achieved good performance score on the economic pillar than the rest two pillars of sustainable development (see Table 4.20).

The Koga scheme was supposed to use the Koga River's water resources for irrigation, forestry, livestock, soil conservation, water and sanitation. There were some evidence that livestock development could contribute to the sustainable development, with little trade offs. Income from livestock is one of the most popular sources of non-farm income in Ethiopia. The current study discovered that off-farm income (also known as non-farm income) improved technical efficiency by removing financial constraints on the timely acquisition of inputs such as labor, capital, and fertilizers. It was shown that there is direct connection between off-farm revenue and economic sustainability. Farmers with higher non-farm income have been found to be more economically sustainable, showing a proclivity to produce on the frontier. However, there is dilemma for poor people between selling their (expensive) livestock products or consuming high-nutrient products. In Koga scheme, the average value of cattle sold per household per year is low. The obvious objective is to use animals for draught power, transportation, and domestic consumption (ADF , 2001). Livestock consumption in the study area can improve households' nutritional and health. A small amount of animal source foods have been found to contribute to dietary requirements and the prevention of undernutrition and nutritional deficiencies. Not only can livestock play a socio-economic role in rural farming societies, but interactions between livestock and the environment in poor countries can be beneficial. The environmental benefits are attributable in part to the irrigation of fodder crops for animals and the reduction of deforestation. One of the project outputs, the objectively verifiable indicators was farmers' ability to participate in intensive livestock production. The consideration of the role of the livestock sub-sector in socioeconomic and environmental advantages above all reveals that livestock development are an important aspect of sustainable development.

An initial assessment of the situation of livestock development revealed that the diversion of the course of the Koga River during dam building caused pollution of Burqa Spring, which served as the main source of water for livestock and people. As a result, no one desired this project and wished it would go away. Large grazing area was lost and pasture land available in the command area was limited. These factors resulted a decline in livestock production, as well as a decrease in milk and related goods (Gebre et al. , 2008). Many households had to give up livestock-related occupations due to the limited capacity for cattle. They had to sell their livestock because there was no longer any pasture available (Eguavoen and Tesfai , 2012).

OPTIONS:	Score:	% (relative to 1st position)
2	0.4967	100%
5	0.413	83%
6	0.4096	82%
4	0.363	73%
1	0.3407	68%
7	0.2368	47%
8	0.2065	41%
3	0.0467	9%

(a) Responses of Simple Additive Weighting (SAW) in the Triple Bottom Line framework

OPTIONS:	Score:	% (relative to 1st position)
4	0.6959	100%
6	0.3952	56%
2	0.3855	55%
5	0.3695	53%
7	0.1765	25%
8	0.1562	22%
1	0.0724	10%
3	0.0149	2%

(b) Responses of Simple Additive Weighting (SAW) in the Wedding Cake framework

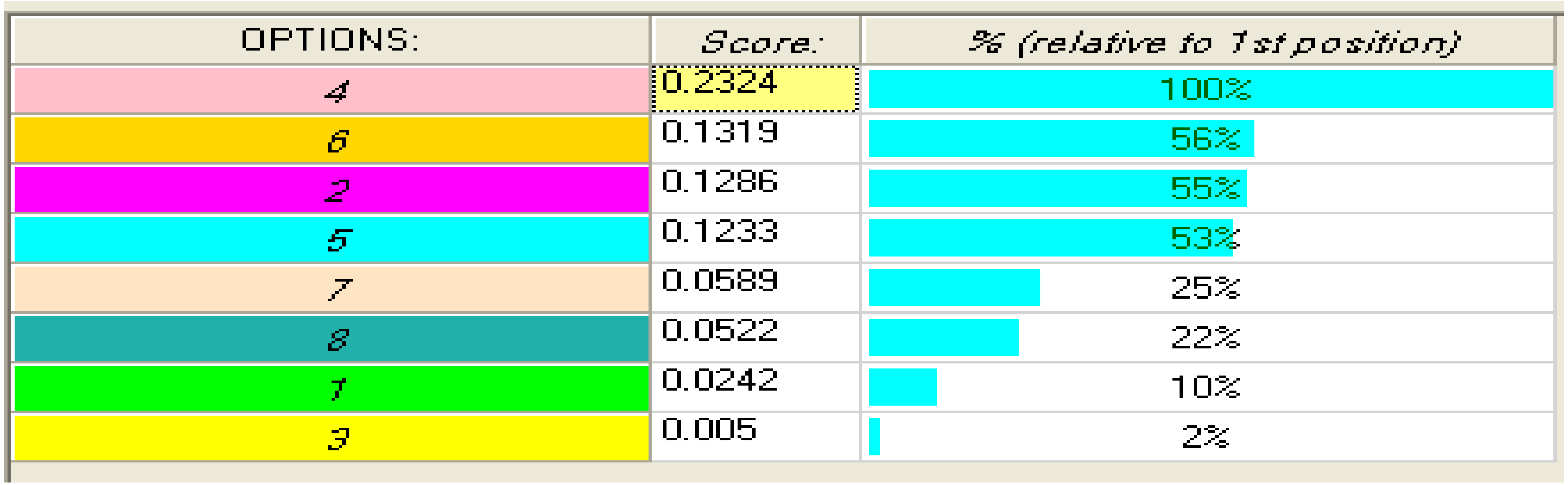
Figure 4.5: Responses under Simple Additive Weighting (SAW) and criteria weighting framework

II. Order Weighting Average (OWA) Decision Rule

The following Figure 4.6 shows the responses under Order Weighting Average (OWA) decison rule in the two frameworks. When the three pillars are considered equally important in triple bottom line framework, planting forest seedlings is the most preferred measure, followed by irrigation agronomic procedures. The relative performance of the second sustainable measure is 56 percent relative to the first (see Figure 4.6a). Based on PWC results of wedding cake framework, training and extension courses for farmers, on the other hand, have been found to be the best adaptation and mitigation measure to ensure sustainability. Irrigation agronomic practices are the second most preferred sustainable adaptation measure (67 percent relative to the first)(see Figure 4.6b). In three circumstances, irrigated agronomic practices—a sustainable solution—appeared as the second-best measure under the SAW and OWA decision rules. The Koga scheme in Ethiopia demonstrates how sustainable agriculture can be achieved through the implementation of various practices, such as terracing, contour farming, crop diversification, water-saving irrigation techniques, and agroforestry. These practices have been shown to promote soil conservation, crop diversification, efficient water management, and agroforestry. By improving productivity, enhancing ecosystem services, and improving food security and livelihoods for local communities, these irrigation agronomic practices have proven effective in the Koga scheme area.

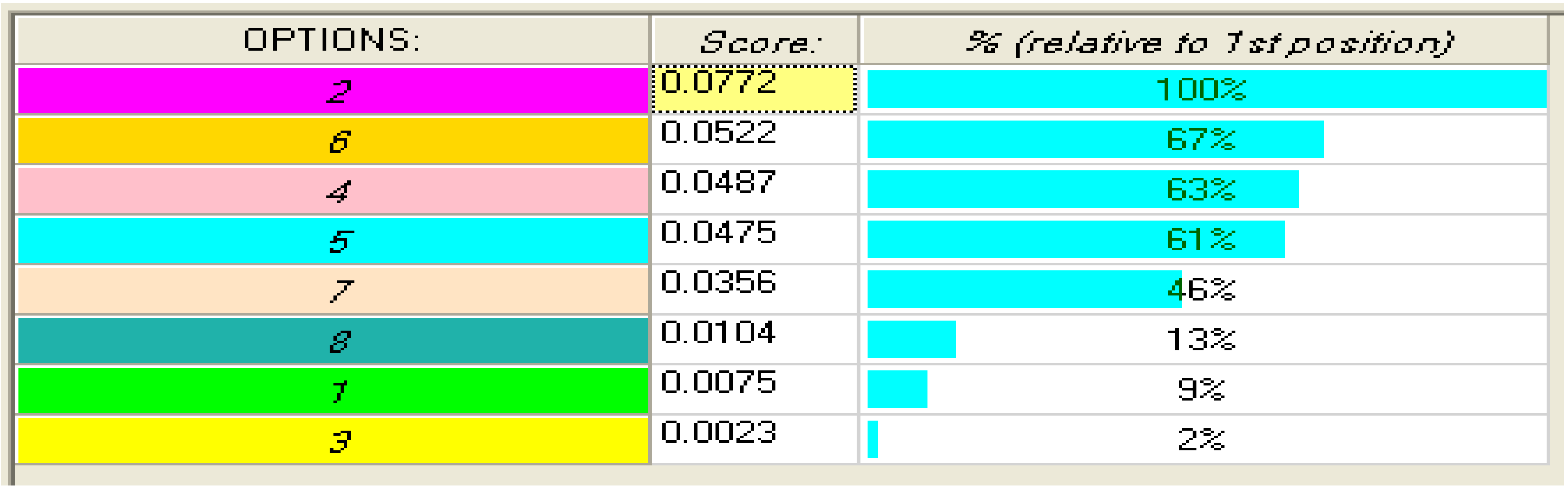
Terracing and contour farming in the Koga scheme contributed to soil erosion and maintain fertility, and long term productivity Mekonnen et al. (2016). Abebe et al. (2015) emphasize the importance of crop diversification for enhancing agricultural sustainability and resilience to climate change, as it reduces crop failure risk, improves soil fertility, and maintains ecosystem services, ultimately contributing to food security and income generation for local communities. Drip and sprinkler irrigations have been adopted in the area to optimize water use and reduce water scarcity (Tadesse et al. , 2018). These techniques help conserve water resources and maintain agricultural productivity. Bishaw et al. (2017) highlight the benefits of integrating agro-forestry practices into the project's agricultural systems, as they contribute to sustainable development by enhancing biodiversity, improving soil fertility, and providing additional income sources for local communities. Mekuria et al. (2015) found that the use of organic fertilizers, crop rotation, and intercropping significantly improved soil fertility and crop yield, contributing to sustainable development. Tesfaye et al. (2014) found that drip irrigation and rainwater harvesting reduced water consumption, leading to increased agricultural productivity and sustainable development. The integration of trees into agricultural systems has been shown to increase biodiversity, enhance carbon sequestration, and improve soil fertility, all of which contribute to sustainable development (Woldemariam et al. , 2016). Agronomic practices led to increased income, reduced poverty, and improved food security for the local community (Getahun et al. , 2014). Assefa et al. (2015) found that planting drought-tolerant crop varieties and improved water management, helped farmers better cope with climate change-induced stresses, enhancing their resilience and adaptation capacity.

The literature confirmed the various contributions of irrigation agronomic practices in different aspects of sustainable development, supporting the economic, social and environmental objectives.



OPTIONS:	Score:	% (relative to 1st position)
4	0.2324	100%
6	0.1319	56%
2	0.1286	55%
5	0.1233	53%
7	0.0589	25%
8	0.0522	22%
1	0.0242	10%
3	0.005	2%

(a) Responses of Order Weighted Average (OWA) in the Triple Bottom Line framework



OPTIONS:	Score:	% (relative to 1st position)
2	0.0772	100%
6	0.0522	67%
4	0.0487	63%
5	0.0475	61%
7	0.0356	46%
8	0.0104	13%
1	0.0075	9%
3	0.0023	2%

(b) Responses of Order Weighted Average (OWA) in the Wedding Cake framework

Figure 4.6: Responses under Order Weighted Average (OWA) and criteria weighting framework

III. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) Decision Rule

The closeness to the ideal best solution measure is provided in Tables 4.23 and 4.24, showing the details of weighted normalized matrices outputs in the two frameworks of criteria weighting. When criteria are expected to be considered equally, planting forest seedlings is the most preferred measure, followed by training and extension courses for farmers. The relative performance of the second sustainable measure is 86 percent that of the first (see Figure 4.7a in Figure 4.7). When a PWC of the Wedding Cake framework is taken, the same ranking results between the first and the second most preferred measures, but with a relative performance of 34 percent compared to the first (see Figure 4.7b). When the

Table 4.23: TOPSIS Weighted Normalized Matrix in the Triple Bottom Line framework

				Distance from the ideal solution	0.289	0.251	0.329	0.329	0.327	0.318	0.377	0.392
				Distance from the ideal neg.	0.286	0.19	0.245	0.178	0.174	0.105	0.098	0.032
	Ideal solution	Ideal solution		SCORE	0.497	0.431	0.426	0.351	0.348	0.249	0.206	0.077
Weights	point positiv	point negativ	Type	Criteria \ Options	4	2	1	6	5	7	8	3
0.334	0.265	0.0204	HIGHER is better	Social sustanability	0.0204	0.149	0.265	0.0309	0.0457	0.1097	0.0295	0.0527
0.333	0.1901	0.0209	HIGHER is better	Economic sustanability	0.0356	0.1422	0.0232	0.1901	0.1878	0.0549	0.1183	0.0209
0.333	0.3015	0.0157	HIGHER is better	Environmental sustanability	0.3015	0.0846	0.0175	0.0696	0.0595	0.0595	0.0157	0.0188

Table 4.24: TOPSIS Weighted Normalized Matrix in the Wedding Cake framework

				Distance from the ideal solution	0.131	0.44	0.47	0.49	0.501	0.581	0.588	0.588
				Distance from the ideal neg.	0.577	0.171	0.173	0.16	0.094	0.078	0.046	0.009
	Ideal solution	Ideal solution		SCORE	0.815	0.28	0.269	0.246	0.158	0.118	0.073	0.015
Weights	point positiv	point negativ	Type	Criteria \ Options	4	2	6	5	7	8	1	3
0.063	0.05	0.0038	HIGHER is better	Social sustanability	0.0038	0.0281	0.0058	0.0086	0.0207	0.0056	0.05	0.0099
0.265	0.1513	0.0166	HIGHER is better	Economic sustanability	0.0283	0.1132	0.1513	0.1495	0.0437	0.0941	0.0185	0.0166
0.672	0.6084	0.0316	HIGHER is better	Environmental sustanability	0.6084	0.1708	0.1404	0.1202	0.1202	0.0316	0.0354	0.0379

Response of TOPSIS is considered under equal relative importance of pillars, the performance of measures are more balanced (i.e., the sixth preferred measure accounts for 50 percent of the first most referenced choice)(see Figure 4.7a in Figure 4.7). This suggests that the office and other stakeholders have many and different range of measures to choose from when it comes to sustainable development. If one measure fails, it can be compensated for by other measures in terms of sustainable development. There are indeed multiple roads to sustainable development, and each measure contributes to the overall goal in different ways. In contrast, under the same decision rule in wedding cake framework, there is a substantially more imbalanced performance of measures (i.e. the second preferred measure accounts for just 34 percent of the first most preferred alternative)(see Figure 4.7b). There is a huge difference in measures' performance. Planting forest seedlings appears to be the sole means of achieving sustainability. The failure of planting forest seedlings measure cannot be compensated for by other measures in terms of sustainable development. There is, indeed, a singular, if not limited, path to achieving sustainable development. Commitments towards sustainable development in the Koga scheme appears to be solely dependent on environmental measures, particularly afforestation.

OPTIONS:	Score:	% (relative to 1st position)
4	0.497	100%
2	0.431	86%
1	0.426	85%
6	0.351	70%
5	0.348	70%
7	0.249	50%
8	0.206	41%
3	0.077	15%

(a) Responses of Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) in the Triple Bottom Line framework

OPTIONS:	Score:	% (relative to 1st position)
4	0.815	100%
2	0.28	34%
6	0.269	33%
5	0.246	30%
7	0.158	19%
8	0.118	14%
1	0.073	8%
3	0.015	1%

(b) Responses of Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) in the Wedding Cake framework

Figure 4.7: Responses under Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and criteria weighting frameworks

In terms of health measures, the study discovered that, unlike in most cases, it is thought to be one of the top three rankings that are fundamental to the three pillars of sustainable development (see Figure 4.7a). Investments in health, particularly in disease prevention, boost a country's economic output through improving educational attainment and skill acquisition, labor productivity and employment, and higher savings and investment. The scheme was supposed to target development prospects such as health in the Koga scheme area. The Bureau of Health was one of the institutions whose actions were expected to have an impact on the project. The scheme was supposed to fund operations related to health care, sanitation, water-borne diseases, as well as HIV/AIDS control awareness, but also help raise the productivity of labor. It was able to minimize the negative the expected consequences on HIV/AIDS resulted from the surge of employees during the dam construction period (ADF , 2001).

Other measures that are considered to be less preferable for sustained development include marketing activities, and settlement and compensation payments. In terms of marketing, agricultural production and productivity growth would be relevant and sustainable only if there was a sufficient and reliable market to absorb the surplus produce. Market for surplus output can help farmers to maintain production and productivity of products of particulary easily perishable products. The main irrigation issues anticipated was farmers' lack of crop marketing during the initial stage of project implementation (Eguavoen , 2011). The renovation of the Bahar Dar-Addis-Abeba road, which goes through Merawi, has the potential to expose the town to a larger national market. The seed companies were certain that they could market the entire crop. Local officials were optimistic that the command's output could be easily sold locally. Water Users Associations were expected to serve as a foundation for cooperative or collective marketing of certain products (ADF , 2001). However, research suggests that farmers perceived a market problem. There were few, if any, actual attempts made by accountable institutions to address the market problem. The efforts were fruitless (Yilak , 2013). The main issue that reduced the scheme's efficiency was a lack of market access (Getnet et al. , 2021). Unlike the performance score of settlement and compensation payment's contribution to sustainable development, ADF (2001) believed that resolving resettlement and re-distribution difficulties was a critical prerequisite. The relevance of social issues in the scheme's resettlement and compensation strategy cannot be overstated. Fair, open re-settlement and redistribution criteria are thought to be important to the overall success.

Synthesizing the response results of different decision rules above, the most sustainable measure is either training and extension courses or planting forest seedlings, but the least sustainable EIA-recommended mitigation measure is settlement and compensation payment. It was determined that planting forest seedling is most preferred in two of the three decision rules used for the analysis in both Triple Bottom Line and Wedding Cake frameworks. Furthermore, when the environment is used as the foundation for other economic and social sustainability, such as a wedding cake framework, planting forests appears to be the only method to achieve sustainable development in some circumstances. Moreover, planting forest seedlings is the most favoured EIA recommended sustainable development measure, in four of the six cases, it came out on top.

Afforestation has the ability to give sustainable development benefits by lowering waste, slowing soil deterioration, regulating water runoff, and, in the case of large land areas, influencing local weather patterns. According to Gebre et al. (2008), approximately 30 percent of the area in the scheme is used for grazing and forestry. The initiative was expected to promote the planting of individual trees, multipurpose trees, forage, fruit, and so on in the upstream. The aim was to decrease siltation from catchment to dam by about up to

50 percent . Unlike the initiative, however, it was unsuccessful and deforestation is the common practice in the area (ADF , 2001). The are offices, such as, the Bureau of Agriculture (BOA) that promotes afforestation, and farmers start planting tree around major roads for market purposes. Furthermore, eucalyptus is the most often planted species, despite its role in soil fertility is still debatable. Farmers know many indigenous tree species that have different uses, but they are drawn to Eucalyptus due to their high growth rate and guaranteed market. Nowadays, Eucalyptus tree planting along farm field borders have become a defining characteristics of Ethiopia's central highlands, particularly the Koga Watershed. Eucalyptus was the most commonly planted tree in the area (Alemie , 2009), particularly in Ambomesk and Enguty command area blocks (Chanie et al. , 2013). Moreover, farmers were spotted growing more trees in 2011 and 2012, turning their crop fields to eucalyptus vegetation (Yeshaneh et al. , 2013). Between 2001 and 2014, Eucalyptus trees were largely planted in mixed fields with maize and eucalyptus, as well as on cultivated land. The year 2014 saw a significant quantity of cultivated land converted to Eucalyptus tree plantation (Biru et al. , 2015). The amount of the farm covered by trees in the study by Chanie et al. (2013) was typically between 0.15 and 0.25 hectares. However, in a few large farms, the plantings were much larger, ranging from 1 to 2 hectares. When we compared the average total land size of 1.39 hectares of the households sampled with 0.25 hectares the tree covered, it just about 18 percent of their land. The figure so significant, as planting the tree means a lot to farmers and overall landscape of these farms in terms of crop production. The conversion of croplands into eucalyptus plantations in the Koga project in Ethiopia has several implications, both positive and negative. The area's tree planting was planned for fuel wood, income generating, and construction. Environmental conservation was not stated as a planting aim (Chanie et al. , 2013), and no one mentioned the tree planting was intended for environmental conservation (Alemie , 2009).

The environmental benefits of eucalyptus afforestation are controversial. Fortunately, some areas were recently converted from eucalyptus woodlots to irrigated. The question was what would happen to fate of croplands that had been converted to the tree if it were necessary to return to farming after tree harvests multiple times, say 4 to 5. The results found to be conceivable without compromising soil characteristics or crop productivity, informing the conversion to crop fields as needed (Yitaferu et al. , 2013). On the contrary, this tree planting activity within 20 metres of crop fields damaged soil nutrients, and found to reduce maize yield. Moreover, largest negative effects when planted east, and the least when planted north of agriculture (Chanie et al. , 2013). Crops should be grown at a distance of at least 15 metres from Eucalyptus stands (Alemie , 2009). The negative repercussions are primarily due to inadequate management. Being an efficient water user and absorbs more nutrients from the soil, it grows quickly. Through applying adequate management it could contributes environmental restoration, as well as tackling socio-economic problems. Therefore, there are no compelling justifications that don't support planting eucalyptus in Ethiopia (Zegeye , 2010). Since priority in Koga scheme is food security , eucalyptus trees shall be on marginal lands, including wetlands and wastelands (Alemie , 2009).

Due to its potentially harmful environmental impact, the transformation of agricultural lands into eucalyptus plantations, focusing on eucalyptus as a means of income generation rather than believing in its environmental benefits, it does not fully comprehend the idea of planting forest seedlings (as farmers are primarily planting eucalyptus) as a sustainable solution in Koga scheme. Contrary to expectations and the results of multi-criteria analysis under various decision rules, forest seedling plantation may have a negative impact on sustainable development efforts, largely due to potential environmental damage of eucalyptus and a danger to food security. This is because farmers are turning fertile croplands into eucalyptus plantations. One major concern is that forestation may impair food security, as it has placed fertile agricultural land at risk. This issue arises when forests are established on land that was previously used for agriculture, potentially reducing the availability of food resources. This can negatively impact food availability in the area. Proper planting and management are essential to ensure that the planting forest seedling contributes to sustainable development while minimizing potential negative consequences.

4.3.3.4. Sustainability analysis: balancing effect

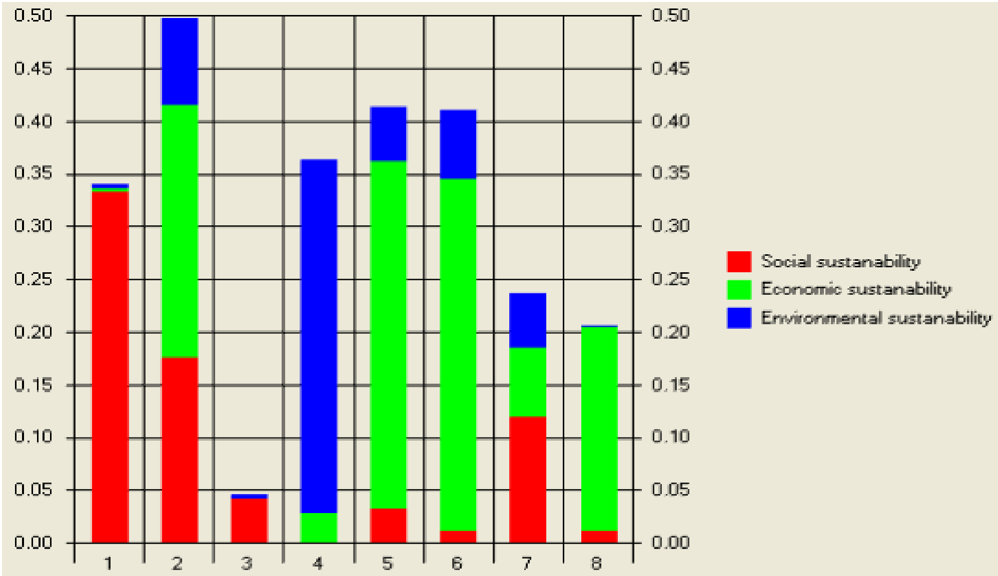
Some adaptation and mitigation activities produce synergies for sustainable development, while others include trade-offs. Measures that are more environmentally sustainable are less likely to be economically viable. Social considerations can lead to improved economic viability. Sometimes farmers must choose between economic and environmental benefits, as well as environmental and social gains. This, however, is consistent with the claim that economic gains contributed to social challenges, as income and financial prosperity are essential aspects for improved social services (Ait et al. , 2022). In certain cases, interconnections may have unintended negative consequences, whereas in others, the combination of sustainability pillars provide trade-offs and synergetic linkages. Problems produced by environmental and economic imbalances frequently result in resource drains at the local level, prompting state and local government authorities to seek measures to overcome such imbalances. According to the World Resources Institute, sustainability entails, at a minimum, interacting economic, social, and environmental elements that aim to "reconcile or build a balance" between these factors (Hammond et al. , 1995). Adaptation measures must be all-inclusive. This means they must address the individual demands of all impacted stakeholders while keeping in mind that groups' needs will differ. As a result, transitioning to measures that balances various sustainable development objectives necessitate planning and implementing appropriate strategies. It is now necessary for governments to provide detailed reports on how they are carrying out their integrated promises and commitments.

Sustainable adaptations differs from general adaptation, through their focus for social justice and environmental integrity; that is, sustainable adaptation considers (or does not substantially undermine) these two aspects. Sustainable adaptation ensures that no one is left behind. It refers, at least in this study, to balancing the three social, economic, and environmental goals. The concept of sustainable adaptation calls into question development routes that contribute to unfairness and poverty. Some adjustments may have no effect on social equality or environmental integrity. However, research on how stakeholders address concerns of sustainable adaptation and maladaptation is scarce. This section seeks to explore how sustainable adaptation is viewed in order to further boost the adaptation agenda. How sustainable is current adaptation in terms of its balancing effect? What can we learn from EIA recommended measures to inform sustainable adaptation? Striking an optimal balance between the three pilars is still a major difficulty in sustainable development. Adaptation needs to be tailored into EMP decision making to meet different needs and circumstances. This section investigates how EIA-recommended adaptation and mitigation measures balance the social, economic, and environmental criteria. By doing a sustainability analysis, it is determined how well various measures balance the three pillars of sustainability. It depicts how each measure is inclined or balanced in relation to the pillars.

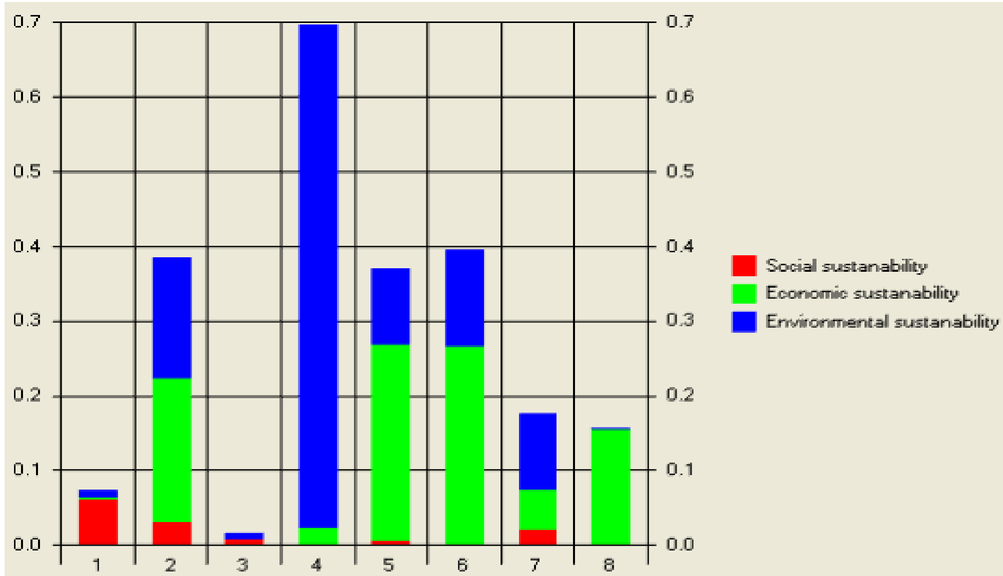
The total score results in the previous section were decomposed into pillars' contribution. By doing so, we can clearly identify how measures fared at individual sustainable development criterion and the total score distribution among pillars to determine the performance of each measure's balancing effect. The partial scores measure the performance of each EIA recommended measures in each sustainable development criterion. Table 4.25, 4.26 and Figure 4.8 show the total score of each measure, the contribution given to that score by the partial scores. The ranking histogram result in Figure 4.8 has a special feature that illustrates how each mitigation measure performs in terms of balancing pillars. This feature aids in determining the sustainability analysis of each alternative in terms of balancing. As a result, the ranking histograms and tables can be used to assess the sustainability of any EIA-recommended measure in Figure 4.9, 4.10, 4.11a, 4.11b, 4.12a and 4.12b. The most preferred and chosen measure in the previous section may not be a realistic solution in terms of balancing. Almost all adaptation and mitigation measures maintained imbalance scores across three pillars, even while the majority of high sustainability ranking scorer measures had an imbalance score. This demonstrates considerable existing trade-offs across all pillars. Among the bottom-ranking measures, cooperative organization maintained balanced scores across the three pillars in terms of balancing. Furthermore, the economic pillar was more predominant overall.

The weights for the macro criteria and sum are shown in Tables 4.25 and 4.26. The challenge is that we need all three for a sustainable future, despite the fact that they all involve tradeoffs and may pull in opposing ways. However, the economic, social, and environmental sectors can all be 'optimized' or prioritized in different ways. "A cord of three strands is not easily broken," the Bible says. Similarly, human civilisation may only be regarded to be really sustainable if all three pillars of sustainability are met. In some ways, 'sustainability' is the best indicator of the success of the others. If economic requirements take precedence above environmental concerns, the environment may collapse, resulting in the collapse of economic activities. As seen the share of each pillar in the table below, livestock development, irrigation agronomic methods, and marketing activities are more oriented toward the economic pillar, which may endanger the environment and social aspects (see the share of economic sustainability for the three adaptation and mitigation measures). While when the environment is sought at the expense of the economic or social, such as planting forest seedlings, it can result in a backlash of activity, such as desperate and famished farmers. Similar effects occur when the social is pursued at the expense of others, such as public health and settlement and compensation payments.

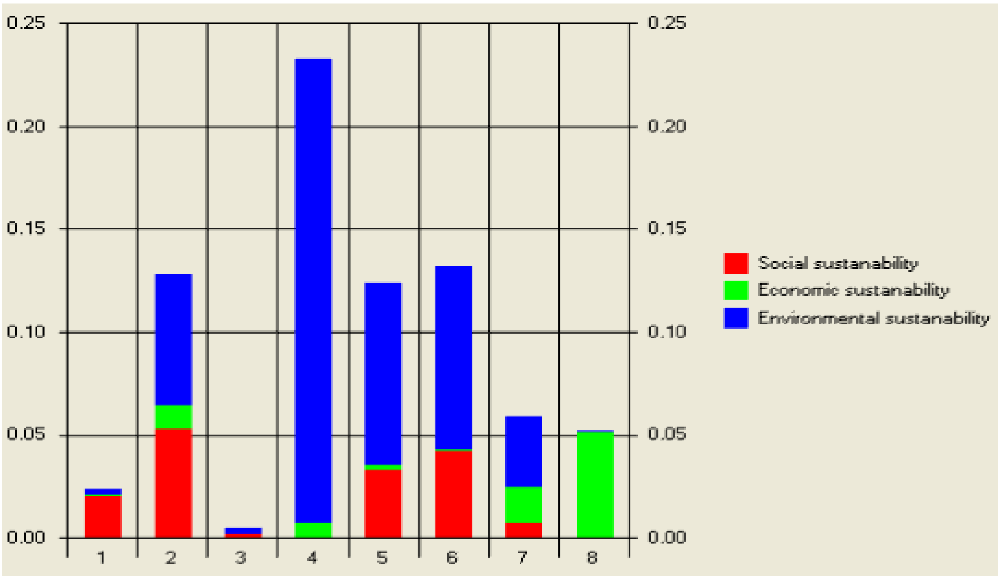
We can only approach sustainability if all three are recognized according to balancing effect in sustainabiity. Training and extension courses, as well as cooperative organizations, are excellent measures in this regard, relatively fared better. They optimize the three sustainability pillars. In the similar way, the stacked bar charts in Figure 4.8 have approximately equal sizes, indicating more balance for cooperative organization and training and extension courses for farmers. This interpretation of balanced and unbalanced measures corresponds to the sustainable char shown in Figure 4.9, 4.10, 4.11a, and 4.11b. If the total score in Table 4.25 and 4.26 were evenly distributed across the pillars, the spot indicating the best balancing performance would be in the center of the triangle shown in Figure 4.9 and Figure 4.10. The poor performance of measures in terms of balancing is explained by the position of each spot's particular measure. The dots are mostly closer to the triangle's corners, indicating that the measures are not equally suitable to achieving the three pillars. The position of the spots intended to show the EIA recommended measures' balance performance, without considering their overall performance and ranking that are represented with size of the circles in the charts. As a result, cooperative organization and training and extension courses for farmers mitigation measures are located near the center of the triangle. Public health, planting forest seedlings and marketing activity measures are closer to the corners, indicating the most unbalanced measures (see Figure 4.9 and 4.10).



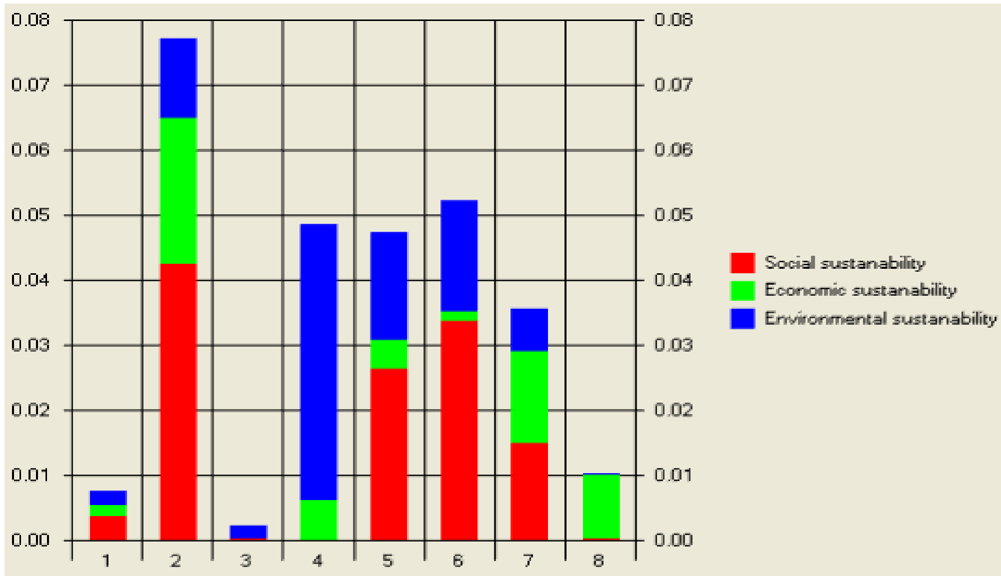
(a) Sustainability of Simple Additive Weighting (SAW) in Triple Bottom Line framework



(b) Sustainability of Simple Additive Weighting (SAW) in Wedding Cake framework



(c) Sustainability of Order Weighted Average (OWA) in Triple Bottom Line framework



(d) Sustainability of Order Weighted Average (OWA) in Wedding Cake framework

Figure 4.8: Ranking Histogram

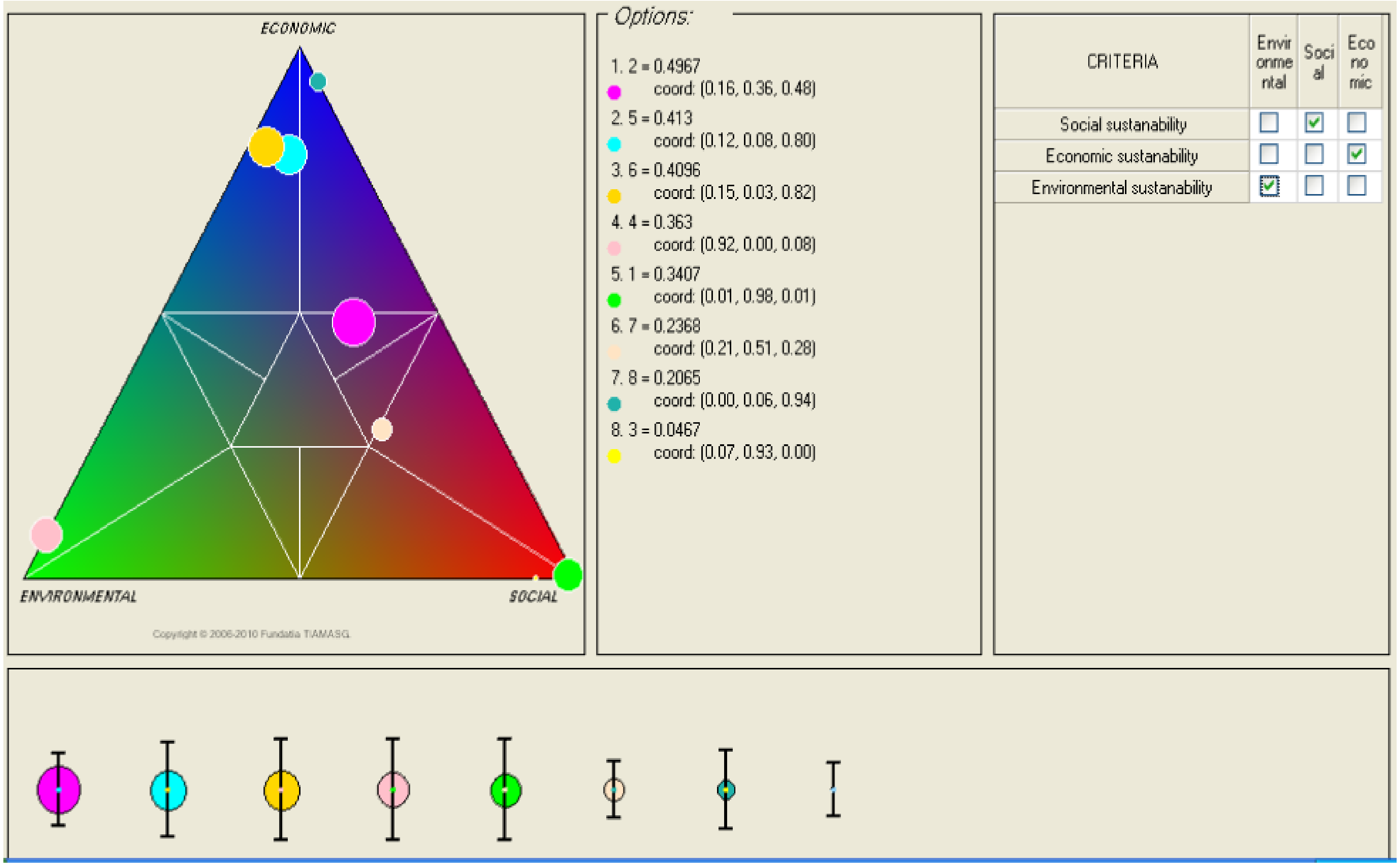


Figure 4.9: Sustainability of Simple Additive Weighting (SAW) in Triple Bottom Line framework

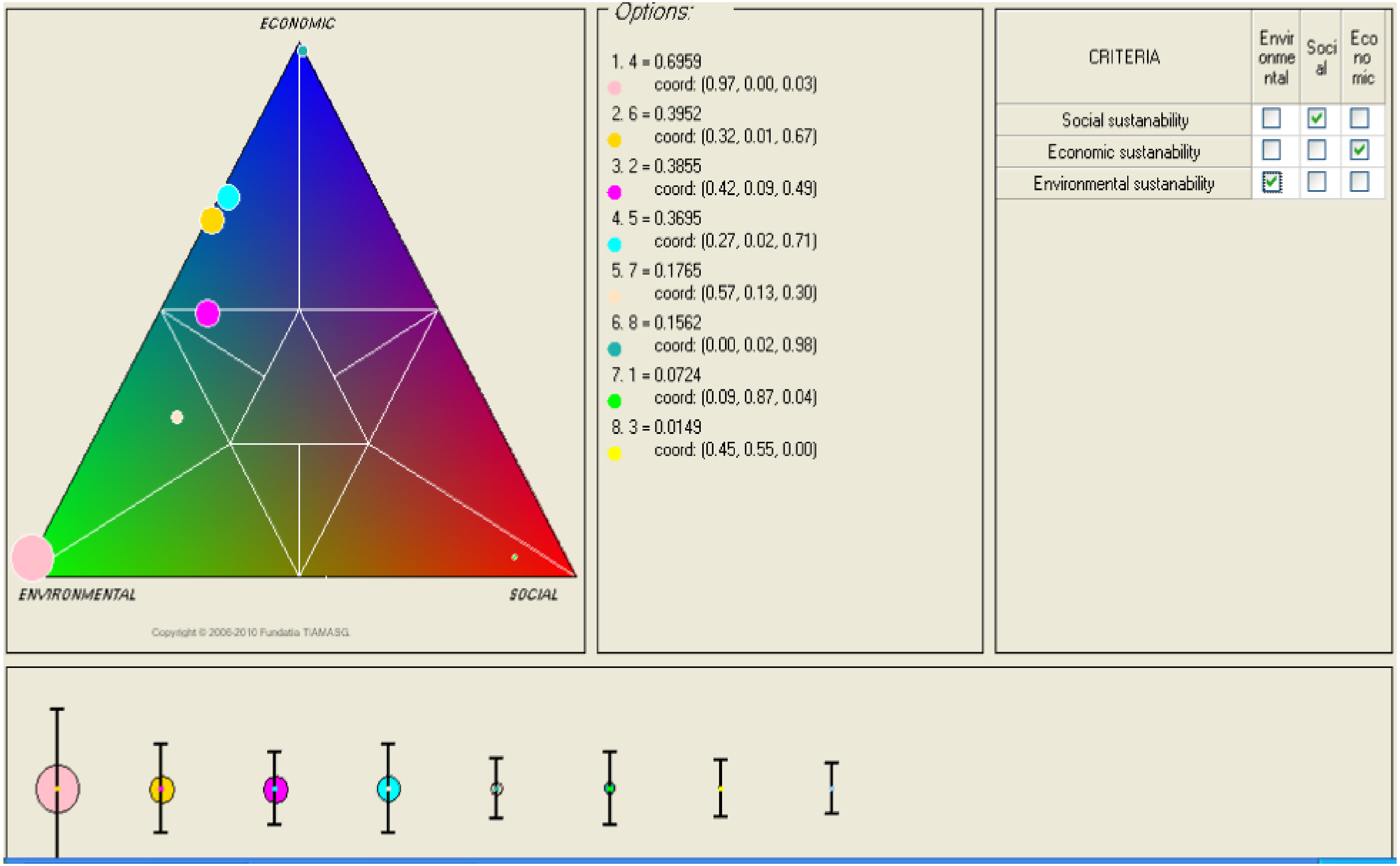


Figure 4.10: Sustainability of Simple Additive Weighting (SAW) in Wedding Cake framework

Table 4.25: Total score of each alternative option, the contribution given to that score by the partial scores Simple Additive Weighting (SAW) in Triple Bottom Line framework

Adaptation and mitigation measures	Social	Economic	Environmental	Total score
Public health	0.334 (98.0%)	0.003 (1.0%)	0.003 (1.0%)	0.3407
Training and extension courses	0.177 (35.6%)	0.240 (48.4%)	0.080 (14.0%)	0.4967
Settlement and compensation payments	0.043 (93.5%)	0.000 (0.0%)	0.003 (6.5%)	0.0467
Planting forest seedlings	0.000 (0.0%)	0.030 (8.3%)	0.333 (91.7%)	0.363
Livestock development	0.033 (8.0%)	0.330 (80.0%)	0.050 (12.0%)	0.413
Irrigation agronomic practices	0.013 (3.2%)	0.333 (81.4%)	0.063 (15.4%)	0.4096
Cooperative organization	0.120 (50.6%)	0.067 (28.3%)	0.050 (21.1%)	0.2368
Marketing activities	0.013 (6.3%)	0.193 (93.7%)	0.000 (0.0%)	0.2065

Sustainability analysis of the various adaptation and mitigation measures exhibits that they almost all perform most strongly on economic sustainability, implying a higher concentration of the measures on economic criteria corner. Despite the fact that environmental sustainability appears to be prominently important in the case of the use of appraisal tools such as EIA, the findings demonstrate that practically almost all measures perform poorly on environmental criteria. It is possible to establish, with a reasonable degree of balance among ecological, economic, and social parameters, if the Environmental Management Plan is likely to succeed in the sustainable development arena. The more difficult it is to make judgments about its sustainability, except in the context of training and extension services for farmers and cooperative organizations in the Koga scheme. Training and extension courses for farmers, as well as cooperative organization, have been determined to be the most sustainable adaptation measures for balancing the three pillars.

There are numerous literature that reveal important aspects of sustainability through extension services in a more balanced manner. The training and extension services touch every aspects of sustainable development pillars. Agricultural extension fulfills several functions in the social, economic, and environmental spheres with little trade-offs in short run. The training programs often address a wide range of topics, including productivity, ecology, social issues, and the relationship between poverty and environmental deterioration. Smallholders can benefit from agricultural extension services in this regard, that Ethiopia is committed to pursuing sustainable development as a UN member state (FAO , 2015).

Extension and training services are seen as a crucial component in some programs, such as Sustainable Development and Poverty Reduction Program (SDPRP) and the Plan for Accelerated and Sustainable Development to End Poverty (PASDEP) (MoFED , 2006). It is an effective tool by removing obstacles of sustainable agricultural development, and improving decision making (Wang et al. , 2021). There are several institution mainly Bureau of Agriculture (BOA) both at zonal and local involved in providing and strengthening extension service and training for farmers in Koga scheme. The service is aiming at both to farmers on rainfed as well as irrigated farms. Farmers choose the cropping pattern based on their circumstances, personal preferences and through guidance from extension workers for economic gains. The technical inefficiency models result also confirm the positive role of advisory service farmers' technical efficiency. The implication is that access to advisory services offers farmers enormous productivity and efficiency gains through the mechanisms of providing access to technical knowledge and new skills and as facilitating the introduction of new technologies. Another significant extension activity was planing the establishment of a smaller and simple farmers' center in Merawi town. The extension service assists farmers in

Table 4.26: Total score of each alternative option, the contribution given to that score by the partial scores Simple Additive Weighting (SAW) in Wedding Cake framework

Adaptation and mitigation measures	Social	Economic	Environmental	Total score
Public health	0.063 (86.3%)	0.003 (4.1%)	0.007 (9.6%)	0.0724
Training and extension courses	0.033 (8.6%)	0.191 (49.6%)	0.161 (41.8%)	0.3855
Settlement and compensation payments	0.008 (53.3%)	0.000 (0.0%)	0.007 (46.7%)	0.0149
Planting forest seedlings	0.000 (0.0%)	0.024 (3.5%)	0.672 (96.5%)	0.6959
Livestock development	0.006 (1.6%)	0.262 (71.0%)	0.101 (27.4%)	0.3695
Irrigation agronomic practices	0.003 (0.7%)	0.265 (67.0%)	0.128 (32.3%)	0.3952
Cooperative organization	0.023 (13.0%)	0.053 (30.0%)	0.101 (57.0%)	0.1765
Marketing activities	0.003 (1.9%)	0.154 (98.1%)	0.000 (0.0%)	0.1562

understanding the benefits of irrigation technology, allowing them to boost crop yield across multiple cropping seasons. However, the crop intensity in Koga scheme is only twice a year, despite three time is a common practice in irrigation. This part due to inadequate extension service support (Yilak , 2013).

Another focus area in social issues include coping with the effects of HIV/AIDS and other agricultural health challenges; concentrate on gender, equity, and empowerment in relation to sustainable agricultural production (Anderson , 2008). In particular, it is necessary to emphasize the issues of sensitization and attitude in society. In 2010, training programs were not yet implemented to compensate for the impact on livelihoods caused by the scheme, as it was suggested in the EMP report (Eguavoen and Tesfai , 2012). Sustainable farming and natural resource management are generally knowledge-intensive fields that necessitate the application of general ecological concepts to a specific context and natural resources conservation in a sustainable manner (Swanson , 2008). This, in turn, is dependent on the quality of farmer training and extension services (Garforth and Lawrence , 1997). Soil and water conservation that benefit the environment is positively associated with the use of extension service (Danso , 2022). Extension services are one of the important sub-components of the watershed management component that has attracted attention in Koga scheme. The main conservation and watershed preservation effort was intended to focus on farmer demonstration and training in broad conservation agriculture practices. A successful, coordinated agricultural extension service is one of the objectively verifiable indicators of environmental conservation. Environmental training and awareness development are also incorporated as project components to ensure sustainability of the project (ADF , 2001). The watershed management training was designed for both the upstream and downstream kebeles, as well as experience-sharing in Tigray and Oromia regions (Gebre et al. , 2008). The water application efficiency rated good due to best practices of extension workers and the requisite training (Getnet et al. , 2021).

The success of sustainable agriculture depends not just on the motives, abilities, and expertise of individual farmers, but also on collective action by groups or communities. Individuals in positions of leadership in communities, not just farmers, must have skills that are vital to the Water Users' Association. This emphasizes the importance of WUA organizational leadership training programs. There is a need for new skills for WUA leaders; they should have a deeper awareness of technical disciplines connected to water users, irrigation system operation and administration, and economics, ecology, legal and social elements. The awareness creation is one area of intervention, which cooperatives actively work on a regular basis to their members. The extension service and cooperative organization adaptation and mitigation measures complement each other, creating possible synergies. The Amhara

Region Cooperatives Promotion Agency was tasked with organizing about 7,000 households in irrigation users' service cooperatives in the Koga scheme. Until 2008, 3,886 household heads were organized, the functionality of which was indeed doubtful (Gebre et al. , 2008).

The literature also highlighted the role of cooperatives in balancing economic, social, and environmental gains, staring from its definition. The way cooperatives defined clearly portrays how they are so important for sustainable development. They are voluntary associations established to meet common economic, social, and cultural needs and aspirations through joint effort (ICA , 2014). They have a favorable effect on economic, environmental, and social dimensions (Candemir and Duvaleix , 2021). As a result, they are well-positioned to contribute according to triple bottom line framework of sustainability (Wanyama , 2014). These are form of institutions where the private and public initiates are compatible. Non-monetary considerations influence farmers to join an agricultural cooperative (Candemir and Duvaleix , 2021). In some cooperative principles, they prioritize environmental issues than economic gain. In the areas where self interest impact social interest, such as the tragedy of the commons cooperatives serve as an institutional mechanism for a more environmentally friendly production (Yu and Nilsson , 2021). Members were satisfied with the cooperatives' environmental activities, however their economic and social contributions were even more valued (Yu and Nilsson , 2021).

Farmers in Koga scheme were expected to actively participate in irrigation system management through the development of Water Users Associations (WUA), so that irrigation schemes were efficient, sustainable, and equitable (Yilak , 2013). Cooperatives take agricultural inputs such as fertilizer, improved seed and chemicals are distribution duties (Tafere et al. , 2014).[3] Developing guidelines for operation, maintenance of the scheme, and ensure guidelines are followed for fair use of water are some of the major duties that WUAs have to play. WUAs participation in water-land-related activities demonstrated their importance in environmental and ecological restoration. Furthermore, the WUAs were required to participate in conflict resolution, and the scheme was supposed to aim to consider gender equality (ADF , 2001). There are misconception, indeed, regarding with its goal to some extent. Farmers were hesitant to join producers' cooperatives due to negative experiences with such organizations during the socialist military regime in Ethiopia.

The sustainability analysis findings based on total score and balancing approach pose the following three interesting issues. Both short-run trade-offs and long-run synergies are crucial aspects in the sustainable development debate. When considering the trade-offs in short-term and long-term synergies, it is essential to consider the specific context and goals of the project or initiative in question. Both planting forest seedlings and establishing cooperative organizations can contribute to sustainable development, but their effectiveness may depend on the particular circumstances and priorities. Planting forest seedlings is a top sustainable measure based on the total core of sustainability, as it directly addresses environmental concerns and contributes to the preservation of biodiversity. While it may have a larger short-term trade-off, such as low economic activities, indicating poor performance in balancing the three objectives. On the other hand, a cooperative organization is among the least sustainable solutions based on the total score method, but it excels in balancing. Establishing a cooperative organization can create jobs, promote social cohesion, and support local economies, while also addressing environmental concerns through collaborative decision-making and resource management through little trade off in short run.

[3] It is also used synonymously to refer to Water Users' Associations (WUA) and other types of farmers' associations, if any, established with similar goals.

Given these considerations, the choice between planting forest seedlings and establishing a cooperative organization as a solution to sustainable development (should we be more concerned with short run trade off or long term synergies) depends on the relative focus. If the primary focus is on environmental conservation and long-term synergies, planting forest seedlings may be the more appropriate choice. However, if the goal is to achieve a more balanced approach that addresses all three pillars of sustainability, a cooperative organization may be the better option.

1. Should we choose an adaption and mitigation measure that has high short run trade off but with long term synergy or

2. Should we choose an option that strikes a balance and concerned with a trade-off in the short run?

3. Striking a balance now or to strike a balance between addressing immediate challenges and investing in long-term benefits to achieve sustainable development

Sustainability is generally viewed as striking a balance, as described in the mDSS tool. However, the interpretation of sustainability primarily focuses on environmental sustainability, as confirmed by experts when asked about their perception of sustainability. Actions that improve the environment can be a good sustainability strategy, so they might opt for a measure with a high short-term trade-off but a long-term synergy. Although short-term trade-offs are sometimes unavoidable, it is crucial to emphasize long-term synergies in sustainable development. Costanza et al. (1997) highlighted the importance of long-term perspectives in sustainable development, as the long-run synergies can lead to more sustainable and resilient ecosystems, which in turn contribute to economic growth and social well-being. By investing in long-term solutions, such as panting forest seedlings in this study, societies can build a more resilient and sustainable future. This long term perspective is more likely to lead into a stable and resilient economy, which can better withstand shocks and changes in the global environment (Acemoglu and Zilibotti , 2013). Conversely, efforts in the Koga scheme through planting forest seedlings may not produce the desired synergy, as the area is predominantly focused on eucalyptus cultivation. This is suspected to have environmental impacts and may pose a threat to food security, since it is cultivated on fertile lands.

The practical implications of the two sustainability analysis approaches, indeed, pose a different perspectives on the relationship between economy, environmental, and society, as well as how sustainability achieved. Moreover, it is essential to strike a balance between addressing immediate challenges and investing in long-term benefits to achieve sustainable development. It may, thus, be beneficial to explore hybrid solutions that does not substantially undermine others, in order to maximize the potential for sustainable development.

4.3.4 Farmers' perception of adaptation and mitigation orientation

The direction of mitigation and adaptation responses at the household, community/cooperative and governmental level needs to be carefully examined to determine whether the practices of different groups are converging or diverging. One of the adaptation and mitigation measures at the household level is the influence and choice of farmers on cultivation patterns and crop selection. The Koga scheme office makes analysis each season which crop to grow by considering many factors, but farmers make final decision mostly based on relative profitability (Reynolds , 2012). This study also confirms this. However, in order to maintain a sustainable level of production, the farmer must have certain knowledge, including agroecological knowledge, to reconcile the technical aspect of production with soil conservation practices or environmental aspects of the production system, which can influence decision-making to balance economy and environment (Rola A.C. , 1998). The focus to the environment was also supported by household survey result. According to the result, the second largest factor in crop selection is environmental (soil and water) conditions, and consider environmental impact when choosing their products.

It is important that the diverse and often conflicting goals of all stakeholders are properly considered. At the heart of sustainable development, there are trade-offs between those who prioritize the environment, those who prioritize social development, and those who prioritize economic development. In it we find competing interest groups that have negotiated a viable compromise (Fortunate M. and Steven L. , 2017). The main focus of household-level adaptation and mitigation measures is primarily economic sustainability (see Figure 4.13a). However, at the community/cooperative level, the majority of farmers (51%) consider adaptation and mitigation measures to be more sustainable (see Figure 4.13b). In fact, the state is also responsible for socially just and environmentally friendly development activities, which is also confirmed by 50% of farmers in the survey (see Figure 4.13c). In contrast to this perception, while the physical and technical aspects of the scheme received adequate attention, minimal attention was paid to the social and environmental aspects. Although the social complexity the project necessitates more or equal attention to other pillars, the survey results show that it has been given the least attention. The government officials also admitted that the watershed management component is not adequately implemented. There was no institutional responsibility for environmental management activities, as well as resources allocated including finance far below what is required. Soil and water conservation comes at no cost through community participation (Gebre et al. , 2008).

Although an overlap of views among stakeholders based on the belief that the scheme ultimately benefits local communities is evident, serious misjudgments were made in setting priorities related to environmental sustainability. This divergence exists even between government agencies in relation to watershed management. There were two groups of offices: those that were more concerned with watershed management and those that were not. The Amhara Region Environmental Protection, Land Use, and Administration Authority, Bureau of Agriculture and Rural Development and the Cooperative Development Agency were in the first group. In contrast, the Amhara Region Water Resources Office and the Koga Watershed and Irrigation Management Office in Bahir Dar were in the second group. The divergences of interest in these group of offices arise due to perceptions related to siltation and sedimentation in the reservoir (Gebre et al. , 2008). There was also a conflict of interest between upstream and downstream communities regarding watershed management activities, as upstream people were uninterested.

After addressing the alignment of mitigation and adaptation actions at different levels, farmers were asked whether current management activities at scheme level balance pillars of sustainability. According to Figure 4.13d, the overall assessment shows that management activities seek to balance the social, environmental and economic pillars of sustainability. Despite the great divergence of interests between measures at household and community/cooperative level/government, the same stakeholders have broadly overlapping views. Therefore, it is now widely recognized that training and awareness raising should be strengthened as one of the scheme's components in order to ensure convergence of interest.

4.3.5 Sensitivity Analysis

One of the goals of the study is to determine how robust the ranking of different EIA recommended measures is, i.e. how much the sustainability criteria weights must be changed to change the ranking of the different adaptation and mitigation measures. Sensitivity analysis is based on uncertainty associated to judgments largely in criterion weighting. The goal is to determine how any modifications to the decision models affect the ranking. Throughout the weights, preference judgments are vulnerable to uncertainty.

I. Most Critical Criterion

The criterion that requires the smallest change in weight to change the score and ranking of measures is considered as the most important criterion in decision-making. The present ranking of options can be altered by even the smallest change in current criteria weight. When criteria are expected to be deemed equally significant, the most critical criterion is social sustainability when Simple Additive Weighting (SAW) is used. However, it is economic sustainability if criteria that are supposed to be viewed as NOT equally significant are taken into account. In the triple bottom line framework, a slight adjustment in the weight of social sustainability can change the scores and rankings of measures, whereas in the wedding cake framework, the ranking can be shifted by a minor change in the weight of economic sustainability. The implication is that the performance measure of EIA recommended activities depends on criteria weighting particularly the social and economic sustainability.

II. TORNADO diagram

In Tornado diagram the researcher compared the performances of two EIA recommended measures (basic and a challenging) at a time. The bars show the different performance ranges of the options based on changing each weight. The bars are organized from widest to narrowest, creating a tornado-like shape. The farther 0 is from the current situation, the more stable the ranking is. The orange bars indicate the criteria where adjusting the weights could result in a reversal of the compared measures (options). A larger orange bar indicates a bigger potential difference in ranking from adjusting the weight of that criterion. If a bar has no orange area, changing the weight of that criterion would not reverse the order of the two options.

The TORNADO diagram based on Simple Additive Weighting (SAW) under triple bottom line framework (see Figure 4.14) shows that adjusting weights in social, economic and environmental pillars would not reverse the order of the 2 and 7, 2 and 8, and 2 and 3 options (see Figure 4.14e, 4.14f and 4.14g)[4]. The ranking between 2 and 7, 2 and 8, 2 and 3 options are the most stable rankings. In addition, a change in environmental sustainability criterion doesn't cause a reverse of the ranking between 2 and 5, 2 and 6, and 2 and 1 EIA-recommended measures (see Figure 4.14a, 4.14b and 4.14d). A bigger orange bar indicates a larger ranking difference between 2 and 5, and 2 and 6, which could result from changing the weight of the economic sustainability pillar (see Figure 4.14aand 4.14b), whereas the environmental criterion can distort the ranking between 2 and 4 (see Figure 4.14c). The change in weights of social criteria may cause the ranking of 2 and 1 to be reversed (see Figure 4.14d). In the Wedding Cake framework (see Figure 4.15), a change is economic sustainability criterion weight doesn't alter the ranking between the basic option (4) and 1, and 4 and 3 (see Figure 4.15f and 4.15g). A change environmental criteria weight doesn't affect the ranking between

[4]The basic option is 2

4 and 3 (see Figure 4.15g). The most important criterion whose weight cause a change in ranking between 4 and 1, 4 and 7, and 4 and 3 is the social sustainability (see Figure 4.15d and 4.15f). The weights of economic sustainability can distort the ranking between 4 and 5, 4 and 6, 4 and 2, and 4 and 8 options. Moreover, the ranking between 4 and 3 options is the most stable one.

Because the most desired adaptation is either training and extension courses (option 2) or planting forest seedlings (option 4), it is more relevant to investigate the criterion weight that impacts the ranking between 2 and 4. Changes in environmental sustainability criterion weights may reverse the ranking between 2 and 4 when criteria are assumed to be equally important (see Figure 4.14c), whereas changes in economic sustainability criterion weights may favor option 2 (see Figure 4.15b) when criteria are assumed to be not equally important in Simple Additive Weighting (SAW) decision rule. The weight of criteria in decision-making is based on expert judgment and can change as thinking and sustainability models evolve. This can impact the performance of measures for sustainable development. The perception of the relative importance of different pillars is also a major influencer in this process.

4.3.6 Assessment of Implementation of EIA Recommendations

The implementation of EIA recommendations was assessed using a four-point scale ranging from poor to excellent performance based on the expert group's assessment. There is currently no considerable effort being made to improve the region's health care system, which is rated as poor with significant omissions and shortcomings. Settlement and compensation payments, the planting of tree seedlings, and marketing activities are adaptation and mitigation measures that have received good performance ratings. Grevillea and other plant seedlings were planted on a short plot of land, and planting at larger extent in upper catchment is planned. Marketing initiatives such as the export marketing of Avocado products, marketing of other vegetables, and planning of wheat marketing, to name a few, are in good performance. The remaining four measures—farmer training and extension service, livestock development, irrigation ergonomics, and cooperative organization—are all making very good progress. Training on wheat and vegetable production, as well as trained water users' associations with cluster training at plan, deserve recognition for their very good progress. In terms of irrigation agronomic methods, every farmer understands and practices row planting, irrigation scheduling, and drip irrigation.

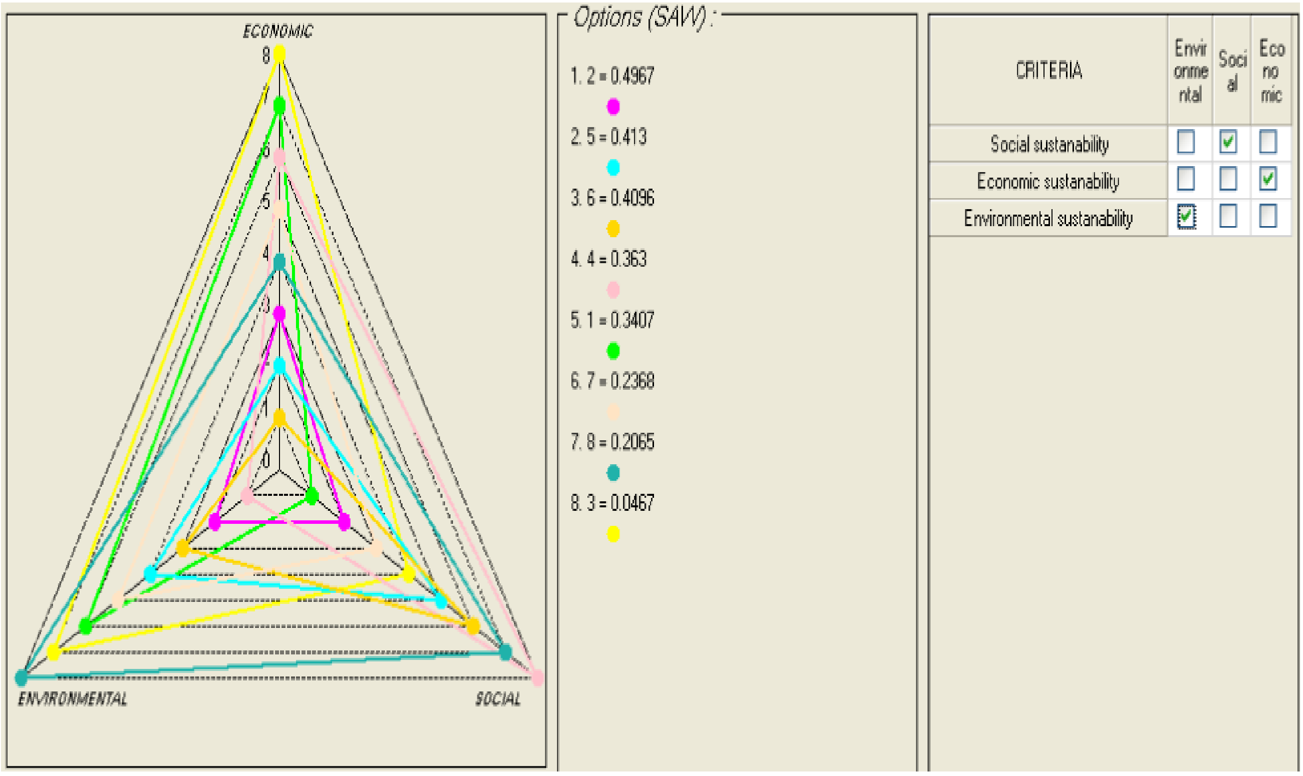
Some positive achievements in cooperative organization include the development of WUAs, marketing cooperatives, unions, and the planned cluster association formation. However, none of the measures were thoroughly and completely executed, rated an excellent situation. The same findings also found in literature. According Abebe et al. (2007), just two activities, such as planting forest seedlings and livestock development, have advanced adequately from the major activities mentioned in the EMP. It seems that there were delays in resettlement/compensation payments and poor public health measures. There are 15 actions that haven't been addressed or reported on. The environmental mitigation measures outlined in the Environmental Impact Assessment (EIA) are not being adequately implemented. It's crucial to ensure that these measures are followed to mitigate environmental impact effectively (Abebe et al. , 2007). The overall assessment of the tent of EIA-recommended interventions and their sustainability performance shows that the most sustainable adaption measures (based on the total scoring method rather than balancing), which were thought to be of high relevance for sustainability, were advancing well. It sounds like the Koga scheme is well-positioned to succeed in the field of sustainable development.

4.4 Conclusion and policy implication

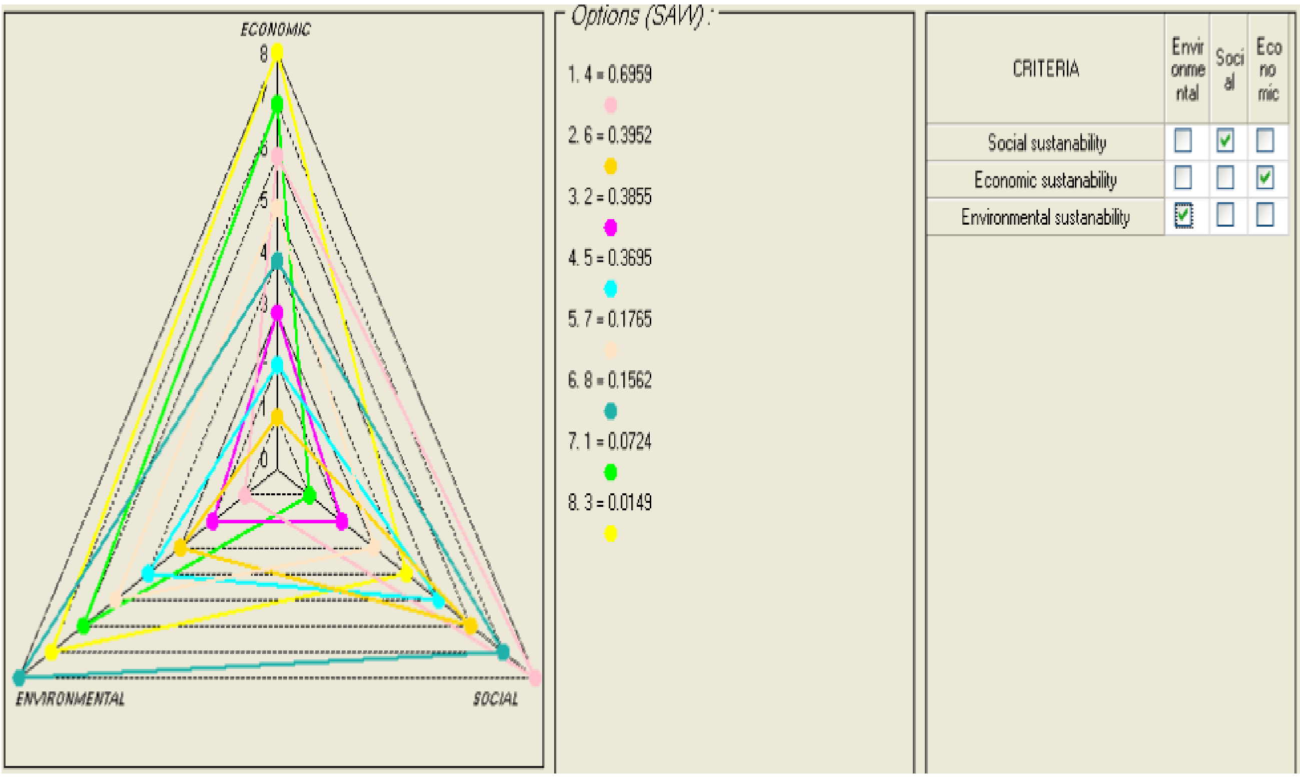
In this chapter of the dissertation, the study aimed to explore how and to what extent water management in Koga scheme performed in terms of sustainable development, with a particular emphasis on IWRM and EIA-recommended measures based on triple bottom line and wedding cake frameworks. The study found some indicators of IWRM implementation in the area based on predefined principles, but its support for sustainable development is deemed dubious. The six dimensions of sustainability were not adequately addressed. The study posits most themes (26 out of 40) of sustainable development were poorly considered in the IWRM plan and implementations. However, 35 (87.5 percent) of the 40 themes mentioned in the grid were assessed to be the key focus. Twenty goals are classified as react index, suggesting that they must be addressed immediately, so that the office must take improvement measures automatically. Ninety-nine goals necessitate less immediate action, while attempting to keep the forty-four goals performance. As a result, stakeholders must develop improvement instruments for react and act priority indexed goals, which account for 71.6 percent of all goals. Unlike the sustainability assessment of IWRM, the EMP is likely to succeed. The most favored adaptation and mitigation measures in all cases are either training and extension courses or the planting of forest seedlings. Except for the planting of forest seedlings, the most sustainable measures discovered during Multicriteria Analysis in both the triple bottom and wedding cake frameworks reveal that these measures were progressing quite well. Planting forest seedlings may be the only viable measure for achieving sustainability in some circumstances. However, planting forests may not result the desired synergy in long run, as planting eucalyptus in fertile land is a threat to food availability and the environment. In terms of balancing the three pillars, the most favoured and chosen measures may not be a feasible solution. Almost all adaptation and mitigation measures maintained imbalance ratings across all three pillars. Except in the context of training and extension services for farmers and cooperative organization in the Koga scheme, it is more difficult to make judgements regarding its sustainability in terms of balancing. The policy implication is that the GADD avoids the difficulties of comparing or ranking the scheme in isolation. It can be used to compare the scheme as it grows by identifying mechanisms for improvement in react and act indexed goals for sustainability assessment of IWRM plan. The EMP analysis of the sustainable development will only succeed when the core problem of criteria weighting for relative importance of pillars adjust as well. There are still a lot of work remains to be done in terms of sustainability integration; should it be viewed as a balance across all three sustainability dimensions rather than a hierarchy with the environment at its core; should we be more concerned with total score value/long-term synergy or balancing effects/short-term trade offs? The choice between these sustainability frameworks is likely to have an impact on that organization's policies and programs. The study recognizes the difficulty of striking this balance, emphasizes the need to think holistically and progress toward a shared vocabulary, and encourages collaboration between development, society and environmental planners. Therefore, governments need to convey their efforts in establishing efficient and inclusive institutions for sustainable development, which is considered as the fourth essential element of sustainable development. These institutions should aim to include everyone and not exclude any individual goals.

[5]

[5] The following charts and figures have been misplaced after the conclusion and policy implication section. They should have been placed before this section. The placement of the charts and figures at the end of the document is an error caused by the LaTeX typesetting.

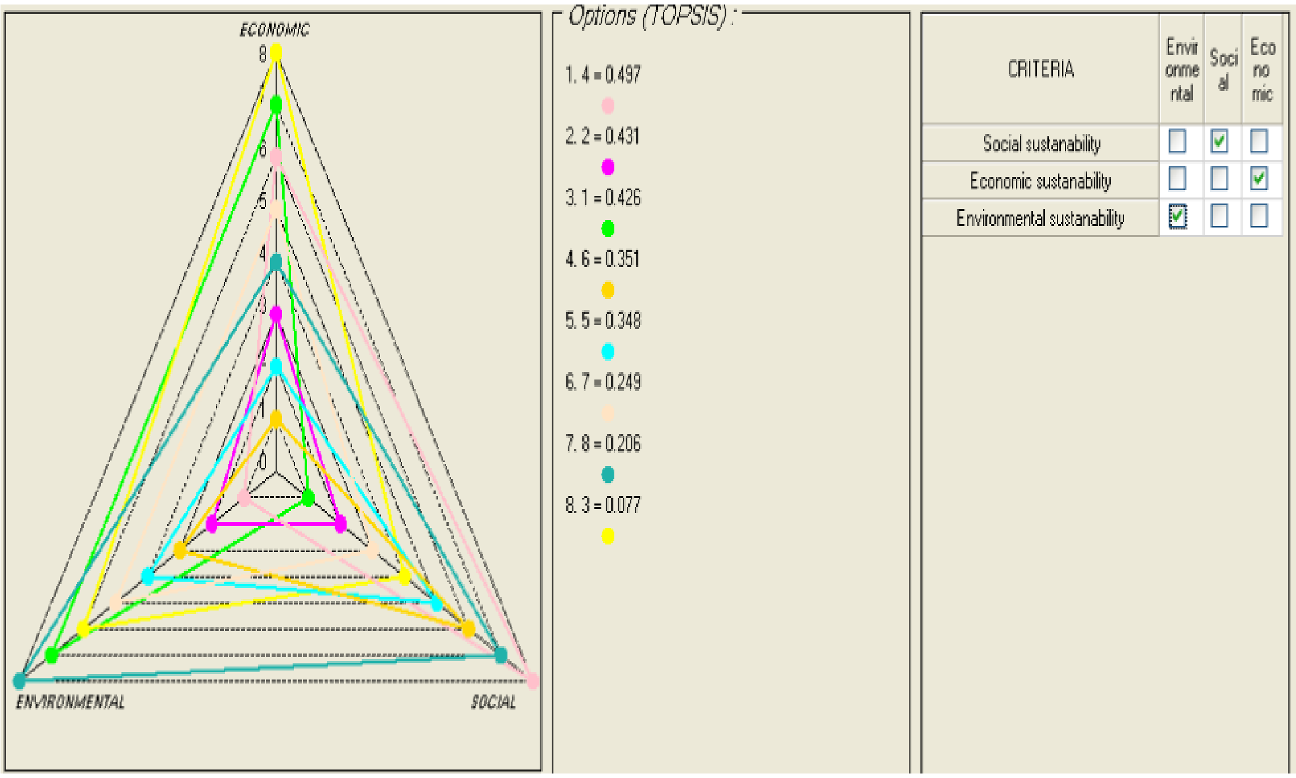


(a) Sustainability of Simple Additive Weighting (SAW) in Triple Bottom Line framework

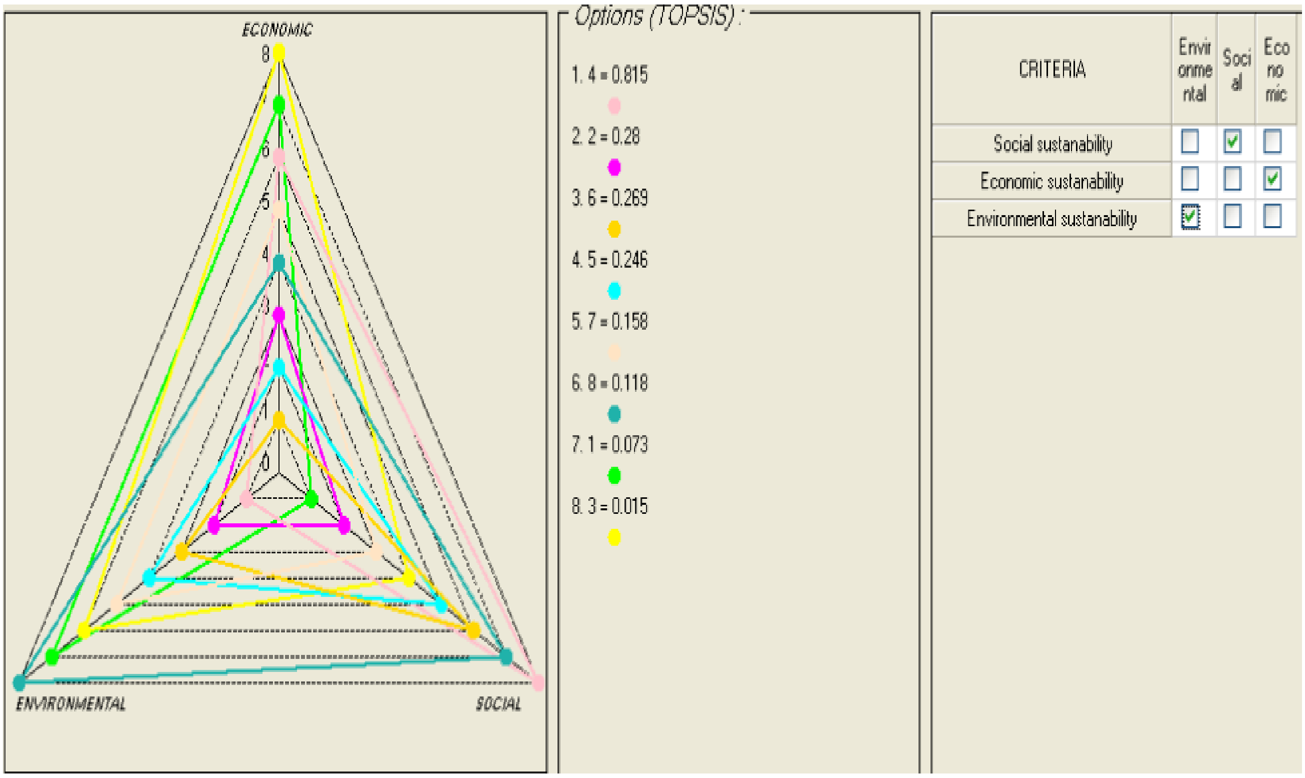


(b) Sustainability of Simple Additive Weighting (SAW) in Wedding Cake framework

Figure 4.11: Sustainability chart under Simple Additive Weighting (SAW) aggregation method

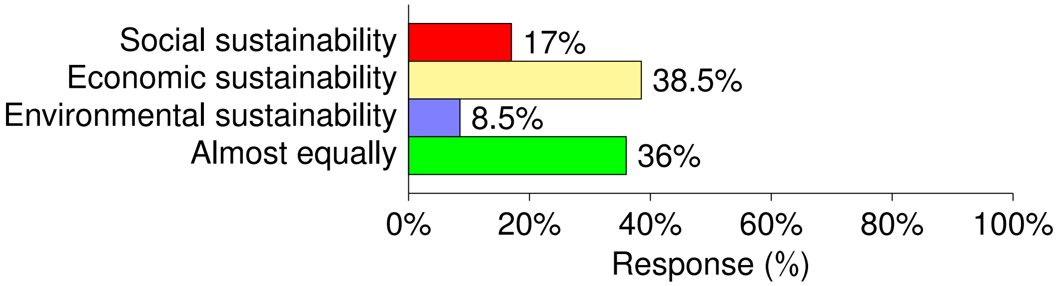


(a) Sustainability of Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) in Triple Bottom Line framework

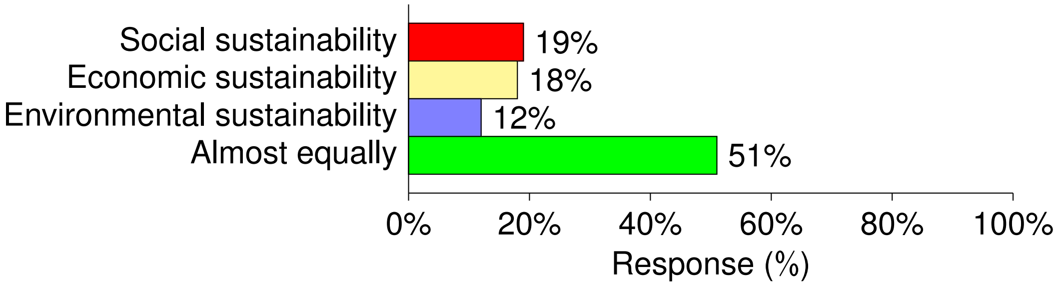


(b) Sustainability of Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) in Wedding Cake framework

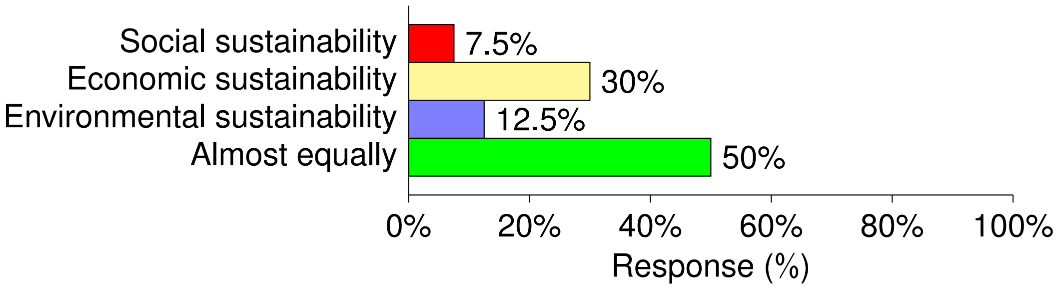
Figure 4.12: Sustainability chart under TOPSIS method



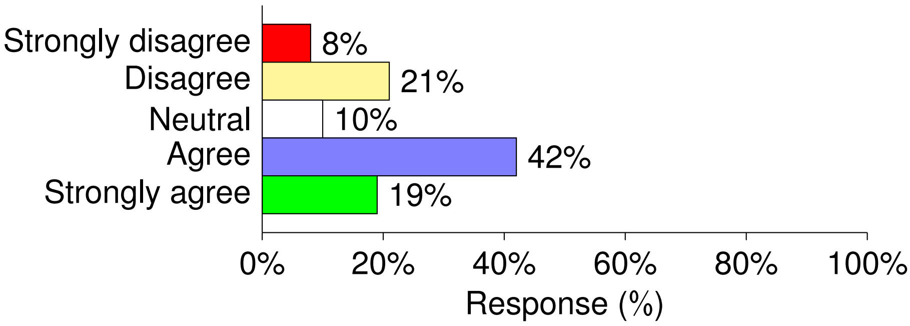
(a) Adaptation and mitigation measures orientation at the household level



(b) Adaptation and mitigation measures orientation at community/cooperatives



(c) Adaptation and mitigation measures orientation at the government level



(d) Current management activities balance the three pillars of sustainability

Figure 4.13: Adaptation and mitigation measures orientation perceptions

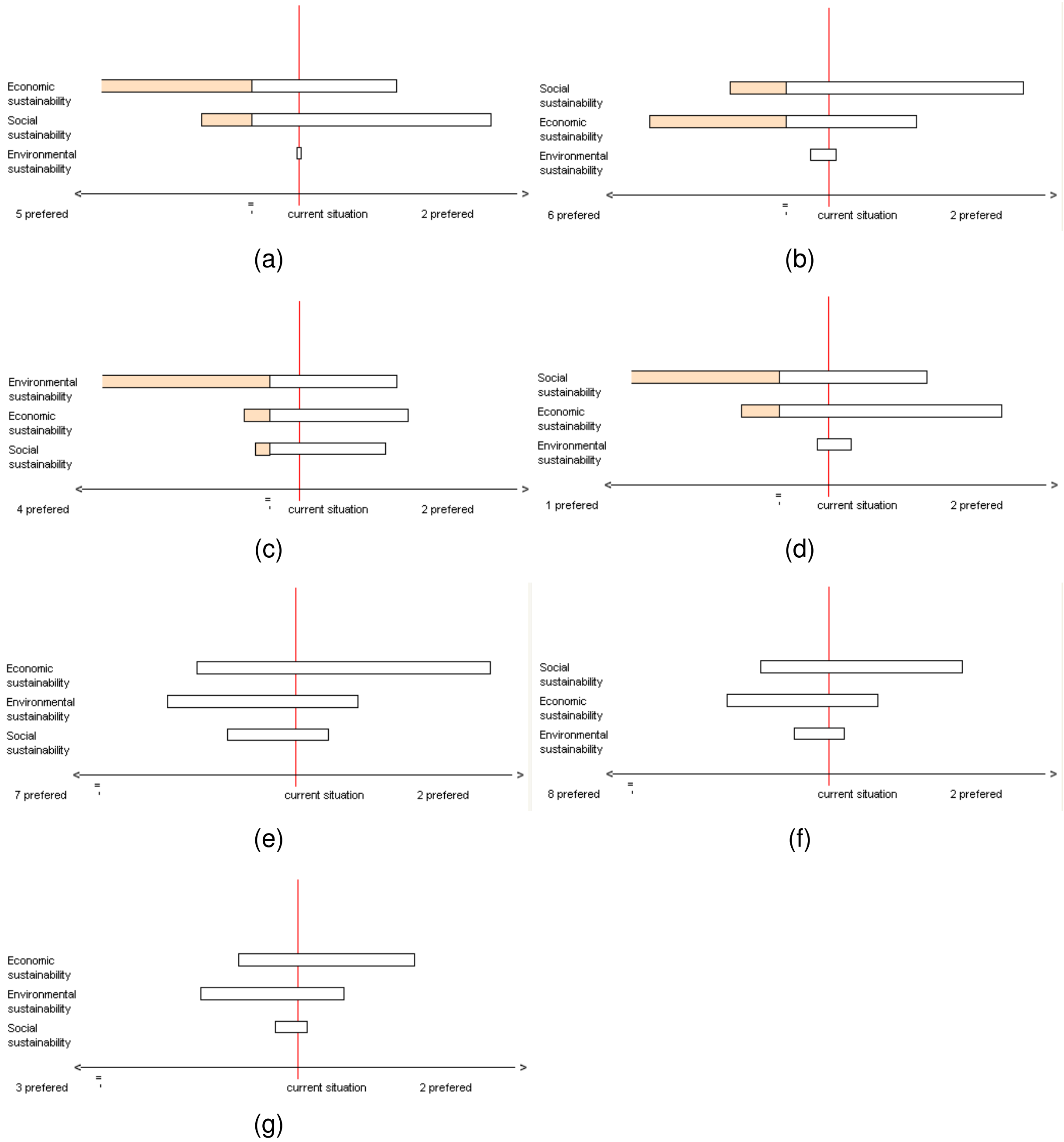


Figure 4.14: TORNADO diagram based on Simple Additive Weighting (SAW) in Triple Bottom Line framework

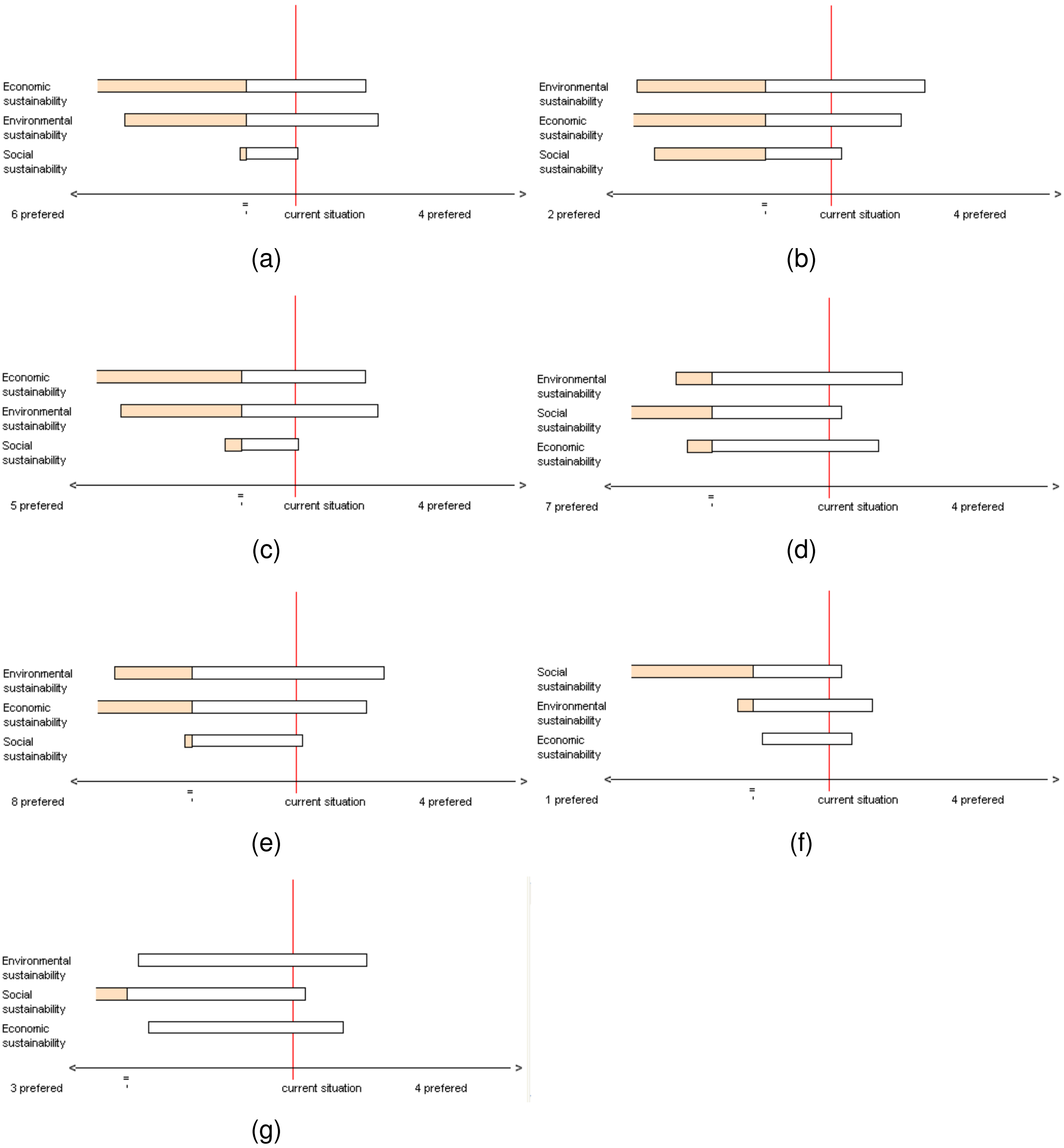


Figure 4.15: TORNADO diagram based on Simple Additive Weighting (SAW) in Wedding Cake framework

CHAPTER 5

SYNTHESIS

5.1 Synthesis

Human development efforts, such as the Koga scheme, are inspired by reducing poverty and achieving food security, but interact with the environment and social systems. This, in turn, inspires different adaptation and mitigation measures to minimize the effects of such development projects on society, the economy, and the environment. These measures should optimize the impact of efforts to achieve social, economic, and environmental sustainability for all. Measures that are advantageous from one point of view or for one group may affect the viability of other groups' livelihoods or access to resources. Certain methods of farming are more sustainable compared to others (Dalsgaard et al., 1995). Recognizing that not all adaptations are beneficial has heightened awareness of the need for sustainable adaptation techniques and measures, as well as specifying which types of adaptation are desired. Designing an appropriate enabling environment, such as policies, strategies, plans, and projects, is crucial for sustainable development. Although these efforts represent pledges, their performance is determined by a variety of circumstances, including climate change, water resource availability, and even societal sustainability beliefs. Some of these factors, if not all, can, indeed, be influenced by better management practices, such as IWRM and EIA follow-up. By implementing these management approaches, we can improve the effectiveness of sustainable development efforts and address challenges like climate change, water resources availability, and social sustainable perceptions.

Although irrigation and watershed management components in Koga scheme are expected to be treated equally significant, this is not the case in reality on the ground. The scheme is a significant experiment within national IWRM, garnering national and international interest. Furthermore, it is under Environmental Category 1. Category 1 projects may have negative and serious environmental effects, demanding a comprehensive Environmental Impact Assessment (EIA). An EIA was conducted, the impacts were identified, and mitigation techniques were integrated into the project design approach and ideas. The decision to prioritize the scheme was stemmed from the government's policies of sustainable environment and agricultural development. If the scheme fails in terms of sustainability, it will be deemed a failure for future similar projects in the country.

There are certain features of IWRM, with the three most principles are integration, participation and decentralization in management activities. When it came to implementing the IWRM principles in Koga command areas, a significant percentage of farmers during the survey agreed that most principles are implemented with some verifiable indicators for integration, participation and decentralization in management . However, most sustainable development themes are currently in an improvable state, with the themes being poorly regarded in the IWRM plan and implementations. The Koga scheme scored less than 60 percent on all six dimensions. IWRM is unlikely to succeed in the area of sustainable development. Only few 9 themes, including land use, water, economic viability, work, entrepreneurship, peace, institutions, participation and citizenship, and information, are in a satisfactory state and are taken into account. Moreover, the themes, including risk management and resilience, transmission of cultural heritage, energy, food, and safety, are in a problematic state and are not sufficiently taken into account. The react index is assigned to twenty goals, the act index to ninety-nine goals, and the maintain index to forty-four goals. The 119 out of 166 goals require immediate and less immediate actions. Stakeholders are required to identify improvements for react and act priority indexed goals, which account for 71.6 percent of the goals.

Another water management approach and regulatory process for managing water and environment that take into account sustainable development ambitions into the project is EIA and its follow up procedure mitigation measures in Environmental Management Plan (EMP). The chances of the EMP achieving sustainable development are greater. Farmer training and extension service, livestock development, irrigation agronomic practices, and cooperative organization measures are all making great strides. Except for the planting of forest seedlings, the most sustainable measures were progressing quite well. The most favored adaptation and mitigation measures for total sustainability are either training and extension courses or planting forest seedlings. When the environment serves as a foundation for other aspects of economic and social sustainability, planting forests seems to be the only way to achieve sustainable development in certain situations. However, the conversion of agricultural lands into eucalyptus plantations, as seen in the Koga project in Ethiopia, may not fully understand planting forest seedlings as a sustainable solution. This is because farmers are primarily planting eucalyptus for income generation rather than focusing on its environmental benefits. Contrary to expectations and the results of multi-criteria analysis under various decision rules, forest seedling plantation may have a negative impact on sustainable development efforts, largely due to the potential environmental damage of eucalyptus and a threat to food security. This is because farmers are turning fertile croplands into eucalyptus plantations. In terms of striking the balance of sustainability, almost all adaptation and mitigation measures maintained imbalance ratings across all three pillars. Although environmental sustainability seems crucial when using appraisal tools like EIA, the results show that nearly all measures have low performance in terms of environmental criteria. Almost all perform most strongly on economic criteria, implying a higher concentration of the measures on economic criteria corner.

Unlike higher concentrations of measures on the economic pillar corner, the primary focus of household level measures to this pillar, and households' perception of economic sustainability is crucial to overall sustainability, the average technical efficiency indicator of farmers' economic sustainability at the scheme level is 0.406, which is low, indicating low economic sustainability in the area. There were found wasteful agricultural practices that endangered future resource availability for the viability of agriculture in the long term. Substantial resources were lost due to mismanagement. About 59.4 percent of inputs could have been saved if an optimal level of economic sustainability had been achieved, without affecting the level of output. The loss may be attributed to sustainability perception of households, such as the relative importance of current production/living standards over future production and profit motive, perception of their technical efficiency status as they feel they are efficient. When comparing pre- and post-project/scheme income achievements and looking into the degree of efficient utilization of resources represented by technical efficiency scores, the source of the increased income could be the utilization of more inputs and unsustainable practices, rather than the efficient use of resources. This income comparison result may be misleading when determining the feasibility of farming, as long-term viability ultimately depends on efficient resource utilization, not income. The comparison of benefits from efficiency improvement versus the use of more input resources shows in some areas that efficiency improvement is advantageous. There is another argument that corroborates this based on growth potential from efficiency and returns to scale up of all resources. There were low technical efficiency scores, with significant differences across blocks in the Koga scheme area. Moreover, some inputs, such as land area and seed per hectare, have unintended negative impacts on output when increased. Therefore, efficiency improvement rather than more input use is more advantageous, and management shall target this in planning. Thus, the economic sustainability convergence study was triggered by low levels of economic sustainability in the area, significant differences between sustainable and unsustainable households or blocks, and significant inefficiency loss measured by wasted resources, growth potential from efficiency improvement compared to returns to scale, and negative elasticity of output in some inputs, such as seed per hectare and land size. According to the findings based on scenario development as a methodology, it requires a 9.42 percent expected growth rate in the first scenario for temporal economic sustainability over 10 years as a long-term plan, while a 5.58 percent growth differential for catching up in the next five years. These growth rates are not overly ambitious and are attainable based on empirical evidence found on technical efficiency growth rates in Ethiopia.

Recognizing the susceptibility of a water resource to climate change is a key focus for water resource managers, researchers, and others. A slight change in temperature and precipitation results a considerable impact on the hydrological cycle, particularly at the basin level. A supply-side evaluation of water for agriculture is a prerequisite to address downstream irrigation needs in regions where reservoirs are the primary sources of supply, such as the Koga scheme. Accurate information regarding a country's water resources' state and trend is necessary to promote long-term economic and social development while maintaining environmental quality (WMO, 2012). Temperature trend was increasing and stronger in Merawi, where the scheme is located, than at the nearby Wetet Abay station. In context of climate change, it means climate has changed in the Koga scheme area. High rainfall concentration refers to rainfall being highly irregular and having a unimodal distribution. The main rainy season contributes for about 85.5% of total rainfall in Merawi, with July accounting for 29.2%. Moreover, runoff concentration within a few months, most notably during the main rainy season (72%), combined with runoff variability exceeding 30% in Koga Nr/@. Merawi raises issue. The variability of runoff at Koga Nr/@. Merawi is generally greater than at Gilgel Abbay Nr. Merawi. These hydro-climatic conditions have greater implications for future water management. Temperature and rainfall both influence water availability, as measured by runoff. A rise in temperature creates greater demand for water, while a statistically insignificant trend in total rainfall and total runoff makes water management more complicated by exacerbating water demand and supply balance for agriculture. The nonparametric estimate of temperature elasticity of runoff in Koga watershed is -1.43367, while it is -1.44365 in Gilgel Abbay watershed. In Koga, the nonparametric estimate of rainfall sensitivity is 1.438282, while in Gilgel Abbay, it is 0.769782. In most years of analysis, temperature is the most influential factor influencing runoff, and the Koga watershed is more sensitive than the Gilgel Abbay watershed. Climate change, high runoff concentration, variability, and the fact that rising temperature is the dominant climate variable affecting runoff combined with the highly sensitive Koga watershed, endangering the future water demand and supply balance for irrigation activities. If these trends and facts continue in the future, it will significantly impact efforts towards sustainable development, potentially hindering the achievement of this goal.

5.2 Conclusion and recommendations

The household survey results show that while most Integrated Water Resource Management (IWRM) principles were implemented in water management, these principles were not effectively implemented to support sustainable development goals. The IWRM failed to achieve sustainable development, with only a few themes (goals) addressed effectively. Immediate actions are required to address the significant number of goals. The Environmental Management Plan (EMP), on the other hand, was successful in achieving sustainable development when the long term perspective of sustainability is adopted, but struggled to balance the three pillars, implying a high trade-off in adaptation and mitigation measures. The unequal adaptability of measures can best explain the potential trade-off in sustainable development in Koga scheme area.

Despite the concentration of measures towards the economic pillar, economic sustainability based on the technical efficiency measure, was low, it can be concluded that the scheme was not successful in achieving economic sustainability. There were wasteful production system owing to technical inefficiency, which is attributed to farmer mismanagement. Economic sustainability varies greatly between farmers and command areas. Household size, frequency of consultation visits, male household heads, sharecropper mentality, and non-farm income can all help to ensure economic sustainability. When comparing the growth potential with existing inputs due to better management to the returns to scale of the effect of doubling inputs, significant differences in economic sustainability across blocks, and significant inefficiency loss measured by wasted resources, and negative elasticity of output in some inputs, such as seed per hectare and land size, the findings suggest that improving farmer efficiency is more advantageous and need planning. The convergence results demonstrate that the 9.42 percent annual growth rate in technical efficiency for temporal economic sustainability convergence to the frontier over 10 year is a reasonable and achievable target for long term goals. Additionally, the 5.58 percent growth differential for catch-up effects is also considered to be reasonable and not overly ambitious. Several plausible reasons may contribute to low sustainability, such as sustainable perception. The increased emphasis on current quality of life can lead to a disregard for the environment and the efficient use of resources in farming. According to the pre-project and post-project income comparison results, the scheme was successful in meeting its specific income target. The project benefited nearly all farmers. It can be concluded that the scheme outperforms expectations in terms of raising the income of households. However, the income comparison result may be misleading when determining the feasibility of farming, as long-term viability ultimately depends on efficient resource utilization, not income. Based on crop selection procedure and adaptation orientation results, farmers were unconcerned about the environment because they were preoccupied with household economic goals.

Efforts to achieve sustainable development can be best explained by water management, which is constrained by climate-water availability factors. The primary indicators of climate change in the Koga scheme area include increased average annual and maximum temperatures. It is evident that there is climate change taking place in the project area, with rainfall and runoff concentrated over a short period and longer dry seasons. A percentage change in temperature had a greater-than-proportional negative effect on runoff. The Koga scheme is highly sensitive to temperature changes than Gilgel Abbay watershed.

The researcher has put forwarded the following recommendations:

- The comparison of the returns to scale and the potentials with full efficiency, negative elasticity of output in some inputs, such as seed per hectare and land size, and low levels of economic sustainability in the area all suggest that the local Koga project office, as well as farmers themselves, should help farmers to improve efficiency but at the same time benefit from technology. In some cases, prioritizing efficiency improvement rather than investing in new technology and inputs is advantageous. It doesn't pay more to invest in new technology and use more inputs in agriculture in economic sustainability.

- According to the findings, planning for optimum economic sustainability, as well as regional equality in terms of economic sustainability, are legitimate aims that local governments should include in their strategies. The office should view spatial economic sustainability as a short-term aim (a five-year plan) in the study area's agriculture sector, whereas temporal sustainability is a long-term goal (a ten-year plan). Such plans have various plausible justifications. The local government should focus more on factors that increase technical efficiency, such as household size, frequency of consultation visits, male family heads, sharecroppers' mentality, and non-farm income, all of which are thought to enhance convergence at the frontier.

- More efforts should be made by the office to raise farmers' awareness of current production and environmental links. Farmers' beliefs about the relative importance of current production versus future production may limit the resources available for future usage and generation. In contrast to the quantitative results of the maximum likelihood estimates, the majority of farmers believe that their land is fulfilling its potential. As a recommendation, awareness creation is required to precisely understand their efficiency status versus what they believe. Their mis-perception may impede their efforts toward efficiency.

- The findings indicate that just a few sustainable development themes were in a satisfactory state. The office should consider this fact in the implementation of IWRM. Most sustainable development goals must be handled immediately, if not less immediately, so that the office can take corrective actions. Stakeholders should create improvement mechanisms to achieve the goals.

- Farmers typically cultivate eucalyptus, thus planting forest seedlings may not be a viable solution for sustainable development. Proper planting and management of eucalyptus planation is crucial for promoting sustainable development by limiting negative impacts and its threat to food security. It should be planted in marginal lands.

- Adaptation and mitigation measures recommended by the EIA maintained imbalance scores across three pillars. Despite the fact that prioritization and balancing are important frameworks for sustainability, should it be viewed as a balance across all three sustainability dimensions rather than a hierarchy with the environment at its core; should we be more concerned with total score value/long-term synergy or balancing effects/shot-term trade offs in sustainable development are still unanswered in literature. The academia should match these issues, the sustainability integration, and different sustainability frameworks with both immediate and long-term goals.

- A full flagged socio-economic survey is required to have a clear understanding of the Koga scheme.

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APPENDIX ONE

SURVEY QUESTIONNAIRE

A Trans-Log Stochastic Frontier and technical inefficiency models

Table 5.1: Area Identification

S.N	Description	Code	Block Name
1	Irrigation Block		
2	Household Serial Number(ID)		

Table 5.2: Technical Inefficiency Model Variables - Household[HH] Demographics

HH ID	Gender of HH head	Age of HH head	HH head education Year of schooling
	1=Male 0=Female		

HH size [Family Size]	HH members within Productive age		Sector of occupation Source of income
	Members bn 16-65 age = ()		1=Farming 2=Trade 3=Remittances 4=Others

Table 5.3: Technical Inefficiency Model Variables - Operational and Farm Specific Variable

Total Land Owned	Off-Farm Income	Membership In Association	Credit Received
	1=Yes 0=No	1=Yes 0=No	1=Yes 0=No

Land Ownership	Household Type	Training Exist?	Agricultural Experts' Visits (Days/Month)
1=Own land	1=Displaced and resettled	1=Yes 0=No	
2=Rented	0=Host household		
3=Sharecropping			

Table 5.4: Trans-Log Stochastic Frontier Model Variables-Output

Crop/Vegetable Type	Dominant Crop/Vegetable Type	Land Size	Output (Kg)	Revenue from Sale (Birr)
Wheat				
Maize				
Potato				
Onion				
Carrot				
Green piper				
Cabbage				
Bean				
Barley				
Tomato				

Table 5.5: Trans-Log Stochastic Frontier Model Variables-Crop Type & Factors of Production

Crop/Vegetable Type	Improved Seed (kg)	Agrochemicals (Pesticide, Insecticide and Herbicide)	Modern Fertilizer (Kg)
Wheat			
Maize			
Potato			
Onion			
Carrot			
Green piper			
Cabbage			
Bean			
Barley			
Tomato			

Table 5.6: Trans-Log Stochastic Frontier Model Variables-Factors of Production

Factors of Production (Inputs)	Amounts
Irrigation Farm land (Hectare)	
Rainfed Farm land (Hectare)	
Private grazing land (Hectare)	
Woodlot (Hectare)	
Do you hire labor[1=Yes 0=No]	
Labor during peak farming period(number)	
Hours each labor spend in a farming field in a day	
Total Improved Seed (Kg)	
Total agrochemicals (Litters): Pesticide, Insecticide and herbicide	
Total modern Fertilizer (Kg)	
Do you use manure? [1=Yes, 0=No]	
Do you conserve soil or apply sustainable land management? [1=Yes 0=No]	
Irrigation Water Schedule i.e. Water Supply (Days per week)	
Irrigation Water schedule (Hours per Day)	
Water Schedule Time [1=Day time 2=Night time]	

Table 5.7: Perception of sample households related to production, conservation, efficiency & adaption & mitigation measures

Perceptions on (Production, conservation, efficiency & adaptation & mitigation measures)	Degree of agreement/responses
1. Current production is more important than future high production	(1) Strongly disagree (2)Disagree (3) Agree (4) Strongly agree
2. Current water & soil conservation is more important than future conservation	(1) Strongly disagree (2)Disagree (3) Agree (4) Strongly agree
3. A farmer is getting the maximum output from inputs & technology	(1) Strongly disagree (2)Disagree (3) Agree (4) Strongly agree
4. Farmers with smaller land have a higher possibility to produce at its maximum	(1) Strongly disagree (2)Disagree (3) Agree (4) Strongly agree
5. Farmers' perception related to sources of output loss in farming	(1)Only natural hazard (like climate) (2) Only Management inefficiency (3) Both
6. There can be technical efficiency improvement	(1) Strongly disagree (2)Disagree (3) Agree (4) Strongly agree
7. Satisfaction with current yield in farming	(1) Strongly disagree (2)Disagree (3) Agree (4) Strongly agree
8. Farmers' perception related to the primary motive for selecting crop type	
(A)Environmental condition (soil and water conditions)	(B) Market motive/profit
(C)Influence from development agents through guidance	(D) Inherited from the past practice
(E) Almost all	
9. Environmental impact consideration while choosing what to produce	(1)No (2)Yes
10. Adaptation & mitigation measures orientation at the household level	(1)Social sustainability (2) Economic sustainability
	(3) Environmental sustainability (4) Almost equally
11. Relative importance of pillar for overall sustainability	(1)Social sustainability (2) Economic sustainability
	(3) Environmental sustainability (4) Almost equally
12. Adaptation & mitigation measures orientation at the community/cooperatives level	(1)Social sustainability (2) Economic sustainability
	(3) Environmental sustainability (4) Almost equally
13. Adaptation & mitigation measures orientation at the government level	(1)Social sustainability (2) Economic sustainability
	(3) Environmental sustainability (4) Almost equally
14. Overall judgment on sustainability	(1) Strongly disagree (2)Disagree
	(3) Agree (4) Strongly agree

APPENDIX TWO

KOGA IRRIGATION AND WATERSHED PROJECT

B Summarized data on Koga Irrigation and Watershed blocks

Table 5.8: General Information about Koga irrigation & watershed project

	Description
Contractor	China international water & Electric Corporation(KDIP 3)
Contract Price	201,755,796.48(including secondary, tertiary & night storage)
Funding agent	Africa development Bank(ADB)
Start Date	14 June 2005
Contract Completion date	30 January 2007
Project Completion Date	May 2011
Project final cost estimate	Birr 384,743,403.76 (an increase of 90.7%)
Project consultant	Water Works Design and Supervision Enterprise (WWDSE)

Table 5.9: Contract KDIP implemented activities in Upper & Lower catchments

	Upper Catchment		Lower Catchment
Reservoir	Capacity = 83.1mm^3	Irrigated area	Number of blocks=12
Impounded area	1750ha	Net irrigation land	7004ha
Filling time	4 months starting June	Irrigation method	Furrow
Main dam type	Earth fill with clay core	Cropping season	Winter & summer
Main dam length	1730m	Main canal(all lined)length	19.7km
Main dam maximum height	21m	Main canal(all lined)number	1
Saddle dam type	Earth fill with clay core	Capacity	Max. discharge of 9.1m^3/s
Saddle dam length	1162m	Operation	24hrs
Saddle dam maximum height	9m	Secondary canals(all lined) length	42.362km
Access road length	6.3km	Secondary canals(all lined) operation	12hrs
		Secondary canals(all lined) number	12
		Tertiary canals(lined unlined) number	95
		Tertiary canals(lined) length	33.662km
		Tertiary canals(unlined) length	117km
		Tertiary canals(lined unlined) operation	12hrs
		Lined night storage reservoirs number	11
		Lined night storage reservoirs operation	24hrs
		Unlined drains length	131km
		Unlined drains operation	24hrs

Table 5.10: Summarized data of irrigation blocks

Region Block	Section of work of work	Distance away from main dam Km	Min. level of water storing capacity of night storages(m^3)	Sec. canal Num.	Sec. canal leng.	Ter. canal Num.	Ter. canal leng.	Quat. canal Num.	Quat. canal leng.	Ter. Num.	Ter. leng.	Ir. size Ha.
Kudmi	3	3.238	20,006	1	0.875	7	9.0	31	47.9	3nr	4.6	373
Chihona	3	9.76	33,593	1	3.756	9	14.5	47	68.5	6nr	15.7	617
Ambo mesk	4	10.804	40,176	1	7.186	15	12.4	54	95.6	10nr	20.9	812
Adbera	4	11.0	40,747	1	8.054	15	13.1	53	90.0	5nr	4.4	803
Lasi	5	13.780	25,195	1	2.505	5	8.8	31	59.2	5nr	12.2	484
Enguti	4	11.94	19,700	1	0.779	3	7.3	26	44.7	4nr	13.4	393
Tagel wedefit	6	11.94	37,727	1	4.472	11	8.8	41	75.1	8nr	9.7	616
Bered	5	14.85	24,728	1	2.875	6	8.0	30	52.8	3nr	6.3	468
Andenet	5	17.34	40,695	1	2.641	4	6.3	33	46.1	4nr	7.9	497
Amarit	5	17.34	-	1	0.868	4	5.6	19	27.1	2nr	4.4	290
Tekel dib	6	-	44,064	1	5.53	9	12.1	53	91.4	11nr	19.6	864
Teleta	6	19.7	41,887	1	2.841	7	11.1	51	84.6	6nr	11.9	787
Total			662,518	12	42.382	95	117.0	469	783.0	67	131.0	7004

nr	/per command area
Sec.	Secondary
Ter.	Tertiary
Quat.	Quaternary
Leng.	Length
Ir.	Irrigation
Ha.	Hectars

STOCHASTIC FRONTIER MODEL VARIABLES

C Trans-Log stochastic frontier and inefficiency model variables

Table 5.11: Trans-Log stochastic frontier & inefficiency model variables

Variables	Variable Description
Trans-Log Stochastic Frontier Model Variables	$X_i s$
Output	Most crops in area are potato, onion, cabbage, maize, and wheat produced for cash crop. Since farmers are producing quite a mix of crops value of output instead of physical quantity is taken.
$Labor_{hec}$	Labor is measured by the total maximum hrs per hectare during peak farming
$Seed_{hec}$	Seed of dominant crop type measured by kg per hectare.
$Agrochemicals_{hec}$	Agrochemicals including pesticide,insecticide & herbicide measured in litters
$Fertilizer_{hec}$	Fertilizer is measured by quantity of DAP & UREA applied in kilograms.
$Wateruse_{hec}$	In absence of volumetric measure, water schedule from farmers' points of view measured by hours of water release in a week as proxy is used.
Manure	A dummy variable with "1" if a farmer used manure as a fertilizer
Soilconservation	A dummy variable with "1" if soil & water conservation were applied in production during the period.
Landsize	It is measured by the area under cultivation in hectare. During survey the data on size of land was collected in terms of"qada" (one forth of a hectare) which later converted to hectare.

Variables	Variable Description
Inefficiency Model Variables	$Z_i s$
Household size	Total number of family members in a household
Extension visits	Frequency the extension agent i.e. Development agents visited the farmer in a month (Days per Month)
Male household head	A dummy variable with "1" if household head was Male
Membership in farmers' association	A dummy variable with "1" if a household was member of farmers' cooperatives
Credit access	A dummy variable with "1" if household had access to credit
Tenure system(Own land)	A dummy variable with "1" if household own land (different arrangements like own land,rented land, both & share cropping arrangements)
Tenure system(Rented land)	A dummy variable with "2" if household rented land

SOCIO-ECONOMIC CHARACTERISTICS OF FARMERS

D Socio-economic characteristics of farmers

Table 5.12: Socio-economic characteristics of farmers

S.N	Characteristics	Number	Proportion %
1	Average land size (hectare)	1.39	
2	Average household size(number)	6	
3	Male household head	257	66.9%
4	Age of household head	Number	Proportion %
	(a) ≥30	379	98.7%
	(b)≥40	323	84%
	(c) ≥50	132	34.4%
	(d) ≥60	27	7%
5	Average year of schooling for head	1.33 years	
6	Off-farm income	192	50%
7	Manure	217	56.5%
8	Water & soil conservation	203	52.8%
9	Membership in farmers' association	238	62%
10	Access to credit	58	15%
11	Land tenure arrangement	Number	Proportion %
	(a)Own land	314	81.8%
	(b) Rented land	55	14%
	(c) Own & rented land	3	0.8%
	(d) Sharecropping	12	3%

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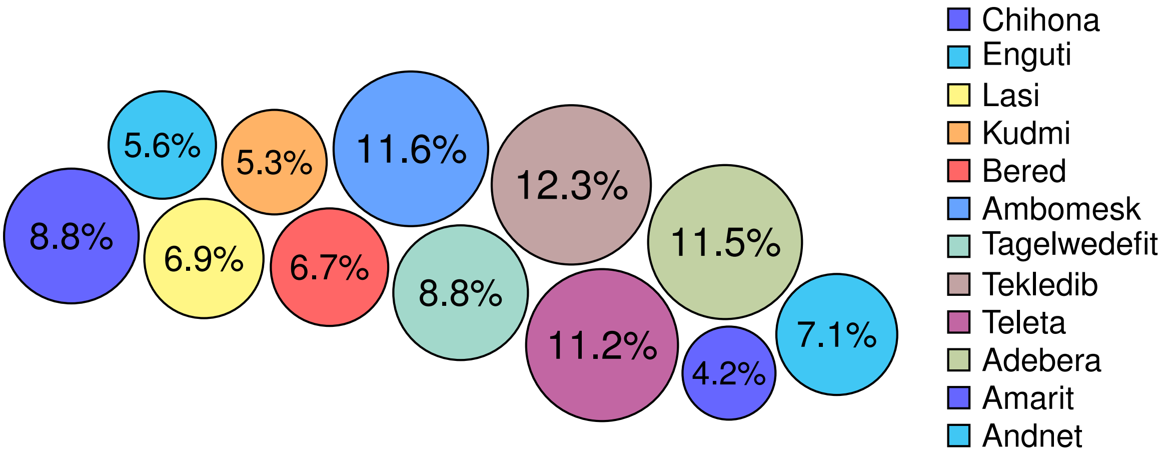


Figure 5.1: Proportion of irrigation land in each block

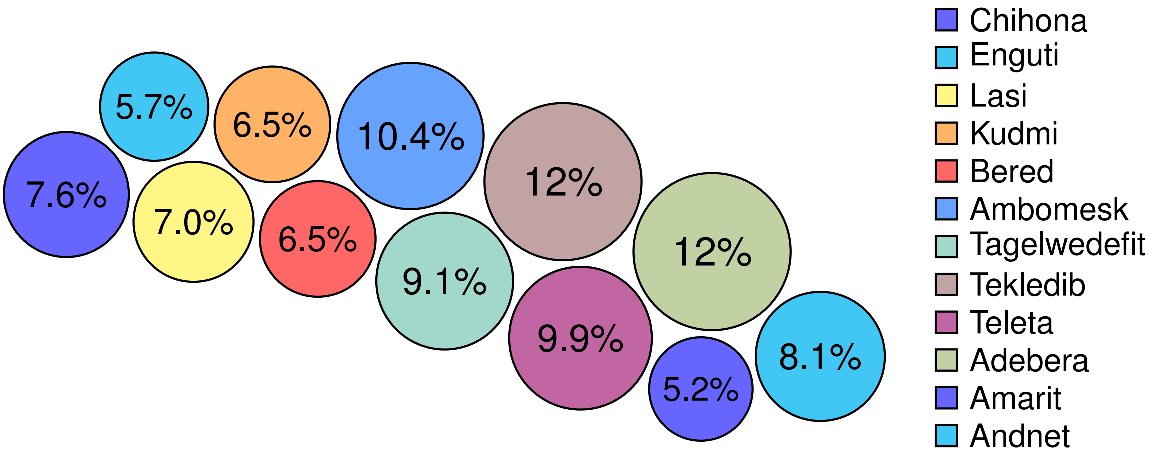


Figure 5.2: Proportion of sample size in each block

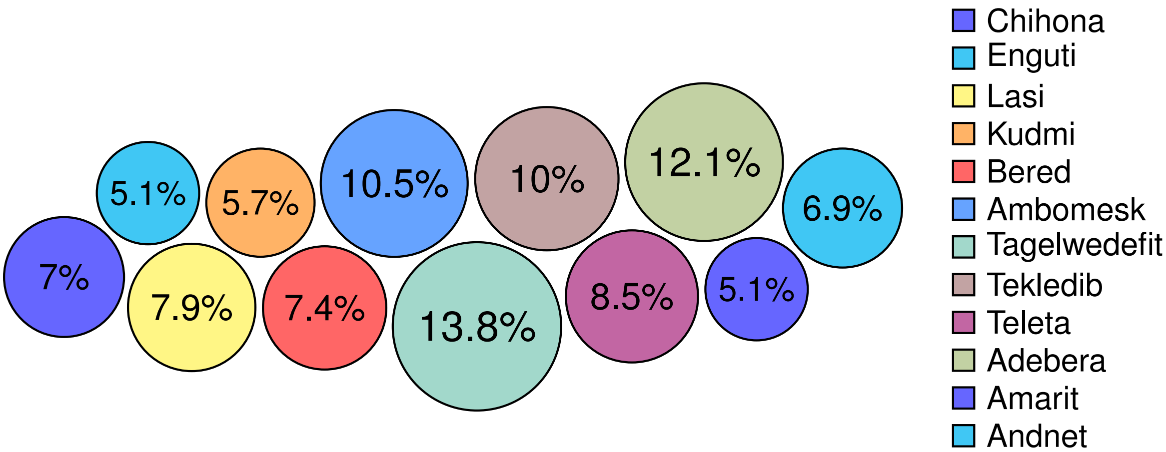


Figure 5.3: Proportion of sample land size in each block

APPENDIX FIVE

STOCHASTIC FRONTEIR MODEL (SFM)

E Stochastic Frontier Model (SFM) Results

Table 5.13: Trans-Log Stochastic Frontier Model results

Frontier/Value of output	Coef.	Std. Err.	P-Value
$\text{Ln}(Labor_{hec})$	3.625255	1.02259	0.000
$\text{Ln}(Agrochemicals_{hec})$	-11.08138	3.712087	0.003
$\text{Ln}(Fertilizer_{hec})$	2.512799	.8501957	0.003
$\text{Ln}(Wateruse_{hec})$	-5.473264	1.331143	0.000
Manure	-2.876573	1.399952	0.040
Soilconservation	-8.503961	3.435358	0.013
$\text{Ln}(Landsize)\text{Ln}(Agrochemicals_{hec})$	3.404723	1.16034	0.003
$\text{Ln}(Landsize)\text{ln}(Fertilizer_{hec})$	-1.097369	.3766584	0.004
$\text{Ln}(Labor^2_{hec})$	-.0696968	.043328	0.108
$\text{Ln}(Labor_{hec})$ $\text{Ln}(Fertilizer_{hec})$	-.6958222	.2420711	0.004
$\text{Ln}(Seed^2_{hec})$	-.8346883	.23753	0.000
$\text{Ln}(Seed_{hec})$ $\text{Ln}(Agrochemicals_{hec})$	3.276398	1.00768	0.001
$\text{Ln}(Seed_{hec})$ $\text{Ln}(Wateruse_{hec})$	1.078865	.3731038	0.004
$\text{Ln}(Agrochemicals^2_{hec})$	.8316063	.3809571	0.029
$\text{Ln}(Agrochemicals_{hec})\text{Ln}(Fertilizer_{hec})$	-.6817744	.42198	0.106
$\text{Ln}(Agrochemicals_{hec})$ $\text{Ln}(Wateruse_{hec})$	-1.119857	.3388904	0.001
$\text{Ln}(Fertilizer_{hec})$ $\text{Ln}(Wateruse_{hec})$	.76498	.2570212	0.003
$\text{Ln}(Wateruse^2_{hec})$	-.2023842	.0781978	0.010
*Manure** $\text{Ln}(Landsize)$	.8216497	.4461063	0.066
*Manure** $\text{Ln}(Agrochemicals_{hec})$	.5849126	.3822614	0.126
*Manure** $\text{Ln}(Fertilizer_{hec})$	.4598834	.2622536	0.080
$Manure^2$	-9.39e-11	(omitted)	-
*Manure** $\text{Ln}(Wateruse_{hec})$	-.2889632	.1158822	0.013
*Soilconservation** $\text{Ln}(Landsize)$	2.345885	.882956	0.008
*Soilconservation** $\text{Ln}(Seed_{hec})$	2.173058	.877671	0.013
$Soilconservation^2$	-2.86e-11	(omitted)	-
Cons	11.68523	3.682887	0.002

Table 5.14: Technical Inefficiency Model results

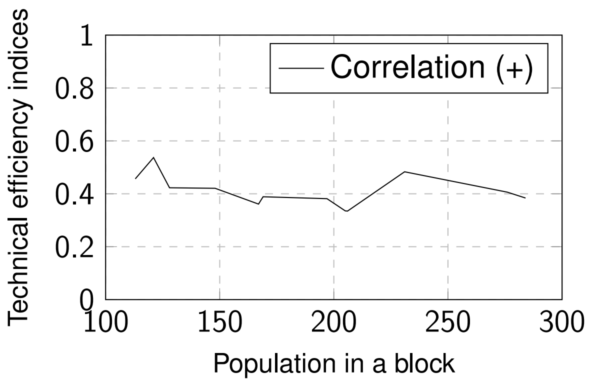
MU	Coef.	Std. Err.	P-Value
Household size	-.0476679	.0172186	0.006
Frequency of extension visits(Days/month)	-.1153604	.0388855	0.003
Male household head	-.1135847	.0568521	0.046
Off-farm income	-.1170705	.0575086	0.042
Membership in farmers' association (cooperatives)	.0787286	.0687057	0.252
Credit access	.1654055	.0796441	0.038
Land ownership type(Own land)	.6409611	.3055769	0.036
Land ownership type (Rented Land)	.7841473	.31047	0.012
Cons	.8017508	.7114188	0.260
Usigma	-2.709232	1.134694	0.017
Vsigma	-1.73559	.430366	0.000
sigma-u	.2580463	.1464018	0.078
sigma-v	.4198765	.0903503	0.000
lambda	.6145767	.2352024	0.009
Significance level	5%		

Table 5.15: Optimal Model and Appropriate Functional Form

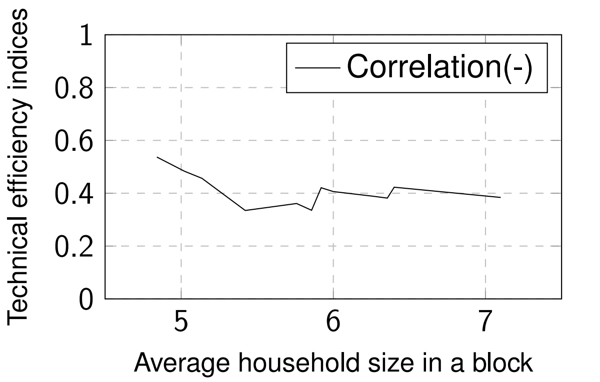
Assumption: CD nested in TL	Likelihood-ratio test
LR chi2(33) =	72.11
Prob > chi2 =	0.0001

Table 5.16: Determinants in Inefficiency model are simultaneously zero

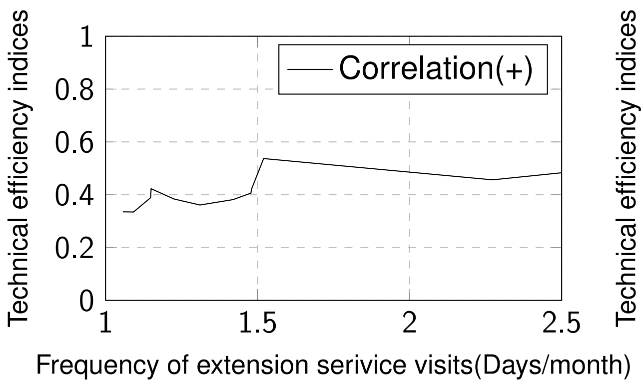
Result	Likelihood-ratio test
LR chi2(33) =	44.87
Prob > chi2 =	0.0000



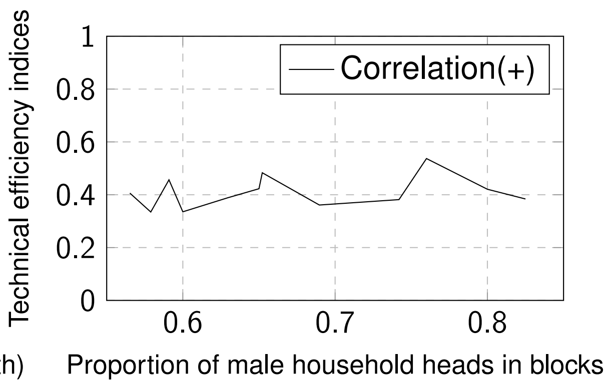
(a) Total population size & technical efficiency



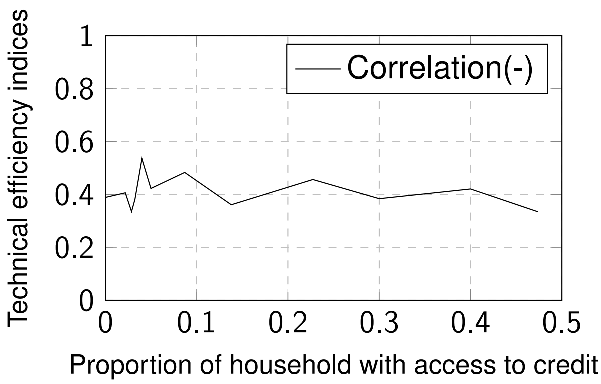
(b) Average household size & technical efficiency



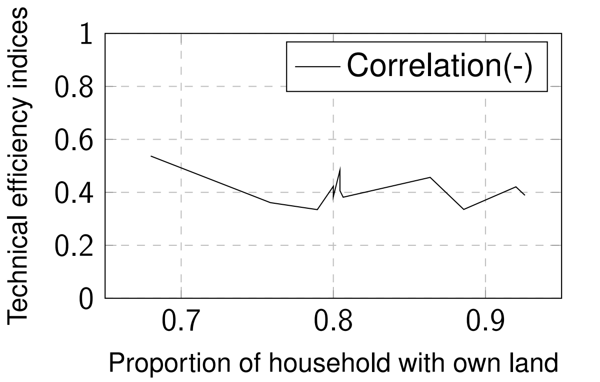
(c) Frequency of extension visits & technical efficiency



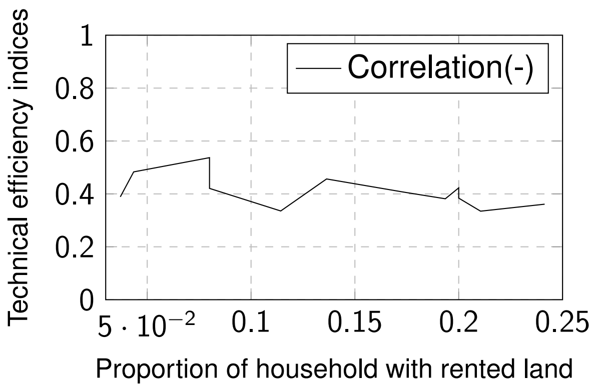
(d) Proportion of male household head & technical efficiency



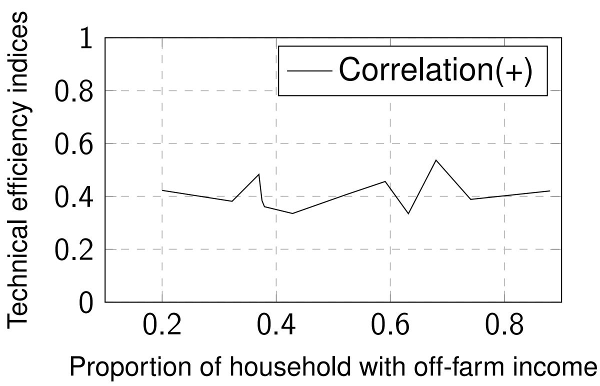
(e) Household with access to credit & technical efficiency



(f) Household with own land & technical efficiency



(g) Household with rented land & technical efficiency



(h) Off-farm income & technical efficiency

Figure 5.4: Plot analysis of farm, household specific variables & technical efficiency

APPENDIX SIX

MANN-KENDALL TREND TESTS

F Summary of Mann-Kendall trend Test results/ Hydro-climatic data analysis

Table 5.17: Summary of Mann-Kendall trend Test results/ Hydro-climatic data & sensitivity analysis

S.N	Data type	Merawi station Koga Nr./@ Merawi	Wetet Abbay station Gilgel Abbay Nr. Merawi	Trend Pattern	Strength of the trend
1.	Average annual temperature	+	+	same pattern	Stronger trend at Merawi
2.	Main Rainy Season (MRS) temperature	+	+	same pattern	Stronger trend at Merawi
3.	Short Rainy Season (SRS) temperature	+	+	same pattern	Stronger trend at Merawi
4.	Dry season temperature	?	?[1]		
5.	Total annual rainfall	+	?	Different pattern	
6.	Main Rainy Season (MRS) rainfall	?	?		
7.	Short Rainy Season (SRS) rainfall	?	+	Different pattern	
8.	Dry Season rainfall	?	?		
9.	Total annual runoff	?	?		
10.	Main Rainy Season (MRS) runoff	?	?		
11.	Short Rainy Season (SRS) runoff	+	+	Same pattern	Stronger trend at Gilgel Abbay Nr. Merawi
12.	Dry Season runoff	?	?		

APPENDIX SEVEN

SUSTAINABLE DEVELOPMENT ANALYSIS GRID (GADD)

G Sustainable development dimensions, themes and goals

Table 5.18: Sustainable Development Goals in the grid based on their closeness to a specific theme and their contribution

Dimensions	S.N	Themes Goals	Opportunity for improvement	Priority
SOCIAL	1	Poverty reduction		
	1.1.	Put in place measures to support the most disadvantaged and most vulnerable within local communities		Maintain
	1.2.	Implement measures to support the most disadvantaged and most vulnerable, at the national level		Long-term use
	1.3.	Contribute to actions seeking to reduce poverty at the supranational level		Long-term use
	2	Water		
	2.1.	Ensure a potable water supply for everyone		Maintain
	2.2.	Ensure adequate quality of water supply according to its uses		Maintain
	2.3.	Ensure access to adequate sanitation and hygiene services		Act
	2.4.	Increase the population's participation in mastering water and improving its management		Maintain
	3	Food		
	3.1.	Ensure access to food		Act
	3.2.	Ensure the nutritional quality of food		Act
	3.3.	Ensure food security		React
	3.4.	Enhance food sovereignty		Act
	3.5.	Implement sustainable agricultural and fishing practices		Act
	4	Health		
	4.1.	Improve and maintain the health of populations		Act
	4.2.	Ensure access to health care		Act
	4.3.	Promote preventive interventions in health, healthy environments and the adoption of healthy lifestyle habits		Act
	4.4.	Reduce factors likely to cause mental health issues		Act
	4.5.	Meet the specific needs of maternal and infant health		Act
	4.6.	Reduce irritants		Act
	5	Saftey		
	5.1.	Create a feeling of security		Act
	5.2.	Ensure effective safety		Act
	5.3.	Provide basic safety education		Act
	6	Education		
	6.1.	Ensure access to a quality educational system		Maintain
	6.2.	Ensure basic functional education for all		Maintain
	6.3.	Allow everyone to acquire the level of education they wish to attain		Act
	6.4.	Allow access to continuing education and training		Act
	6.5.	Provide education on sustainable development and citizenship		Act

Table 5.19: Sustainable Development Goals in the grid based on their closeness to a specific theme and their contribution....continued

Dimensions	S.N	Themes/ Goals	Opp.improvement	Priority
SOCIAL	7	Community and involvement		
	7.1.	Promote involvement		Maintain
	7.2.	Value and recognize personal and collective achievement		Act
	7.3.	Promote social cohesion		Act
	7.4.	Promote connections		Act
	7.5.	Allow for the development of self esteem and self confidence		Act
	7.6.	Improve the independence and resilience of communities		Act
	8	Human settlements		
	8.1.	Ensure access to housing		Act
	8.2.	Prioritize sustainable mobility		Act
	8.3.	Build sustainable infrastructures		Act
	8.4.	Promote sustainable cities and human settlements		Act
	8.5.	Work to make the real estate sector secure and reliable		Act
	8.6.	Promote equity and territorial solidarity		Act
	9	Gender		
	9.1.	Seek to implement equal rights without gender distinctions		Maintain
	9.2.	Seek gender equity		Act
	9.3.	Promote the independence of women and girls		Act
ECOLOGICAL	1	Ecosystems		
	1.1.	Develop knowledge of ecosystems and the species that depend on them		Act
	1.2.	Preserve continental ecosystems		Maintain
	1.3.	Restrict the biological, chemical and physical degradation of the soil		Maintain
	1.4.	Combat desertification		Act
	1.5.	Preserve marine and coastal ecosystems		Long-term use
	1.6.	Establish objectives for restoring degraded ecosystems		Maintain
	2	Biodiversity		
	2.1.	Encourage biodiversity protection		Act
	2.2.	Protect rare, threatened and at-risk species		Act
	2.3.	Raise awareness of symbolic species		React
	3	Resources		
	3.1.	Preserve the resources needed to sustain life in ecosystems		Act
	3.2.	Choose low-impact resources		Act
	3.3.	Plan for the prudent use of renewable resources		Act
	3.4.	Plan for the prudent use of non-renewable resources		Act
	3.5.	Optimize resources that are at the end of their life		Act

Table 5.20: Sustainable Development Goals in the grid based on their closeness to a specific theme and their contribution...continued

Dimensions	S.N	Themes Goals	Opportunity for improvement	Priority
ECOLOGICAL	4	Output		
	4.1.	Identify liquid, solid and gaseous outputs and the impacts of releasing them into the environment		Act
	4.2.	Minimize outputs		Act
	4.3.	Minimize impacts		Act
	4.4.	Manage hazardous waste properly		Act
	4.5.	Limit global pollutant emissions		Act
	5	Land use		
	5.1.	Optimize land use		Maintain
	5.2.	Limit usage conflicts		Maintain
	5.3.	Maintain landscape diversity		Maintain
	6	Climate change		
	6.1.	Quantify greenhouse gas emissions		React
	6.2.	Reduce GHG emissions		Act
	6.3.	Increase carbon sinks		Act
	6.4.	Compensate for greenhouse gas emissions		Act
	6.5.	Plan for adaptation measures to respond to the new climate reality		Act
ECONOMIC	1	Responsible production		
	1.1.	Producing quality goods and services		Act
	1.2.	Ensure adequation between needs and the goods and services produced		Maintain
	1.3.	Promoting eco design from a product life cycle perspective		Act
	1.4.	Promote sustainable industrialization		Act
	1.5.	Implement extended producer responsibility		Act
	2.	Responsible consumption		
	2.1.	Facilitating access to goods and services		React
	2.2.	Encourage responsible purchasing and consumption		Act
	2.3.	Encourage responsible investment		Act
	3	Economic viability		
	3.1.	To ensure economic viability		Maintain
	3.2.	To encourage responsible sources of funding		Act
	3.3.	To limit the financial risks		Act
	3.4.	To limit the return on capital		Act
	4	Work		
	4.1.	To promote access to an occupation		Maintain
	4.2.	To ensure fair value for people's work		Act

Table 5.21: Sustainable Development Goals in the grid based on their closeness to a specific theme and their contribution...continued

Dimensions	S.N	Themes Goals	Opportunity for improvement	Priority
ECONOMIC	5	Wealth and prosperity		
	5.1.	To stimulate exchanges between people and societies		Act
	5.2.	To aim for wealth growth		Maintain
	5.3.	To establish sustainable tourism practices		Act
	5.4.	To limit the possibility of capital flight		Act
	6	Energy		
	6.1.	To ensure access to reliable and affordable energy services		React
	6.2.	To promote the use of energy with less impact		Act
	6.3.	To plan a wise use of energy		Act
	7	Entrepreneurship		
	7.1.	To develop an entrepreneurial culture		Maintain
	7.2.	To support entrepreneurial capacity		Maintain
	7.3.	To ensure equitable access to means of wealth production		Maintain
	8	Economic models		
	8.1.	To eliminate distortions from economic models		React
	8.2.	To value social and solidarity economy		Act
	8.3.	To maintain or integrate traditional economic models with the dominant economy		Act
	8.4.	To support emerging and innovative economic models		Act
CULTURAL	1	Transmission of cultural heritage		
	1.1.	To promote individual expression, freedom and pluralism of beliefs, opinions and identities		Act
	1.2.	To ensure the conservation, restoration and compensation of the cultural heritage		React
	1.3.	To recognize cultural representations of the environment		React
	1.4.	To develop knowledge of the past and of history		React
	1.5.	To value and support linguistic diversity		Act
	2	Cultural and artistic practices		
	2.1.	To encourage cultural expression		Act
	2.2.	To affirm the plural and evolving nature of culture		Act
	2.3.	To recognize the importance of minorities and their contributions to society		Act
	2.4.	To provide access to culture through education at all levels		Act
	3	Cultural diversity		
	3.1.	To promote interculturality		Act
	3.2.	To ensure equity between cultures		Act
	3.3.	To support the diversity of cultural expressions		Act

Table 5.22: Sustainable Development Goals in the grid based on their closeness to a specific theme and their contribution...continued

Dimensions	S.N	Themes Goals	Opportunity for improvement	Priority
CULTURAL	4	Contribution of culture to development		
	4.1.	To promote the emergence of a cultural industry that generates jobs and wealth		Act
	4.2.	To make explicit the links between culture, development, employment and economic prosperity		Maintain
	4.3.	To ensure an equitable sharing of innovations arising from cultural assets or traditional knowledge		Act
ETHICAL	1	Responsibility		
	1.1.	To act with integrity and transparently		Maintain
	1.2.	To apply the precautionary principle		Maintain
	1.3.	To respect human rights		Maintain
	1.4.	To assume responsibility for human beings, other living beings and non-living beings		React
	1.5.	To balance individual freedom and collective responsibilities		Act
	1.6.	To promote the adoption of sustainable lifestyles		Act
	2	Peace		
	2.1.	To promote a culture of peace and non-violence		Act
	2.2.	To search for peaceful solutions to conflicts		Maintain
	2.3.	To work towards post-conflict resolution and reconstruction		Maintain
	2.4.	To foster a sense of justice		Maintain
	3	Benevolence		
	3.1.	To increase accessibility		Act
	3.2.	To offer compensation to affected individuals and groups		Act
	3.3.	To develop community spirit and solidarity		Maintain
	3.4.	To embrace otherness		React
	4.	Sharing		
	4.1.	To maximize benefits		Act
	4.2.	To ensure a redistribution mechanism		Act
	4.3.	To respect common goods		Maintain
	5	Ethical process		
	5.1.	To question ethical goals		Act
	5.2.	To develop an ethical dialogue		Maintain
	5.3.	To promote the emergence and sharing of common values		React
	5.4.	To ensure consistency between actions and values		React

Table 5.23: Sustainable Development Goals in the grid based on their closeness to a specific theme and their contribution...continued

Dimensions	S.N	Themes Goals	Opportunity for improvement	Priority
GOVERNANCE	1	Institutions		
	1.1.	To improve the effectiveness, accountability and inclusiveness of institutions		Maintain
	1.2.	To ensure access and equality in the face of justice		Act
	1.3.	To limit opportunities for corruption		Maintain
	1.4.	To encourage competence		Act
	2	Tools and processes		
	2.1.	To integrate sustainable development into management processes		Act
	2.2.	To optimize the use of instruments for operationalizing sustainable development		React
	3	Participation and citizenship		
	3.1.	To promote engagement and mobilization around a common vision		Maintain
	3.2.	To encourage stakeholder Participation and citizenship		Maintain
	3.3.	To ensure the inclusiveness of participatory mechanisms		Maintain
	3.4.	To recognize the contribution of donors		Act
	3.5.	To develop partnerships		Act
	3.6.	To consider the level of acceptability		React
	3.7.	To make exercising active citizenship possible		Maintain
	4	Subsidiary		
	4.1.	To bring decision-making closer to stakeholders		Maintain
	4.2.	To promote the accountability of actors		Maintain
	4.3.	To ensure consistency among the various levels of decision making		Act
	5	Local integration		
	5.1	To respect the legal context		Act
	5.2.	To include specific local issues		Maintain
	5.3.	To ensure systemic coherence		React
	6	Information		
	6.1.	To ensure access to prior, relevant, comprehensible and fair information		Act
	6.2.	To use the appropriate communication mechanisms		Act
	6.3.	To provide basic information to decision-makers		Maintain
	6.4.	To establish monitoring and evaluation measures		Maintain
	6.5.	To be accountable in a transparent way		Act

Table 5.24: Sustainable Development Goals in the grid based on their closeness to a specific theme and their contribution...continued

Dimensions	S.N	Themes Goals	Opportunity for improvement	Priority
GOVERNANCE	7	Innovation		
	7.1.	To optimize innovation potential and diversify options		Act
	7.2.	To promote research and development		Maintain
	7.3.	To encourage the implementation of new solutions		Maintain
	7.4.	To promote access to knowledge and technologies		Act
	7.5.	To manage risks associated with new technologies		Act
	8	Risk management and resilience		
	8.1.	To identify risks		React
	8.2.	To apply the principle of prevention		Act
	8.3.	To consider the perception of risk		React
	8.4.	To promote an equitable distribution of risks		React
	8.5.	To provide for adaptations to changes		React

PAIRWISE COMPARSION (SAATY (1980)

H Criteria weighting and relative importance of adaptation and mitigation measures

Table 5.25: Pairwise comparison of criteria/pillars of sustainability [This pairwise comparison determine the criteria weighting]

	More important than				Equal important	Less important than				
	More	more	more	more	equally	Less	Less	Less	less	
Criteria	9	7	5	3	1	3	5	7	9	Criteria
Economic sustainability	O	O	O	O	O	O	O	O	O	Social sustainability
Social sustainability	O	O	O	O	O	O	O	O	O	Environmental sustainability
Environmental sustainability	O	O	O	O	O	O	O	O	O	Economic sustainability

Table 5.26: Pairwise comparison to determine the relative importance of mitigation and adaptation strategies for economic sustainability (Table 1)[It should be noted that the five-member analysis group repeated the comparison for the remaining two pillars]

	More important than				Equal important	Less important than				
Adaptation / mitigation Measures	More 9	more 7	more 5	more 3	equally 1	Less 3	Less 5	Less 7	less 9	Adaptation / mitigation Measures
Public health	O	O	O	O	O	O	O	O	O	Settlement and compensation
Training and extension courses	O	O	O	O	O	O	O	O	O	Planting forest seedlings
Settlement and compensation	O	O	O	O	O	O	O	O	O	Livestock development
Planting forest seedlings	O	O	O	O	O	O	O	O	O	Irrigation agronomic practices
Livestock development	O	O	O	O	O	O	O	O	O	Cooperative organization
Irrigation agronomic practices	O	O	O	O	O	O	O	O	O	Marketing activities
Cooperative organization	O	O	O	O	O	O	O	O	O	Public health
Marketing activities	O	O	O	O	O	O	O	O	O	Training and extension courses
Public health	O	O	O	O	O	O	O	O	O	Training and extension courses
Training and extension courses	O	O	O	O	O	O	O	O	O	Settlement and compensation
Settlement and compensation	O	O	O	O	O	O	O	O	O	Planting forest seedlings
Planting forest seedlings	O	O	O	O	O	O	O	O	O	Livestock development
Livestock development	O	O	O	O	O	O	O	O	O	Irrigation agronomic practices
Irrigation agronomic practices	O	O	O	O	O	O	O	O	O	Cooperative organization

Table 5.27: Pairwise comparison to determine the relative importance of mitigation and adaptation strategies for economic sustainability (Table 2)[[It should be noted that the five-member analysis group repeated the comparison for the remaining two pillars]

	More important than				Equal important	Less important than				
Adaptation / mitigation Measures	More 9	more 7	more 5	more 3	equally 1	Less 3	Less 5	Less 7	less 9	Adaptation / mitigation Measures
Cooperative organization	O	O	O	O	O	O	O	O	O	Marketing activities
Marketing activities	O	O	O	O	O	O	O	O	O	Public health
Public health	O	O	O	O	O	O	O	O	O	Planting forest seedlings
Training and extension courses	O	O	O	O	O	O	O	O	O	Livestock development
Settlement and compensation	O	O	O	O	O	O	O	O	O	Irrigation agronomic practices
Planting forest seedlings	O	O	O	O	O	O	O	O	O	Cooperative organization
Livestock development	O	O	O	O	O	O	O	O	O	Marketing activities
Irrigation agronomic practices	O	O	O	O	O	O	O	O	O	Public health courses
Cooperative organization	O	O	O	O	O	O	O	O	O	Training and extension courses
Marketing activities	O	O	O	O	O	O	O	O	O	Settlement and compensation
Public health	O	O	O	O	O	O	O	O	O	Livestock development
Training and extension courses	O	O	O	O	O	O	O	O	O	Irrigation agronomic practices
Settlement and compensation	O	O	O	O	O	O	O	O	O	Cooperative organization
Planting forest seedlings	O	O	O	O	O	O	O	O	O	Marketing activities