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OPTIMUM USE OF IRRIGATION WATER: Bioeconomic household modeling of small-scale irrigation scheme in South Central Ethiopia

Inaugural Dissertation

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Abstract

The Ethiopian economy is agrarian, by and large. This is evidenced by the fact that the agricultural sector contributes nearly 36 percent of the GDP and employs 80 percent of the population. However, the sector's growth has been impended by institutional, environmental and other factors. The sector is dominated by smallholders who are vulnerable to external shocks and have limited capacity to invest on their land. This causes low productivity to prevail in the sector, which further exacerbates the prevalence of rural poverty. In recent times, the government of Ethiopia promotes the expansion of small- scale irrigation by optimally using the bounty of water resources in a bid to reducing poverty and food insecurity. But, many of the surface water are dominated by rivers (both small and big) which flow cross different localities. The rivalry in using the water across the course of the river causes continual conflict among communities living on different courses of the river. In the study area, there is a small river that passes through upstream, middle stream and lower stream localities; and there is conflict among users along the way. Despite the prevalence of such burning issues, studies on the optimal allocation of water and on the impact of irrigation on poverty using rigorous economic models are scanty except some that have rather focused on identifying factors urging households to use irrigation. This justifies the need for examining the extent to which the flowing water is optimally shared among users across the course of the river in a way that brings maximum benefits. Against the backdrop of the aforementioned gaps, this study is, therefore, an attempt to bridge the observed gaps by using both bioeconomic and econometrics approaches. Data have been collected from 240 households, which live in upper, middle and lower parts of the stream. The descriptive results have shown that there is significant difference in the socio-economic characteristics between farmers who have access to irrigation and those who do not. Poverty analysis was conducted using the Foster–Greer–Thorbecke (FGT) indices based on own constructed consumption poverty line. The incidence, depth, and severity of poverty were found to be higher among farmers who do not have access to irrigation. Assessment of the physical irrigation infrastructure indicated performance problems of the canals and a significant amount of water loss during transportation. Irrigation is undertaken in turns based on a schedule set by Water Users Association committee. There is also a clear difference in production patterns between households living in upstream, middle stream and lower stream parts of the river. Those households which live in the upper stream produce more Khat than households living either in the middle or lower stream. In fact, in relative terms, those households which live in the middle parts of the river produce more Khat than households living in the lower stream. In the same pattern, the amount of water used per ha by households in the upper stream is by far greater than the amount of water used per ha by households in the lower parts of the river both for Khat and sugar cane production. This could be associated to the location advantage upper stream households have to access more water. The results of the logistic regression showed that institutional set ups and *governance of the irrigation scheme, access to information and social network, and water scarcity level have significant impacts on farmers' decisions to irrigate. Among the factors, the pesticide amount used, and landholding size have a positive and significant impact on the farm income of the respondent households. Plot size and distance to nearest market, on the other hand, have a negative and significant impact on farm income of households. Regarding per adult equivalent food consumption, households' farm income, non-farm income, and household asset have positive and significant impacts. Household size and dependency ratio, on the other hand, have a negative impact. Further analyses were carried out using bioeconomic modeling in order to identify alternative policies that ensure optimal water allocation along the stream. There are two cash crops (sugarcane and Khat) that are produced in the study area. Khat consumes more water than sugarcane and has undesired socio-economic impacts. This situation requires interventions to be designed to reduce the production of Khat such that the water could be optimally allocated across the course of the river. Towards this end, three scenarios were considered for simulations namely improving the efficiency of water use and taxing Khat production, water tax and allocating more land to Sugarcane were considered. Improving efficiency of sugarcane production and taxing Khat improves the production of sugarcane. Water pricing promotes the production of khat, while land allocation promotes the production of sugarcane. Based on the aforementioned analysis, the study pinpointed the fact that both institutional and social factors should be given prime attention to ensure fair distribution of water across the course of the river and to instigate farmers to use irrigation. Besides, enhancing the productivity of sugarcane through improved technology should be the main concern of stakeholders. In this regard, a system that tends to enhance the productivity of sugarcane should be in place such that the community would allocate more land to sugarcane which eventually ensures sustainable water use across the course of the river ultimately benefiting users.*

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1. INTRODUCTION

1.1. Background

After witnessing the tremendous results of the Green Revolution, agriculture has regained its recognition as the most important sector playing crucial role in economic development. Several studies show that this role of agriculture is even more pronounced in countries where farms are mostly small like that of Sub-Saharan Africa *(DIAO ET AL*., 2010). Water is an important element whose availability significantly determines the performance of agriculture and its growth. In fact, water has long been recognized as a scarce economic and social good requiring stringent planning and management. The concept of water scarcity has two dimensions: (1) physical and (2) economic. The former occurs when the existing water resource is inadequate to meet the needs of the users including environmental needs. The latter, which is common in Sub-Saharan Africa (SSA), results from poor governance and mismanagement though the existing water resource is said to be adequate (DUDU & CHUMI, 2008).

Water scarcity is very much regionalized where people who live in Asia and Africa suffer the most (WORLD BANK, 2016). Particularly, the poor and vulnerable population of SSA have more than proportionately been affected by water scarcity. What worsens the problem is 'poor water management practices' and 'limited institutional and household capacities' in utilizing the available water (AMEDE, 2015). This, in turn, puts huge pressure on agricultural production and food security in this region (ESMAEILI & SHAHSAVARI, 2015; SINGH *ET AL*., 2009; YANG *ET AL*., 2003).

Smallholder agriculture is the 'Achilles heel' of the Ethiopian economy whose performance determines the performance of other sectors. This is because the growth of agriculture is based on availability of rainfall whose late onset or early ending may result in crop failure, which further exacerbate poverty and food insecurity. Rainfall variability does not only affect the crop subsector but also the livestock production, ultimately adversely affecting the whole sector. In fact, Ethiopia has 12 major river basins with total annual runoff volume of 122 billion m^3, and groundwater resource potential of 6.5 billion m^3 where one Lake Basin has several rivers. Notwithstanding the high spatial and temporal variability as well as a decreasing trend in the availability of water resulting in acute shortage of food, Ethiopia is mentioned as a relatively water-abundant country in East Africa (AMEDE, 2015; GEBREGZIABHER, 2012; SETEGN *ET AL*., 2011).

Studies show that poverty-growth elasticity is larger when agriculture is set to drive the economic growth. This shows that agriculture is still the key sector in Ethiopia in poverty reduction and meeting rising food demands (WB, 2017). For instance, agricultural led 1 percent increase in per capita GDP leads to a 1.7 percent reduction in the country's poverty headcount per year. Equivalent increase in other sectors, however, results in only 0.7 percent reduction in poverty rate (DIAO *ET AL*., 2010).

But, if agriculture is to continue to play its anticipated role in reducing poverty and spurring growth in other sectors of the economy, there should be judicious use of water resources in the sector. Cognizant of the major role agriculture can play in reducing poverty through gains in productivity by making water available, the Government of Ethiopia has entrusted investing in irrigation development strategies to the core of its policy agenda (GEBREGZIABHER, 2012). Figure 1.1 below shows the trend on how the government has been working on equipping agricultural land for irrigation over the last three decades. As evident in Figure 1.1, the area equipped for irrigation has continuously and sharply been rising, confirming the emphasis given to the sector.

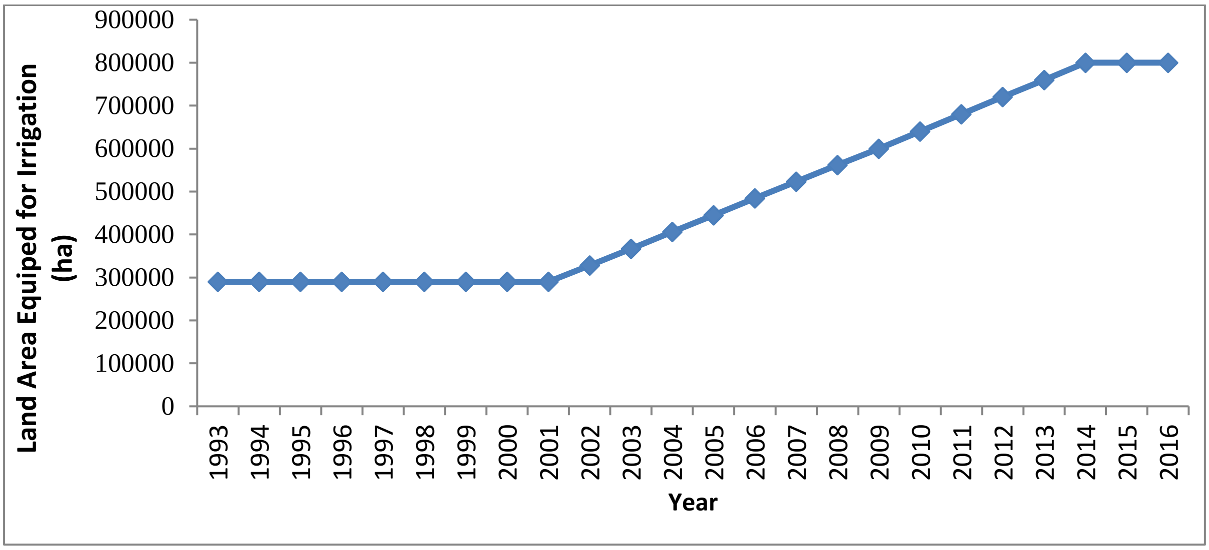

Figure 1.1: Agricultural area equipped for irrigation in Ethiopia
Source: FAOSTAT (2016)

Given the country's irrigable land potential, which is estimated to be 5.3 Million ha (including 1.6 Million ha which could be developed using rainwater harvesting and groundwater source of irrigation water), what has been developed so far is rather minimal; only 5 percent (not more than 0.7 Million ha) (ASEYEHEGU ET AL., 2012; AWULACHEW & AYANA, 2011). Moreover, irrigated agriculture in the country is dominated by small-scale traditional irrigation accounting for 77 percent of the total irrigated area (AWULACHEW & AYANA, 2011). Although the irrigation coverage has been very low, small-scale irrigation projects in the county have contributed largely to the mitigation of the risk of rainfall variability and related vulnerability of smallholder farmers. The implementation of projects improved the productivity of farms and reduced encroaching of farming to less-productive areas, increased production of high value crops, and encouraged stronger collective action to manage schemes and watersheds (AMEDE, 2015). Even though it is way below the country's potential, irrigation agriculture in Ethiopia generates significantly higher income compared to rain-fed agriculture. Income per ha in the former is about 323 USD, while it is only 147 USD in the latter (HAGOS *ET AL*., 2009).

Despite its actual and projected benefits, irrigation agriculture in Ethiopia has been challenged by several factors. Out of the small and medium scale irrigation schemes in the country, 86.5 percent are said to be functional though they irrigate only 74 percent of their design potential. Moreover, only half of the targeted beneficiaries have access to irrigation water brought by the schemes (AWULACHEW & AYANA, 2011). This indicates that although the government is investing huge financial resources on irrigation development, the full potential has not been taped yet. The small-scale irrigation schemes in the country failed to bring the intended results mainly owing to design and engineering problems as well as weak institutional settings to sustainably manage water (AMEDE, 2015; AWULACHEW & AYANA, 2011). On top of the design problems, there is no regular maintenance of the schemes due to lack of capacity while most of the canals except for primary ones are not lined resulting in high water loss (AWULACHEW & AYANA, 2011).

With regard to institutions involved in the management of water and schemes, there are several forms including traditional 'water masters' also called 'water fathers', 'modern Water Users Associations (WUAs)', and 'co-operatives'. These institutional arrangements exist in most of the schemes but lack clear duties and responsibilities resulting in confusion and conflict. Moreover, there is no legal framework which supports the proper enforcement of agreed upon by-laws regarding water use resulting in turn in abuses, corruption, and conflict between upstream and downstream farmers (AMEDE, 2015; DENEKE *ET AL*., 2011). The limited access to market infrastructure is another issue constraining small-scale irrigations in the country from using their full potential (GEBREGZIABHER, 2012; HAGOS *ET AL*., 2009).

Global estimates indicate that demand for water in the developing world from all sectors (including farming, industrial, and urban) will rise by 40 percent by 2030 (NEELY *ET AL*., 2009). Due to population growth, there is a need to increase agricultural production to meet the growing demand for food. Obviously, water is one of the most binding factors for increasing production in agriculture (DUDU & CHUMI, 2008). However, stiff competition from other sectors amidst climate change intensifies the problems of water scarcity (AMEDE, 2015; BJORNLUND *ET AL*., 2014; RIGBY *ET AL*., 2010).

The agriculture sector of Ethiopia is dominated by smallholder rain-fed system. Nevertheless, in the face of highly pronounced hydrological variability, the growth of the sector has been and will be held back resulting in low current as well as future per capita physical water availability (ASEYEHEGU *ET AL*., 2012; AWULACHEW, 2008; BELAY & BEWKET, 2013; GEBREGZIABHER, 2012) affecting the bulk of the populace (ROSEGRANT *ET AL*., 2009; SCHEIERLING *ET AL*., 2016). Figure 1.2 shows a declining trend of per capita water availability in Ethiopia.

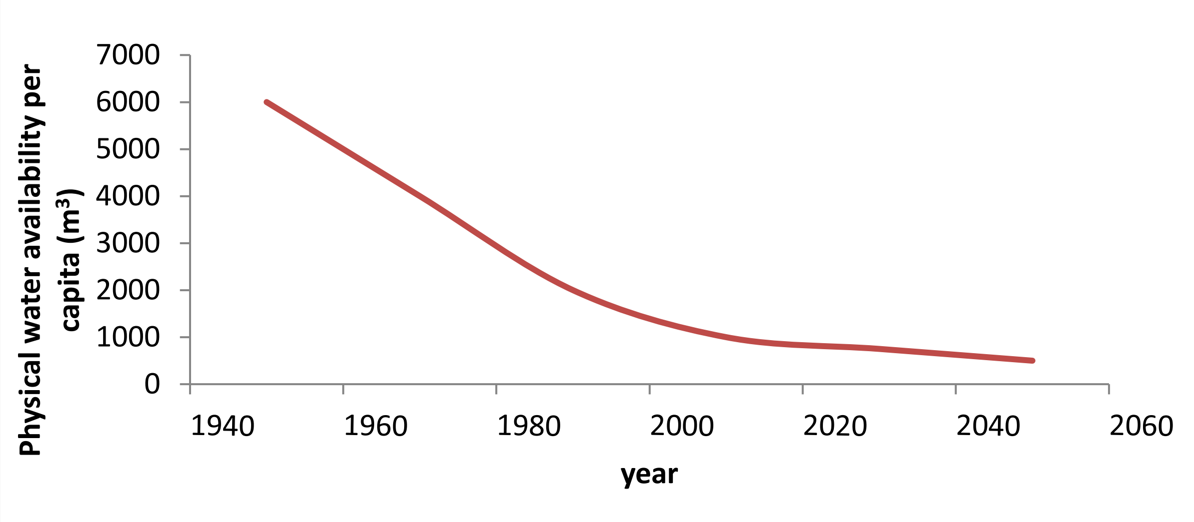

Figure 1.2: Per capita physical water availability in Ethiopia

Source: AWULACHEW (2008)

Agricultural production in countries like Ethiopia is challenged by major biophysical factors like soil degradation in addition to lack of access to safe and reliable water (AWULACHEW, 2008). Among these, water scarcity is the major factor constraining crop production (NAMARA ET AL., 2010; SINGH *ET AL*., 2009). One solution in mitigating the impact of water scarcity could be enhancing supply, which is highly costly and requires huge investment (ROSEGRANT *ET.AL*, 2009). Therefore, besides the physical availability of the resources, the livelihood of the rural poor is heavily dependent on the optimal utilization and management of these scarce natural endowments (BERAZNEVA *ET A*L., 2014).

Optimal utilization and management of agricultural water, accordingly, is vital specially in Ethiopia where the common type of water scarcity is economic because of 'failure to develop and use available water potential' (BELAY & BEWKET, 2013). Even though Ethiopia is considered as water abundant country, the agriculture sector is affected by water scarcity owing to the spatial and temporal variability in the availability of the resource. On the other hand, Ethiopia has been aggressively pursuing a number of small-scale irrigation schemes aimed at improving rural livelihoods. There is, however, significant amount of empirical evidence and growing concern that the performance of the irrigation schemes is below expectations. Several reasons are mentioned for the underperformance of irrigation schemes including design failure, poor water management practices, and weak institutions (AMEDE, 2015; BELAY & BEWKET, 2013; DENEKE *ET AL*., 2011).

Generally, in Ethiopia, the huge investment in the development of small-scale irrigation has not been accompanied by adequate water management and institutional provisions, which resulted in unsuccessful schemes. The 'ineffective policy implementation' resulted in lack of proper bylaws of operation for water use and upstream-downstream allocations, among other things. This, in turn, resulted in upstream users to feel the sole entitlement of the water and conflicts (AMEDE, 2015). Access to irrigation water is highly affected by the location of the farm households (BELAY & BEWKET, 2013). Moreover, inefficient application and water wastage, low conveyance efficiency of canals, and irrigating fields in excess of crops' water requirement are among the critical challenges of the sector (AMEDE, 2015). This situation calls for efforts towards achieving proper management of the already developed schemes which should be given equal attention to developing new ones if small-scale irrigation scheme is to be successful in contributing to poverty reduction and food security (AWULACHEW & AYANA, 2011).

There are some studies that have been conducted so far on the issue in Ethiopia. They, however, focused on identification and description of irrigation potential, challenges, prospects (AWULACHEW *ET AL*., 2010), technical and institutional assessment of irrigation agriculture (AMEDE, 2015; AWULACHEW & AYANA, 2011; BELAY & BEWKET, 2013), assessment of adoption of smallholder irrigation technology and estimation of probability of adoption (GEBREGZIABHER, 2012), optimal irrigation scheduling (SETEGN *ET AL*., 2011), identification and description of problems of small-scale irrigation intervention (ABERRA, 2004), assessment of water centered growth challenges and other welfare impact studies (BACHA *ET AL*., 2011; GEBREGZIABHER *ET AL*., 2009; HANJRA *ET AL*., 2009A; NAMARA *ET AL*., 2010), and investigation of performance of irrigation scheme using indicators mostly focusing on efficiency of water delivery and productivity (AWULACHEW & AYANA, 2011). There is no study so far which had dealt with optimal use and allocation of water among upstream and downstream farm households in irrigation schemes using a framework encompassing both biophysical and socio-economic components of a bioeconomy; only few of previous impact studies have paid attention to institutional factors (or scheme governance problems) and none of the previous studies have tried to quantify and include institutional factors in an econometric analysis.

This study, therefore, intends to fill the aforementioned research gaps by focusing on: (1) examining determinants of adoption and impact of irrigation on poverty with emphasis on institutional variables; (2) modeling of optimum irrigation water use and allocation using the bioeconomic farm household modeling framework; and (3) scenario analysis of several policy options to trigger actions by farm households for achieving sustainable bioeconomy. By doing so, this study is expected to contribute to the existing body of knowledge in terms of methodology as well as contextual knowledge through empirical findings. The developed bioeconomic farm household model extends the traditional farm household modeling approach by incorporating water as a biophysical component in the production function and as a constraint in the biophysical process. The study further develops different possible scenarios based on policy proposals related to input/output price, scheme efficiency, water allocation and use, and cropping plan to simulate the resulting impact on the welfare of households, production decision, resource allocation, and water availability. The result will support policy-level decisions to help achieve the objectives and realize the potential of small-scale irrigation development in the country.

1.2. Objectives of the Study

The general objective of this study is to examine the effect of irrigation adoption and different policy scenarios on welfare of smallholder farmers and water availability using econometric analysis and bioeconomic farm household modeling framework in Wondo Genet, South-Central Ethiopia.

This broad objective will be explored using the following specific objectives:

1. To examine whether the use of water affects poverty level (welfare) of the households,
2. To model the optimal water use which can yield sustainable bioeconomy in the study area, and
3. To measure the possible effects of alternative policy scenarios of water allocation, land use, and input/output prices on households' welfare, land allocation, production, and consumption decision; and on the overall availability of water.

1.3. Organization of the study

The remainder of the thesis is organized as follows: Chapter two discusses small-scale irrigation and practices in Ethiopia and the study area. Chapter three provides a brief overview of the theoretical and empirical literature around the topic under consideration. Chapter four depicts the study methodology, and the context. Chapter five presents and discusses the results of the study. The last Chapter (Chapter six) pinpoints the key summaries, conclusions and recommendations of the study.

2. SMALL-SCALE IRRIGATION AND PRACTICES IN ETHIOPIA

2.1. Overview

Different scholars use various criteria including size, source of water, management style etc., to classify and define irrigation systems as small-scale. For instance, while some define small-scale irrigation as "*a system that draws water from various sources and use different access and distribution technologies to irrigate different types of crops under different management practices*" (BURNEY & NAYLOR, 2012), the definition we found more relevant to the context of this study is as follows:

> "*Irrigation usually on small plots, in which farmers have the major controlling influence and using a level of technology which the farmers can effectively operate and maintain"* (TURNER, 1994: 251)

Small-scale irrigation has been widely promoted since the 1980s after large-scale irrigation project interventions proved unsuccessful especially in SSA (ABERRA, 2004; TURNER, 1994). Large-scale irrigation schemes in Sub-Saharan Africa failed because they were externally imposed and required high cost and relatively sophisticated technological inputs. The schemes also had problems related to institutions, policy, socio-cultural, and environmental issues (ADAMS, 1990; BARGHOUTI AND MOIGNE, 1990). The importance of small-scale schemes has further gained momentum with the shift of 'development paradigm' in line with the emergence of sustainable development which promotes 'development from below' (ABERRA, 2004; ADAMS, 1990).

In addition to enhanced productivity, irrigation can, theoretically, impact poverty reduction in a complex pathway including by enhancing employment, resilience and sustainability, consumption, and nutrition. For instance, the benefits of irrigation can be viewed from the perspective of its impact on the use of productivity-enhancing inputs like fertilizer and improved varieties. The wider economy can also benefit indirectly through a backward linkage in the form of income and employment (GEBREGZIABHER *ET AL*., 2009; NAMARA *ET AL*., 2010; SMITH, 2004). The benefits can also accrue as better opportunities for livelihood diversification and multiple use of the water supplied by the scheme (Smith, 2004).

In view of this, small-scale irrigation schemes have been promoted in SSA to enhance food security situation in the region (BURNEY & NAYLOR, 2012; DETHIER & EFFENBERGER, 2012; DILLON, 2011; XIE *ET AL*., 2017). However, empirical evidences show that not more than 6 percent of the total cultivated area is covered by irrigation (YOU ET AL., 2011) and only 4 percent of the renewable water is used for agriculture (HANJRA *ET AL*., 2009a). Several factors are mentioned to contribute to the extremely low irrigation use in SSA despite their importance and subsequent promotion. These factors include deficient institutions (HANJRA *ET AL*., 2009; MURUGANI & THAMAGA-CHITJA, 2018; YOHANNES *ET AL*., 2017), poor irrigation infrastructure (MDEMU *ET AL*., 2017), mismanagement and corruption (DUDU & CHUMI, 2008; NAMARA *ET AL*., 2010; WORLD BANK, 2016), and governance and context-specific factors (YAMI, 2016).

Moreover, performance of the small-scale irrigation projects has been below expectation in this region owing to several challenges and practical problems. Some of the problems are typical to the unique contexts related to agro-ecological factors. Some others are shared commonly by all small-scale irrigation schemes. These common problems include (1) problems related to physical and engineering issues resulting in poorly designed systems and water loss, (2) Problems related to water distribution and allocation, and (3) problems related to policy, institutions and farmers' participation (ABERRA, 2004).

For small-scale irrigation schemes to be successful interventions should take into consideration the local contexts and existing farming and livelihood system. The interventions should target all components of the irrigation system including the physical infrastructure and 'organizational capabilities of farmers. Regarding technical and physical infrastructure, supplementing the existing traditional agricultural practices is proved to be successful than introducing new technology which require specific new knowledge and skill (ABERRA, 2004). Similarly, the strength and full participation of local institutions like water user associations cannot be stressed more. It is also more logical and viable to use the already established traditional institutions with required adjustments to suit requirements of the irrigation system (ABERRA, 2004; BURNEY & NAYLOR, 2012).

2.2. Irrigation access and distribution infrastructure and technology

The share of irrigated agricultural area is very low in SSA at 6 percent and even goes further down to 2.6 percent for Eastern Africa compared to 18 percent for global average (YOU *ET A*L., 2011). Irrigation infrastructure is one of the essentials for successful economic development like roads, markets, and health and education facilities (SPENCER, 1996). The Asian Green Revolution, for instance, was made possible mainly due to the rural irrigation projects among other things (LEBDI, 2016; SPENCER, 1996). Small-scale irrigation schemes have been promoted in sub-Saharan Africa (SSA) to enhance food security in the region (BURNEY & NAYLOR, 2012; DETHIER & EFFENBERGER, 2012; DILLON, 2011; XIE *ET AL*., 2017). In the African context, small-scale irrigation infrastructure and technology refers to: (1)

smallholder private irrigation systems ranging from watering can, pumps, shallow wells, sprinkler, to drip irrigation systems; and (2) 'small-scale and community irrigation systems' including infrastructures like river diversion canals, dams, or pump schemes with related structural works (SMITH *ET AL.*, 2014).

Technical performance of the existing irrigation facilities is another dimension of assessing the irrigation access and distribution infrastructure and technologies (FAO, 2011). In this regard, worldwide irrigation efficiency[1] is less than 70 percent and the sector is regarded as the major water waster. This calls for demand management through promotion of efficient water use technologies and improvement of conveyance efficiency of water transport systems (LEBDI, 2016) Generally, the small-scale irrigation schemes in Africa are often mentioned for low level of technical performance (FAO, 2011) Besides, surface water irrigation technique is the most common smallholder irrigation approach in Africa including Ethiopia which adds to the low performance at efficiency level of 40-60 percent (LEBDI, 2016).

Moreover, with the very limited irrigation facility, there is additional problem of market access for efficient access and distributional technologies and spare parts (YOU *ET AL.*, 2011). Some claim that the feasible technologies and approaches to irrigation development in Africa are the lower cost technologies. Moreover, rehabilitation of existing systems is more cost effective than constructing new systems (YOU *ET AL.*, 2011). Others, on the other hand, raise issues of sustainability regarding low-cost irrigation technologies in Africa. They claim that in the face of weak institutional settings resulting in high transaction costs in most of rural SSA, cheaper technologies have risks of failure. Empirical evidences indicate instances of dis-adoption where cheap technologies fail to induce the expected net returns to sustain adoption during the initial stages of the learning curve (BURNEY & NAYLOR, 2012).

Notwithstanding the potential role of modern engineering infrastructure in improving performance of an irrigation system, only the existence of effective institutions and 'social capital' in managing and maintaining the infrastructure can help tap this potential (LAM, 1996). Therefore, the task of assessing the success of small-scale irrigation schemes should therefore, focus on both the 'design of the technology' and 'the institutions that support the technology'(BURNEY & NAYLOR, 2012).

2.3. Role of institutions

Institutions generally refer to informal constraints and formal rules governing economic and social exchanges in a society (NORTH, 1990). The concept of institutions has

[1] *Irrigation efficiency refers to the ratio between irrigation water actually utilized by growing crops and water diverted from a source.*

become a popular framework in (natural resource) economics to understand and analyze the governance of common-pool resources (OSTROM, 2010; 1990). She provided pioneering work in expanding our understanding of the relationship between institutions and management of common pool resources. According to OSTROM (2010), successful management of common pool resources cannot be generalized to specific institutional arrangements or set of rules; it rather depends on the context under consideration. A key feature of OSTROM's 1990 seminal work is the eight design principles that set the conditions for effectively managing community-based natural resources such as irrigation systems, pastures, forests, and fisheries. She argued that such design principles are best practices that characterize the sustainable systems of common pool resources (see OSTROM, 2010 for more on the design principles) and are commonly present in successful systems (and absent in the failed ones).

Robust institutions are crucial to manage water rights, access and sustainable use of irrigation water (BUES, 2011). The use of water resources may involve externalities that can only be managed through effective institutional arrangements including government policies, collective action, societal norms, or the market. The issue gets more complicated with the involvement of 'spatial dimension' where an irrigation system is used by group of farmers. This requires the coordination of upstream and downstream users through institutional set up which may be the state, user association, or the market (MEINZEN-DICK, 2007).

The past five decades witnessed several institutional arrangements in water management beginning with 'strong governmental agencies, then user organizations, and finally water markets'. Over the years one or the other of these institutions have been implemented in different places but with an unsatisfactory level of performances largely owing to the ignored contextual situations of different locations. Rather the unique attributes of the locality like 'resource endowments', 'governance', and 'user' play equally important role in the low level of performance of irrigation systems. Hence, there is no one solution to the water problem. Further, failure in one type of institutional arrangement cannot be corrected by replacing it with another one as learned from empirical findings from Asia and elsewhere. Some studies, for instance, indicated better performance of irrigation systems where the state, user groups, and market institutions made combined efforts (MEINZEN-DICK, 2007).

The role of the institutional environment of any irrigation scheme is crucial in the success of the scheme from the very beginning of adoption. More specifically, the adequacy of water management institutions at the local level is as crucial as the biophysical and infrastructural situation for irrigation to have the required level of impact on poverty reduction and enhancing the welfare of smallholder farmers (BELAY & BEWKET, 2013; BURNEY & NAYLOR, 2012). Most countries in SSA are challenged by economic water scarcity while the water is physically available. This economic water scarcity resulted from mismanagement, 'water theft, and 'turn abuses' (BELAY & BEWKET, 2013). This mismanagement has resulted from the limited institutional capacity to efficiently manage and optimally utilize available water resource. And it has been one of the factors that aggravated the impacts of water scarcity in SSA in general and Ethiopia in particular (AMEDE, 2015; YOHANNES *ET AL.*, 2017).

2.4. Irrigation Practices in Ethiopia

Irrigation in general and small-scale traditional irrigation in particular has been practiced in Ethiopia since ancient times (ABERRA, 2004; BACHA *ET AL.*,2011; BELAY & BEWKET, 2013). Modern irrigation, however, dates back to the 1960s with the start of large scale state farms to produce industrial crops (AWULACHEW *ET AL.*, 2007). The promotion of 'peasant based-small-scale irrigation', on the other hand, was started in the late 1980's and early 1990's. The failure of the large scale irrigation projects owing to financial, management, and design and technological problems made the shift inevitable (KLOOS, 1991).

The country has 5.3 million ha of potentially irrigable land (AWULACHEW & AYANA, 2011) of which only 5 percent is actually irrigated at the moment (ASEYEHEGU *ET AL.*, 2012). Irrigated agriculture in the country is dominated by small-scale traditional irrigation accounting for 77 percent of the total irrigated area. Studies made in the sector argue that if water resource could be managed well it can contribute to economic and social development in Ethiopia. For instance, irrigation has the potential to contribute around ETB 140 billion to the country's economy and make 6 million households to be food secure (AWULACHEW & AYANA, 2011; AWULACHEW *ET AL.*, 2010). Accordingly, the government of Ethiopia has been promoting irrigation in recent years as a viable strategy in poverty reduction especially in rural areas. More specifically, small-scale irrigation development has been given due emphasis in the programs to enhance agricultural development especially in water stressed areas of Ethiopia (ABERRA, 2004; BELAY & BEWKET, 2013; YAMI, 2013; YOHANNES *ET AL.*, 2017).

Small-scale irrigation infrastructures in the county are based on sources like river, lakes, ponds, and shallow well through techniques like bucket, treadle pump, motor pumps, electric pumps, and river diversion canals (GEBREGZIABHER, 2012). Especially, the small-scale and community irrigation schemes in Ethiopia are mainly based on diversion schemes over a distance of 1-5 kms (FAO, 2011). Small-scale irrigation has increased from 853,100 ha in 2009/10 to 1,853100 ha in 2012/13 (YOHANNES *ET AL.*, 2017). In addition, the government's first five year Growth and Transformation

Plan (GTP I: 2011-2015) states that irrigated area would be raised from 2.5 percent to 15.6 percent in the planning period (AMEDE, 2015; BACHA *ET AL*., 2011). Moreover, development of small-scale irrigation in the country has been the center of attention among donors like International Fund for Agriculture Development (IFAD) in the past two decades. The programs and grants aimed at improving food security and income of poor rural households. They aimed at specifically improving and expanding smallholder irrigation schemes, improving the 'agricultural support services' and strengthening institutions at different level involved in small-scale irrigation projects (AMEDE, 2015; YAMI, 2013).

Despite this huge investment and support from the government and partners, irrigation has not yet developed to at least satisfactory level in the country (BACHA *ET AL*., 2011). Notwithstanding the inefficiency that may exist in the cultivated command areas, only 74 percent of the already developed irrigation potential is being used specifically with small and medium-sized schemes. In terms of number of beneficiaries only 50 percent of the targeted beneficiaries are being served by the small and medium-sized schemes (AWULACHEW & AYANA, 2011). The major causes of the underperformance of the small and medium sized irrigation schemes relate to: (1) physical and engineering aspects like 'design' and 'construction' failure and lack of maintenance, (2) management and operation of the system, and (3) environmental degradation and related sedimentation (AWULACHEW & AYANA, 2011). Added to this is the adoption level of efficient technologies, which is far from satisfactory because of various factors like high initial and operating costs and lack of adequate technical support. Moreover, the market conditions that most small holder producers face involve high costs of marketing and resulting risks suppressing the benefits of technology adoption in general (GEBREGZIABHER, 2012).

In addition to their low technical performances, the small-scale irrigation schemes in Ethiopia have largely been unsuccessful in the institutional governance dimensions too. The investment in the sector had focused on only the irrigation infrastructure development and ignored the equally important institutional and social infrastructure (YAMI, 2013). They lack (enforcement of) proper water use policy to fairly allocate irrigation water for and resolve conflicts between upstream and downstream users (AMEDE, 2015). In such ill-defined irrigation water use schemes, allocation of water is largely influenced by various institutional and geographical factors (BELAY & BEWKET, 2013). An effective small-scale irrigation scheme calls for the participation of users in the development and management of irrigation water use policies (AWULACHEW & AYANA, 2011) and the formation of cohesive water user associations or cooperatives (ABERRA, 2004; SETEGN *ET AL*., 2011).

Empirical studies on small-scale irrigation schemes in different parts of the country confirmed the existence of the aforementioned challenges. AMEDE (2015), for instance, found out that these challenges are observed in three small-scale irrigation schemes selected for his case study. In Burka Woldya scheme in Eastern Ethiopia there is competition and conflict between upstream and downstream water users because of more water consumption in the upstream. The conflict resolution and negotiation work faced difficulty because of 'unclear managerial roles between the multiple local institutions' like government, WUA, water masters etc. The same study on another scheme named Zatta in Northern Ethiopia indicated design and construction failure, which ended up reducing the scheme discharge by blocking the source point and as a result reduced the number of the beneficiaries from 200 to 77. The existence of coordination problem among different institutions responsible for the development and management of the scheme was also indicated. Another scheme by the name Chelekot in northern Ethiopia is also facing challenges related to salinity problems in addition to management related constraints. A finding from a study in Gumselassa small-scale irrigation scheme also witnesses that the scheme is serving 70 percent of its design potential. The same study indicated that poor water management practices play equally important role as engineering problems in the underperformance of the scheme (YOHANNES *ET AL*., 2017).

The institutional environment involving irrigation schemes in Ethiopia include traditional/ informal institutions, government policies and regulations, farmer groups (such as WUA), cooperative organizations, and market conditions. Most modern irrigation schemes and water use associations in Ethiopia are initiated by the government. In fact, the local government, through the cooperative promotion office, plays a big role in the day-to-day operation of small-scale irrigation schemes. Unfortunately, government and donor-sponsored small-scale irrigation projects tend to pay much attention to the development of the physical irrigation infrastructure and ignore the social aspect of it. Such a top-down, non-participatory approach in small-scale irrigation projects is often viewed by the (prospective) users as an imposition by the government rather than a solution to enhance their livelihoods. A key problem of such a top-down approach is that it ignores/dismantles the informal/traditional irrigation water use practices that had exited for many years (AMEDE, 2015). In several instances there are complains that traditional water rights are compromised for the modern right. The modern water rights emerged with the establishment of the modern WUA where the government gives priority to the later rights in cases of water shortage. Further challenges arise from abusing of power including influencing water allocation in one's favor because of a position in WUA, local administration, corruption, and resulting conflict (DENEKE *ET AL*., 2011).

In this study context, the farmers had an informal water use practice that had served users both in the upstream and downstream parts of the river before the government intervened and formed the present WUA. The so called "water fathers" had played a key role in the governance of irrigation water use in the study area. The water fathers are socially recognized elders who make discussion with the people and make deals with the community about the way the water is used. They determine for how long a household should divert the water to his land. At times when there is a conflict between the lower and the upper stream users, the water fathers from both sides make reconciliation and establish a workable arrangement that amicably solves the problem.

2.5. Irrigation vs poverty

Irrigation agriculture has been popularized as a key input to improve crop yields and enhance food security. It is expected to account for 53 percent of the projected increase in cereal crop production between 2000 and 2050 (ROSEGRANT *ET AL.*, 2009). Irrigation agriculture is particularly important for poor countries (JOSEPHSON *ET AL*, 2014; VANLAUWE *ET AL.*, 2014), as the average land holding is generally less than two haha and continually declining (SINGH *ET AL.*, 2009; VANLAUWE *ET AL.*, 2014). In fact, it can have a multiplier effect through enhancement of employment opportunity, consumption, and dietary changes (HASNIP *ET AL.*, 2001; ROSEGRANT *ET AL.*, 2009). The benefits of irrigation can also be viewed from the perspective of its impact on the increased use of productivity-enhancing inputs like fertilizer and improved varieties and, subsequently, on farm income and economic development (GEBREGZIABHER *ET AL.*, 2009; NAMARA *ET AL.*, 2010; SMITH, 2004). However, lack of consensus on the role of the agricultural sector in poverty reduction and pitfalls in impact study methodologies resulted in mixed findings on the impact of irrigation.

Empirical studies reported mixed results regarding the impact of investment on irrigation agriculture. Several studies, particularly those related to Asia, have indicated a strong positive linkage between irrigation agriculture and enhanced productivity and food security (BACHA *ET AL.*, 2011; FAO, 2003; HUSSAIN & HANJRA, 2004; SMITH, 2004; WICHELNS, 2014). Most of these studies have documented doubled or tripled incomes of farm households who used irrigation agriculture. Much of the success in Asia is often associated with reliance on informal institutions in the governance of irrigation water, implementation of bottom-up approaches to select participants in irrigation schemes, and creation of market linkages for irrigation users (MUKHERJI, 2012; MUTAMBARA *ET AL.*, 2016). However, not much has been documented in SSA regarding the impact of small-scale irrigation schemes in improving rural livelihoods mainly due to factors related to infrastructure, institutions, and social‐economic *(BURNEY & NAYLOR, 2012; MUTAMBARA ET AL., 2016; MWENDERA &*

CHILONDA, 2013; SCHUENEMANN ET AL., 2018). Furthermore, various findings have indicated that farm households that successfully adopted irrigation are relatively better off as opposed to the ultra-poor ones (MANGISONI, 2008; NAMARA *ET AL.*, 2005).

The general conclusion from previous studies is that small-scale irrigation schemes with proper technical supports and institutional setups have the potential to enhance crop yields and rural livelihoods. However, past studies have also indicated the impact of irrigation agriculture on poverty is highly influenced by context, methods employed to measure impact, and scope of analysis. Context-specific studies may be more relevant than cross-country analysis because of their potential to develop local-based water use policies.

2.5.1. Poverty

The concept of poverty has evolved from the original idea of inadequacy of income, consumption and wealth (O'BOYLE, 1999; WATTS, 1968) to SEN (1981) concept of capabilities and functioning and further to multidimensional aspects like socio-political rights, access to services and infrastructure, vulnerability (NAMARA *ET AL.*, 2010; SMITH, 2004). Moreover, absolute and relative poverty are commonly mentioned in the poverty literature. Absolute poverty refers to the head count of households who are unable to afford a certain standard of basic goods and services. Relative poverty, on the other hand, measures the relative shortfall of a household's income from the economy's average. Another concept related to but wider than poverty is equity. It refers to the level of equality in income and wealth distribution. Poverty is also dynamic in that factors that affect poverty can change from time to time (SMITH, 2004).Commonly, the Foster-Greer-Thorbecke (FGT) indices developed by FOSTER *ET AL.* (1984) are used in poverty analysis and estimated as:

$$P = \frac{1}{N}\sum_{i=1}^{H}\left[\frac{z-e}{z}\right]^{\emptyset} \qquad (1)$$

Where Z is the poverty line, N is the number of observations, H is the number of households below the poverty line Z, e is the consumption expenditure per capita for the ith person and ø is a poverty aversion parameter. At $\emptyset = 0$ P gives the headcount index: the number of people below the set poverty line. At $\emptyset = 1$ the resulting P is the poverty gap index, which measures the aggregate shortfall of the consumption of the poor from the poverty line Z. At $\emptyset = 2$ P is the squared poverty gap and measures the severity of poverty. As $\emptyset$ gets bigger the measure gives more emphasis to the poorest of the poor (FOSTER *ET AL.*, 1984).

2.5.2. Water poverty

Water poverty can relate to either physical or economic water scarcity. Most of the time poor people do not have access to adequate quantity and quality of water because the water is physically unavailable. In other cases people face water scarcity or they cannot access water because of poor infrastructure, mismanagement, corruption etc. (DUDU & CHUMI, 2008; NAMARA *ET AL*., 2010; WORLD BANK, 2016).

Water scarcity and incidence of poverty are not necessarily linked; access and control is more crucial than endowment in several cases (NAMARA *ET AL*., 2010). One cannot deny, however, that whatever the cause of poverty may be, increasing scarcity of and competition over water is major challenge to poverty reduction efforts of any kind. It is highly likely that scarcity of water will increase into the future mainly because of population growth, reallocation to competing uses like industries, and climate change. This, in turn, more than proportionately affects the already poor segment of the population (ROSEGRANT *ET AL*., 2009).

3. REVIEW OF THE LITERATURE

3.1. Issues in and methods of impact studies

The critical issue in impact studies is acknowledging the potential biases. Most of the time two sources of biases are mentioned. The first one relates to the possibility of significant difference between the participants and non-participants due to observable farm and household characteristics. These characteristics may have direct and significant impact on the outcome variable. Secondly, unobservable factors like skill and attitude may result in difference among households and may affect the behavior of the households towards deciding to participate. Therefore, it is crucial to recognize that difference between the participants and non-participants may not be attributed only to the treatment but also to initial differences among them. Therefore, the selected impact assessment model should either help to eliminate selection bias or be sound enough to account for it (BACHA *ET AL.*, 2011; WOOLDRIDGE, 2003; WORLD BANK, 2010).

Several methods have been used so far in various impact studies. These methods differ in the way they account for selection bias. Some of the methodologies, however, have major drawbacks of ignoring the issue of self-selection and difference between adopters and non-adopters (KASSIE, SHIFERAW, & MURICHO, 2010; WORLD BANK, 2010). For instance, the simplest method would be using Ordinary Least Square (OLS) through including the treatment as a dummy variable in the outcome function. However, considering the systematic difference between users and non-users resulting in unobserved selection bias, the results of OLS estimation are biased and inconsistent (BACHA *ET AL.*, 2011; DI FALCO *ET AL.*, 2011; WORLD BANK, 2010). Such unobservable factors could not be captured and cause correlation between the observed explanatory variables and the error term (ABDULAI & HUFFMAN, 2014).

Another commonly used method is Propensity Score Matching (PSM). This method assesses treatment effects between participants and matched individuals. The matching is undertaken only on observed characteristics assuming that a selection bias occurs only due to observable characteristics (WORLD BANK, 2010). It, however, does not account for the possibility that there is a latent variable that simultaneously influences selection and outcome (RAVALLION, 2005).

Later econometric models like Heckman's selection model, and endogenous and exogenous switching models emerged. These models assume that the impact of explanatory variables is different depending on which regime applies. There are basic differences on two crucial issues. One relates to the concept that whether the regime is determined inside the model or outside. Hence, the switching could be endogenous or exogenous. Secondly in some instances, both regimes are observable while some others work with only one regime observed (DUTOIT, 2007). A comprehensive switching regression was considered by GOLDFELD & QUANDT (1972) with two regimes observed. This switching regression model was exogenous because of the assumption made about the error terms. The same exogenous switching regression model was extended later by GOLDFELD & QUANDT (1973) to simultaneous equation systems *(LEE ET AL.*, 1982).

MADDALA & NELSON (1975) extended the model to make it possible to deal with endogenous switching. Several studies that used Endogenous Switching Regression approached the modeling in two stage estimation which requires cumbersome adjustment to produce consistent standard errors (KASSIE *ET AL*., 2010; KHONJE, MANDA, ALENE, & KASSIE, 2015). Full Information Maximum Likelihood technique to simultaneously estimate Endogenous Switching Regression models are suggested as the most efficient in this regard (DI FALCO *ET AL*., 2011; KASSIE *ET AL*., 2010; LOKSHIN & SAJAIA, 2004).

3.2. Modelling farm household behaviour in the study area

For studies that use farm households and systems especially in developing countries as a unit of analysis methodological validity is crucial. The selected conceptual framework should lead to solution by capturing the specific context of the problem in a theoretically consistent manner. Farm households in developing countries are characterized by possessing both the features of the firm and household. Hence, they make simultaneous decisions about production and consumption. They are mostly identified with the proportion of family labor usage for own farm and consumption of the own produced goods.

On one extreme, we have pure subsistence farm where all farm productions are consumed by the household and all labor used is family labor. On the other extreme, we have the pure commercial farm where all output is sold and all labor is employed labor. The rest farm households fall in between these two extremes (MENDOLA, 2005). Accordingly, different definitions can be given for farm households depending on the context and scope of a study. The working definition that this study draws on is the one given by ELLIS (1992) where ‘farm households are households with access to a piece of land and utilizing mainly household labor in farm production [and] characterized by partial engagement in markets, which are often imperfect or incomplete.’ Therefore studying economic behavior of smallholder farm households demands understanding of the specific contexts relevant to the market and other constraints they face (DE JANVRY & SADOULET, 2006).

The following sections discuss important economic theories relevant to smallholder farm household production behavior, farm household modeling approach, bioeconomic farm household modeling, empirical reviews of bioeconomic farm household modeling, and finally the underlying conceptual framework of the current study.

3.3. Economic Theories of Farm household

The economic behavior of farm households has been explained differently by several economic theories. These theories assume maximization of different objective functions by farm households. They also make different assumptions about the context in which the farm household operates.

The classical economic theories assume a ‘profit maximizing peasant’ operating in a perfect market. These theories assume that farm households exhibit rational behavior and have ‘profit maximization’ objective. One notable work in this regard is SHULTZ (1964) where he argues that farm households in developing countries are ‘poor but efficient’. SHULTZ sets out his argument with underlying assumption of perfect competition. Several critics followed this theory along points including competing farm household goals and resulting trade-off, risk and uncertainty situations of the farm households.

Accordingly, the classical specification of farm household behavior has evolved from the profit maximizing theory through continuous points of criticism mentioned above to neo-classical theories. The neo-classical economic theories acknowledge that farm households are both producers and consumers. These theories assume utility-maximization as the objective function of the peasant households as opposed to profit.

Later, risk aversion theories were developed with the fundamental assumption that farm households aim at avoiding risk in the process of making economic decision as a measure for survival (MENDOLA, 2007).

3.4. Farm household modeling approaches

More than one fourth of the world population is accounted for by peasant farm households and most of them live in developing countries. Peasant farm households represent 70 percent of the population in these countries (MENDOLA, 2007). They divide their output into household consumption and surplus to be marketed (BARDHAN & UDRY, 1999). Any intervention in this context affects production; consumption and labor supply decisions all together. The traditional economic models, however, have dealt with consumption and production decisions of agricultural households separately because they assumed perfect markets (SINGH *ET AL.*, 1986).

CHAYANOV (1928) was among the first to recognize the inadequacy of the assumption that smallholder can be dealt with the conventional economic concept of ‘the private firm’ mostly because of market imperfection. The assumption of perfect markets may be plausible in situations where markets function relatively well. This assumption, however, does not hold true in rural economies where there are absence of markets for some inputs like land, high transaction costs, and constrained access to credit.

Agricultural Household Models (AHM) are indispensable for studying such rural economies. These models help one to understand the behavior of agricultural household in making production and consumption decisions (TAYLOR & ADELMAN, 2002). AHMs have been used by considerable economic literature to explain farm household behavior under both perfect and imperfect market situations (MENDOLA, 2005). In the case of perfect markets, the household maximizes profits by choosing combination of inputs irrespective of its endowments and consumption decisions. In rural areas of many developing countries, however, markets are not perfect.

Incomplete markets can take many forms. One cause of incomplete markets, for instance, could be absence of input markets like land, water and limited demand for labor at a fixed wage in the labor market, high transaction cost etc. Therefore, in such situation the production and consumption decisions could not be separated, and the production decision of households depends on their preference and endowments (TAYLOR & ADELMAN, 200; BARDHAN & UDRY, 1999; HOLDEN *ET AL*., 2005).

Ethiopian farm households also make joint production and consumption decision. In Ethiopia, there is no land market since land is public property and the farmers have only the right to use. However, there is a hidden informal land market that transfers the use right of the land. On the other hand, there is functioning labor market (ALEMAYEHU, 1998). Water is also a public property and there is no market for agricultural water as a commodity or market to transfer the right to use. Therefore, it is highly recommended that analysis made to study Ethiopian farm household’s behavior should be done in the framework of Agricultural Household Model.

3.5. Bioeconomic Farm Household Modeling

Various studies have been undertaken under the agricultural household framework and have their own unique extensions of the farm household conventional model. One notable advance in the area is the emergence of a farm household model variation, which integrates biophysical and socio-economic components of a system at differing levels. This variant of AHM is called bioeconomic farm household modeling approach. Bioeconomic model refers to all sorts of models that integrate biophysical and socio-economic factors with different level of emphasis on each component. Such model is vital to reflect the linkage between the ecology and the economy (BROWN, 2000). More specifically, its application ranges from modeling biological processes with economic component to it to economic optimization models with intervention on biophysical environment (HOLDEN *ET AL.*, 2005; QUARANTA & SALVIA, 2008).

In this regard, bioeconomic household models, which combine the biophysical and socio-economic aspects of a system, are imperative and increasingly being applied (HOLDEN, SHIFERAW, & PENDER, 2006; QUARANTA & SALVIA, 2010). Such framework can also be used to study the dynamic linkage between the economy and the ecology overtime (HOLDEN *ET AL.*, 2006). In addition to its empirical accuracy, this framework offers important policy insights which differ considerably from the traditional models (SINGH *ET AL.*, 1986; DUDU & CHUMI, 2008).

Moreover, consumption and production decisions usually differ among households and depend on factors like objectives, resource endowments, and market situations. Hence, there is the possibility that the outcome of the decisions diverges from policy-defined goals. The fact that socio-economic and natural environment interplay to define the complex behavior and resulting choices of households necessitates a kind of modeling framework which is adequate to accommodate such complexities. Bioeconomic farm household modeling framework is, therefore, a powerful tool to evaluate different scenarios of technology changes, policy instruments, and triggers as per their impact on motivating sustainable household behavior and production decisions (KRUSEMAN & BADE, 1998).

The strength of bioeconomic model lies on its very nature, which allows to simultaneously account for all the three dimensions of the ‘critical triangle’ of development goals. Accordingly, indicators capturing issues of environmental sustainability like soil and water characteristics, and biodiversity, welfare indicators like farm income and consumption, and economic growth indicators like labor demand and input purchase can be evaluated across time and space. The model helps to show tradeoffs and synergies between options and undertake scenario analysis (BÖRNER, 2005).

The research problem and the implied questions of this study revolve around the resource allocation decisions of farm households and resulting impact on poverty (welfare) and environmental sustainability (water usage). Such a situation calls for sustainable development framework which requires simultaneous achievement of poverty alleviation, environmental sustainability and economic growth (BÖRNER, 2005). Hence, the underlying conceptual framework should enable to establish and show the possible link among these three dimensions of sustainable development. In addition, it should allow the prediction of impact of different shocks and policy options on household production and consumption decision, environmental sustainability indicators, and the economic growth indicators. Accordingly, the conceptual framework of the current study is captured by the diagram in Figure 3.1.

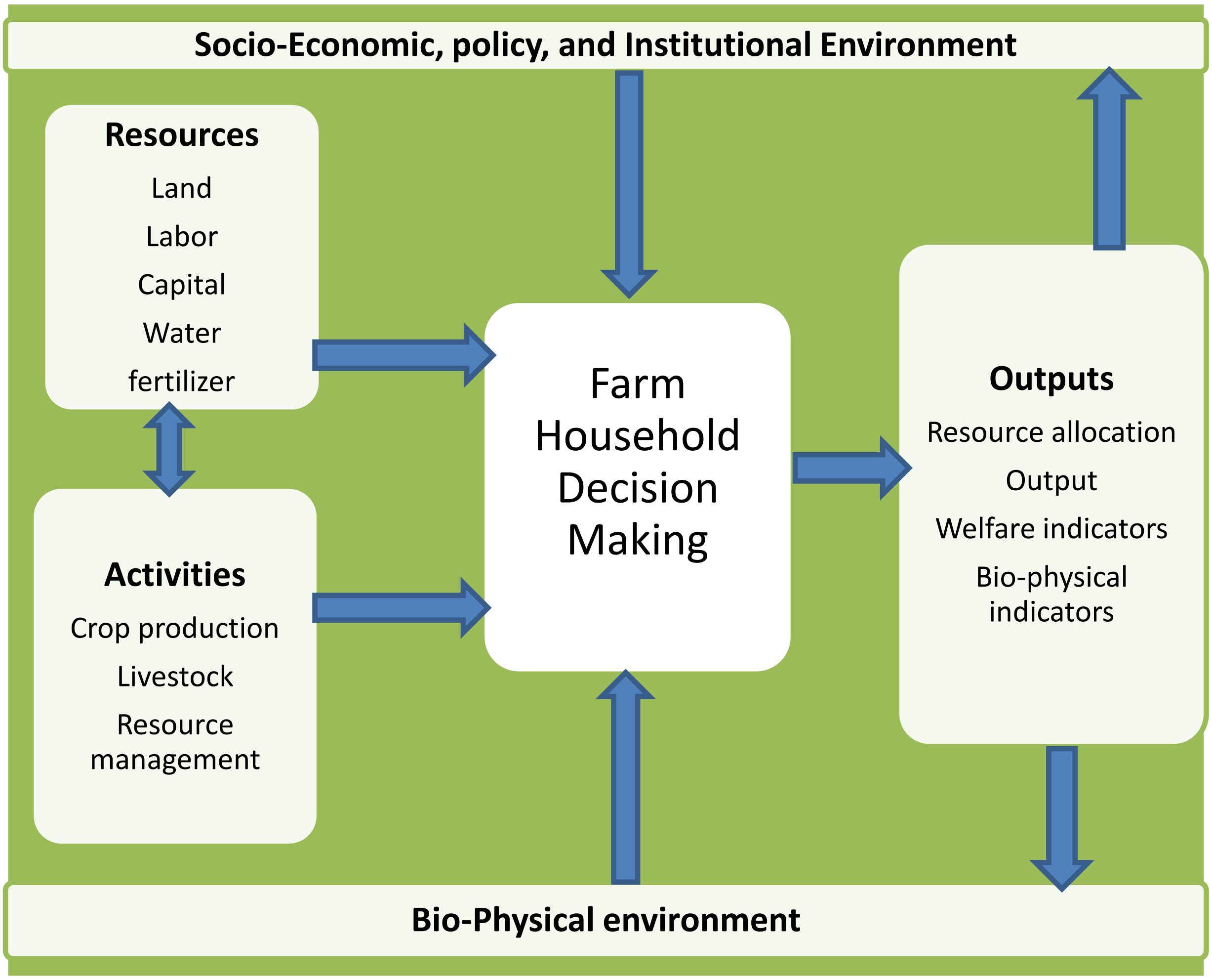

Figure 3.1: Conceptual framework of Bioeconomic farm household modeling

Source: adapted from HENGSDIJK & VERHAGEN (2011)

3.6. Empirical review of bioeconomic farm household models

The emergence of bioeconomic models dates back to 1960s. The first models that dealt with irrigated crop production systems include model for selecting crop mix on irrigated farms and systems (FLINN, 1971; DONALDSON, 1968). Over the past five decades the importance of bioeconomic models has gained momentum and several models have been developed with differing objectives including evaluation of strategies for irrigation scheduling (BOGGESS & AMERLING, 1983) and soil fertility management (CHICO & GILLINGHAM, 1993).

The application of bioeconomic models, on the other hand, ranges from 'direct support of crop production management decisions' to tool development, and theory building among other things. Therefore, the structure and functions of a given model depends on its design objectives. The design objective of the model that we have built is tool development. The primary goal of our model is methodological in the sense that it explicitly recognizes the impact of production, consumption and resource allocation decisions on water availability and resulting irrigation water use. In fact, it also has contribution in terms of management recommendation though they are location specific.

The bioeconomic modeling approach has extensively used to link models from different disciplines to provide multi-disciplinary and multi-scale answers to a given problem. In developing countries such as Ethiopia where resources are scarce, decision of water use depends on the bioeconomic nature and the behavior of households in the entire system. Cognizant of this, bioeconomic models and other household models have been developed and have been widely used. These models provide a comprehensive indication on the relationship between human activities and environmental externalities and take into account simultaneously the technical, economic and environmental impacts of policies. The model links describing farmers' resource management decisions to formulations that describe current and alternative production possibilities in terms of required inputs to achieve outputs and associated externalities. In many studies, bioeconomic farms models have been proposed as tools to assess the impacts of policy changes on agricultural systems (DONALDSON *ET AL*., 1995; FLICHMAN, 1996; RIESGO AND GOMEZ-LIMON, 2006; SEMAAN *ET AL*., 2007).

3.6.1. Global experience

The experiences of different countries have revealed that they have been using different policies to ensure fair distribution and efficient allocation of water. Of these policies, water pricing is one of the most widely used methods of ensuring efficient allocation of water by households. Empirical results showed different results in different countries. CHRISTIAN AND JOSE (2017) have examined the pricing policies on irrigation water use for agro food farmers in Ecuador. They used positive mathematical programming to evaluate the economic impact of pricing policies on agro-food farms. The results of their simulations have depicted that the existing fixed costs do not reduce water consumption. In contrast, volumetric prices impact on the behavior of farmers. The tendency of water consumption to the application of volumetric prices demonstrates that banana farms have greater tolerance to the increase of water costs. On the other hand, the response to an increase in cost in the case of cacao, sugarcane, and rice depends on the productivity of farmers. Thus, they suggested volumetric policies as more efficient in reducing water consumption as well as in recovering the costs of the irrigation system

On the other context, SALMAN AND AL-KARABLIEH (2004) found in the highland areas of Jordan that water prices up to US$ 0.35/m3 reduce farmers' income without any effect on the production structure, but prices higher than US$ 0.35 reduce the cultivated area and drive most agricultural production alternatives into unprofitable situations. SPEELMAN *ET AL*. (2009) also pointed out that further increases in water prices beyond a certain level have not only limited additional effect on the efficient use of water because the higher prices do not only reduce water use but also reduce the profit of the farmers. At higher water pricing rate some farmers which are not profitable anymore may quit from farming activities which leads to water saving at sectoral level (SPEELMAN *ET AL*., 2009).

FRANCOIN *ET AL*. (2008) examined the rationale for, and potential and current impact of, pricing policies in the Jordan Valley. The results revealed that while operation and maintenance (O&M) costs can be recovered higher water prices have limited potential for achieving gains in irrigation efficiency. More substantial increases in water prices raised overall economic efficiency by motivating farmers to intensify cultivation, adopt higher value crops, improve technology, or rent out their land to investors. Lack of capital and credit, and pervasive risk, notably regarding marketing have constrained the success of such water pricing policy. They suggested that pricing policies are best implemented together with positive incentives that reduce capital and risk constraints; and offer attractive cropping alternatives or exit options with compensation. This view has been shared by BERBEL AND GOMEZ-LIMON (2000) who suggested that water pricing as a single instrument for controlling water use is not an ideal means to significantly reduce agricultural water consumption.

Several studies elsewhere have dealt with optimal agricultural water allocation, valuation, and system efficiency issues using different methods. ESMAEILI & SHAHSAVARI (2015) used a programing model to calculate economic value of water in Iran and showed the importance of water pricing to improve water allocation, sustainability, and productivity. Another study by HAOUARI & AZAIEZ (2001) applied mathematical programming to determine optimal cropping pattern in water-deficit regions. A simulation model was also developed by LORITE *ET AL*. (2007) to conduct scenario analysis of different water allocation amounts and its impact on variables like income, productivity, and labor needs. WANG *ET AL*. (2008) also used mathematical programming framework for modeling equitable and efficient water allocation among users. Their optimization model consisted of two steps: (1) optimal allocation of water right initially, and (2) optimal economic reallocation of net benefits using cooperative game theoretic approach with the aim to achieve fair and efficient allocation. Nevertheless, none of these studies considered the unique features of smallholder farm households especially in developing countries like Ethiopia and the type of markets they face.

3.6.2. African experience

There are a few studies that have been conducted so far on irrigation related modeling in Africa. HOUCINE ET *AL.* (2014) used the Farm System Simulator model (FSSIM) in Tunisia to examine the impact of water pricing policy options on water consumption behavior of households. The results revealed that farmers are strongly dependent on the water pricing policy. Particularly, farmers that have private irrigation systems and pay for pumping mainly, are more sensitive to the progressive increase of irrigation water costs compared to farms that obtain water from public irrigation systems, who pay for the amount of water received. A sensitivity analysis showed that increasing the water price with more than 17 percent is not advisable to local decision makers, because the net income continued to decline, while the water consumption remained stable with further increases. Hence, there is no further gain in terms of water saving. Overall, intensive agricultural systems with private irrigation systems seem more vulnerable and unsustainable and therefore the extension of public irrigation systems and semi-intensive agriculture is recommendable to improve the sustainability of agriculture in this arid zone

PASCAL *ET AL.* (2016) explored the likely impacts of a program of small irrigation development using FSSIM-Dev (Farm System Simulator for Developing Countries) in Niger on land allocation, agricultural production, and food security and poverty reduction on a nationally representative sample of farm households. Results revealed that irrigation has a large impact on agriculture production and income of smallholder farmers, mainly during the dry season and in the regions with high potential irrigable land. Farm income would increase by around 7 percent at country level if small irrigation was made available to all farmers. At the regional and individual farm levels the impact is more pronounced (reaching more than 80 percent in one region). Additionally, the income impacts are larger for those households with the lowest agricultural income in the baseline, showing the large potential impacts of small irrigation in terms of poverty and inequality reduction.

3.6.3. Ethiopian experience

There is scanty of literature on water pricing and other related policy option on water use decision of farmers in Ethiopia. MEKONNEN *ET AL.* (2015) tried to examine the impact of irrigation water pricing on water conservation in irrigated agriculture in the Awash River basin. They pointed out that increasing water price only adds burden to farmers and unlikely to be feasible. But, this study also revealed that users in the basin are willing to pay relatively more than they currently pay which could increase the income of the basin authority.

4. METHODS OF THE STUDY

4.1. Introduction

This chapter deals with the presentation of the context of the study area and describes methods of analysis used in the study. It provides important details on the location, climate, agro-ecology, irrigation infrastructure and technology, and important institutional settings of the study area. It gives more detail information about the models used, their presentation, the simulation considered and the mechanism of transmission of the simulation into households' income and welfare.

4.1.1. Location, climate and agro-ecology

Wondo Genet is located in the south-central rift valley of Ethiopia, about 263 Km south of Addis Ababa. This is a small district indicated by the blue shaded part of the map of Ethiopia in the top right part of Figure 4.1. It covers an area with altitude ranging from 1,600 to 2,580 meters above sea level. Wondo Genet falls into an agro-ecological zone known as Woina Dega (middle land). The area is known for its mountainous ecosystem on the Abaro chain of mountains surrounding it. It also has a wet land called Cheleleka at the low altitude area (SNNPRS Agricultural Development Bureau, 2013).

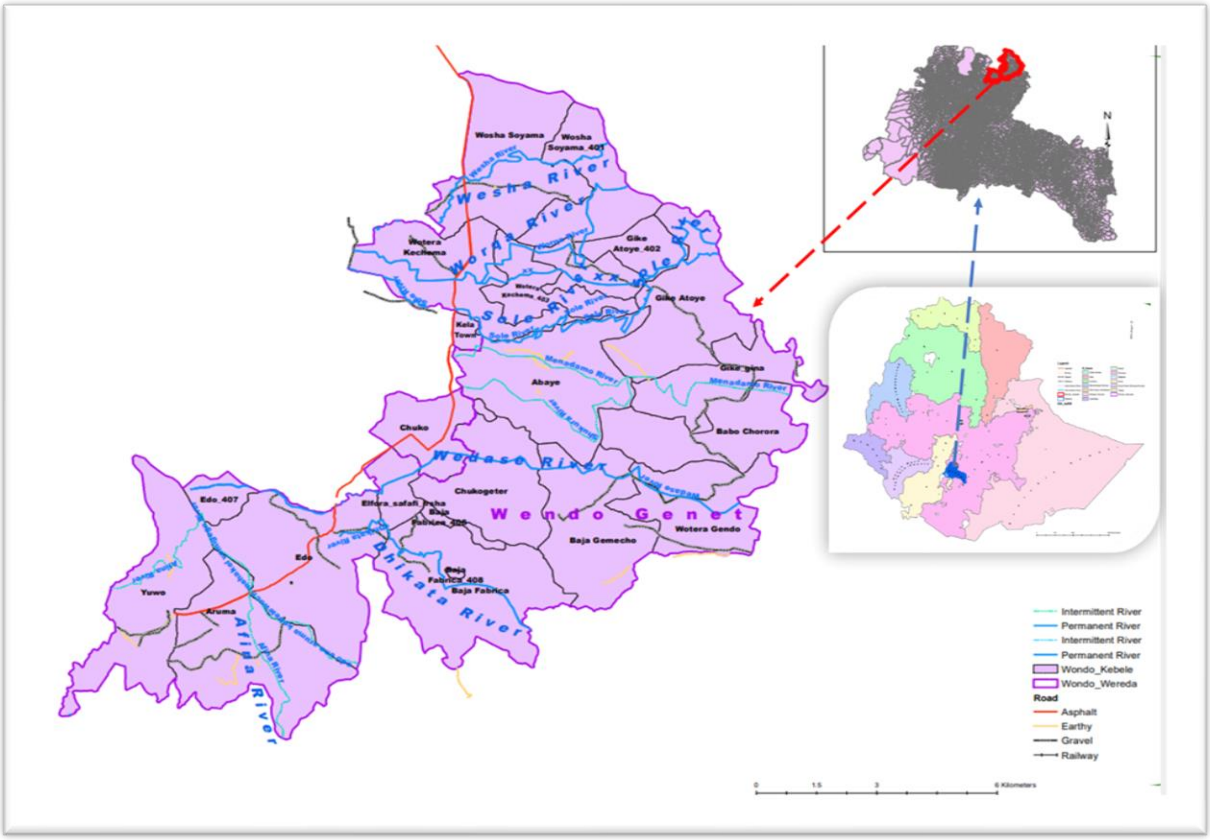

Figure 4.1: Map of the study area (Ethiopia, Sidama, Wondo Genet)

Source: CSA (2016)

The mean annual temperature is between 17°C and 19°C. The climate is characterized as sub-humid with bi-modal rainfall distribution. It receives an annual average rainfall of 1,079.7 mm; February to April is a low rainfall period and June to September is the main rainy season.

According to the Ethiopian Central Statistical Authority (CSA, 2014), the study area has a population of 191,116. Of these, 78.13 percent live in rural areas. The area is one of the most densely populated areas in the country where landholding is highly fragmented. The average land holding of the households participated in the study is reported at 0.40 ha, which is way below the national average of 1.37 ha.

Land use pattern in Wondo Genet generally takes five forms including arable land, grazing land, natural forest, forest plantation, and human structures. There is high scarcity of proper grazing land. Mostly, small open areas along farmlands and accessible forests are used for grazing cattle. This is attributable to the change in land use pattern in the area across years (SNNPRS Agricultural Development Bureau, 2013).

Small-scale perennial crop production is the dominant farming system in the area where enset, *khat*, and sugarcane are the major crops (DESSIE & KINLUND, 2008). Livestock production is the second most important component of the farming system. It includes cattle, small ruminants, and poultry production. The production is both for home consumption and to supplement cash income especially in bad crop year. The economic contribution, however, is not significant as compared to crop production (SNNPRS Agricultural Development Bureau, 2013).

Water from two major rivers -Worka and Wosha- is used for irrigation during dry season to produce sugarcane and k*hat*. The allocation of irrigation water is carried out by the WUA. Before the establishment of the WUA (i.e., the modern scheme), irrigation use in the area used to be governed through informal institutions, called 'water fathers' – a well-respected and trusted group of individuals in the community.

4.1.2. Irrigation infrastructure, technology and water use

The modern scheme was established in 1993 with the help of Lutheran World Federation. It has an irrigation potential of 272 ha of land both in the upstream and downstream part of the river. The headwork of the scheme on the river channels water into two diversions (Wotera Kechema and Wosha diversions) currently covering a total of 245 ha and serving two Kebeles.

The main canal used to divert the river to Watera Kechema is 4.6 km long from the headwork. Only part of the major canal (1.648 km), which is used to divert the river from the head work, is concrete and cement lined. The rest of the waterway is earthen canal dug by the farmers themselves leading to a heavy water loss during transportation. Such water loss through seepage and runoff because of earthen canals is also reported in other irrigation schemes in Ethiopia (YOHANNES *ET AL*., 2017). Records obtained from the irrigation development section of the district agriculture and rural development office indicates an average conveyance efficiency of canals at 65 percent. Mode of irrigation is only furrow and modern irrigation technology is nonexistent. Furthermore, communal or private water storage facility is almost zero; only one farmer in the sample reported to have some kind of water storage system. Of the farmers who did not have any kind of water storage mechanism (reservoir), 13.7 percent claimed to have either small farm size, no storage space or steep slope; 24 percent attributed to the lack of surplus water to reserve; and 53 percent reported to have let the water go indicating their limited awareness about water storing (systems) during times of surplus.

Supplemental irrigation in the study area is mostly practiced from December to March. During these four months, *khat* and sugarcane, on average, get three and four days of irrigation, respectively. As per the bylaw of the WUA, the allocation of water is based on the size of the irrigated plot for both upstream and downstream users. However, it was clear from discussions and observation that the water distribution and use do not consider other agronomic issues and crop water requirements.

4.1.3. Analysis of the Institutional environment

Analysis of the institutional environment is provided based on the results of the key informant interviews and FGDs. The study provides an overview of three types of institutions influencing irrigation water use in the study area: collective action (WUA), market characteristics, and information and extension services.

Water User Association (WUA)

The kebele selected for this study is clustered into 33 farmer groups, and only nine farmers groups are users of the irrigation scheme. A farmer group would include 40 to75 households. There are a total of 680 (660 male- and 20 female-headed) households currently using the irrigation scheme. The WUA in the study area was established by the government in 1993. Activities related to the irrigation water use are coordinated by a committee set by the WUA. Depending on the size, a farmer group is represented by one to two individuals in the WUA committee.

Members of the WUA committee are directly elected annually in a meeting involving all the members of the WUA. The committee consists of 11 individuals: one each as chairperson, deputy, and secretary; two controllers; three water distributors; and three serving as members of a conflict resolution sub-team. A member is supposed to serve for a year but can be re-elected for an unlimited number of times. A committee member could also be suspended or terminated from the committee for violation of established rules. It was, however, revealed during the key informant interviews and FDGs that local government representatives, included development agents, often have undue influence on the election process in the name of "facilitating it".

As per the bylaws of the WUA, the committee would meet once per week to discuss several issues including maintenance, watershed management and development works, distribution and allocation of water, and general management of the scheme. But some participants during the FGD revealed that the WUA committee members do not actually meet regularly as stated in the bylaw. Key informant interviews and FGDs further revealed that there is no formal water right explicitly drawn by the government. Therefore, the work of the WUA is often guided by the informal long-standing water use patterns, which farmers, especially from downstream, complain about. Over-abstraction by upstream users and water theft are common despite the stated fine of 500 birr[2] for such an act.

Currently, the WUA is functioning mostly as water distributing and allocating body while other responsibilities are not being discharged as mentioned by the committee members and other farmers in the area during discussions. As stated by the participants in FGDs and confirmed by the discussion with committee members, there is no regular fee for membership or using the water. The users of the scheme, however, contribute (1) free labor to clean and maintain the tertiary canals, mostly once in a year just before the irrigation season kicks in (2) contribute money if the main canal is damaged and should be maintained and (3) pay 20 to 50 birr to cover part of the expenses related to irrigation canal operators/water guards.

The WUA lacks support from the government, and the committee members are often accused of unfair distribution of water. 78 percent of the respondents believed that the WUA committee members take bribes in exchange for unfair more irrigation water use. FGD participants boldly stated that "*Though there is scarcity there are ways to get more water. If you can bribe the committee and water guards, you can get enough water…*". Of the households who currently have access to irrigation water, 34 percent stated that they had bribed the committee to get more water during the last irrigation season alone. Other studies in Northern and Eastern Ethiopia indicated the existence of 'bribery', 'corruption', and 'rent-seeking' behavior among WUA committee members in the distribution of irrigation water (DENEKE *ET AL*., 2011; YAMI, 2013).

Both the FGDs and one-on-one discussions with farmers revealed that the local government is frequently involved in the irrigation water use decision-making process. This has been gradually eroding the users' trust towards the WUA (committee). The

[2] *One US dollar was approximately equivalent to 29.3 Ethiopian birr at the time of analysis of the study.*

bylaws related to the irrigation water allocation and management of the scheme are hardly enforced (respected). The committee members often align themselves with local authorities and abuse their position in exchange for personal gains. As a result, conflicts over the use of irrigation water is systematic and is expected (as reflected by participants during the FGDs) to be worse in the future unless something is done.

Agricultural Market Characteristics

Market characteristics is one aspect of the institutional factors considered important in this study for two main reasons. First, the decision to grow crops during the off-rainy season (and thus become a member of the WUA) may be influenced by households' market orientation. Second, the two most important crops frequently grown using irrigation water (i.e., sugarcane and *khat*) are the most important cash crops in the study area.

Local markets are located relatively not far from the study area, approximately within 5.4 km radius. The marketing system, however, is underdeveloped and farmers sell their produce at farm gate, often involving brokers. Approximately, half (48 percent) of sales (from all crops) involve brokers (middlemen). About 91 percent of sales related to sugarcane and *khat* in the study area is carried out through brokers. There are no well-functioning marketing cooperatives in the area. Like many other places in Ethiopia, farmers in the study area are dependent on the government for the supply of modern inputs such as fertilizers and improved seed varieties. Access to formal credit is very limited even though two micro-finance institutions by the name Sidama and Omo microfinance have branches in the district; only 4.5 percent reported to have had access to credit considering both formal and informal sources.

Information and extension services

Access to information and extension services is critical to understand the importance and wise use of irrigation water to enhance food production and food security situations of rural communities. In the study context, the district agriculture and rural development office is responsible for the provision of the regular extension services. Accordingly, four extension agents (each specialized in crop production, natural resource protection, livestock, or veterinary) are present to provide extension services in each kebele.

The extension agents are responsible for: (1) the promotion and dissemination of modern agricultural inputs; (2) the provision of technical support and advice to farmers; (3) organizing and training of farmers on new farming practices; and (4) the provision of up-to-date information related to weather and market conditions. The study area is also strategically located close to the regional research center (South Agricultural Research Institute) and agriculture-based academic institutions (Hawassa University, College of Forestry). However, extensions services from such institutions have been fragmented and limited to their own thematic areas and research priorities.

4.2. Sampling framework

A sampling frame was prepared based on a list obtained from the district agriculture and rural development office registry of all farm households residing in Wotera Kechema. Farm households residing in the area were categorized into three categories: upstream, middle-stream, and downstream according to their location. Therefore, upstream are those households, which are living in upper parts of the river while the downstream indicates the area where households are living the lower parts of the river. In between the upper and the lower stream, there are households living the middle stream. Data were collected from 240 smallholder farmers located in Wotera Kechema kebele[3], Wondo Genet district, and based on information pertaining to the 2014/15 cropping season. Then, from these categories 80 households each were selected using systematic random sampling. Wondo Genet district was purposively selected for its relative long years of practice in irrigation agriculture. There are two major rivers (Worka and Wosha) currently being used for irrigation agriculture. Worka river irrigation scheme was selected for the study because the scheme related to this river is relatively older and covers a wider area. It is also a scheme associated with a high level of ‘water scarcity’, according to the district agriculture and rural development office. It has a potential to irrigate about 272 ha of agricultural land; in Wotera Kechema (152 ha) and Wosha (120).

The household survey was undertaken by five enumerators after undertaking an adequate level of training and a pilot survey. The selected enumerators speak the local language (Sidamu Afo), which was used to conduct the survey. The principal investigator also speaks the local language, which made it easier to coordinate the data collection process. The questionnaire (Table A.6) was pre-tested for potential ambiguity in the survey questions. Data were also collected though key informant interviews, focus group discussions, and observation (irrigation canal and other infrastructure related to the irrigation scheme). Key informants were held with three experts (the head of the office, Irrigation work process head, and crop production work process head) from the district agriculture and rural development office to get information on irrigation practices and use of implementation of irrigation schemes related to the river. In addition, three FGDs were undertaken with farmers from irrigation users, non-users, and one with WUA committee members to help triangulate the data obtained through the household survey.

[3]*Peasant association, which is the lowest administrative unit in Ethiopia*

Finally, crop water use and river discharge data was collected by experts in the field using the Area-Velocity method through float technique. In this regard, crop water use for all farmers in the survey is measured per each irrigated crop using appropriate techniques with supervision from a senior expert. Other relevant data including agro-ecological and climate data for the study area is collected from the concerned offices and organizations.

4.3. Models and Methods of Estimation

The collected data was first analyzed using Endogenous Switching Regression (ESR) model, which was undertaken to simultaneously identify determinants of adoption of irrigation and impact of adoption on income and consumption of the surveyed households. Effective rainfall, crop water requirements, and irrigation water requirement were also estimated using Cropwat8 software. Then optimization model was developed with in the bioeconomic farm household modeling framework to identify the optimal baseline production, consumption, and resource allocation decisions as well as to undertake scenario analysis of several relevant policy interventions. The code for the bioeconomic model was written using Non-linear programming techniques on GAMS software (Table A.5).

4.3.1. The Endogenous Switching Regression (ESR) model

Theoretical Model Specification

The decision to adopt a technology can be modeled in a random utility framework by expressing the unobservable utility from adoption and non-adoption through observable variables (KHONJE *ET AL*., 2015). Accordingly, use of irrigation is modeled considering the assumption that smallholder farmers choose between irrigating and not irrigating. It is assumed that farmers consider the benefit from irrigation through the farm income derived from crop production to decide to irrigate. The following model specifies the selection equation P* where P* is the latent variable which is not observed. P* can, however, be expressed as a function of some observed farm, household, and institutional characteristics.

$$p^* = \alpha Z_i + u_i \qquad (2)$$

$$I_i = 1 \; if P^* > 0 \; and \;\; I_i = 0 \; if \; P^* \leq 0$$

I_i is a binary variable, which takes a value of “1” for farmers who irrigate and “0” for those who do not irrigate. Z_i represents factors that affect the irrigation decision. A denotes the vector of parameters indicating the magnitude and direction of each explanatory variable's effect on the decision to irrigate. The residual u_i captures the unobserved factors and measurement errors.

The two regimes that the smallholder farmers fall into are represented by the following two regression equations:

$$Regime\ 1\colon\ Y_{1i} = \beta_1 X_i + \varepsilon_{1i} \quad if I_i \ = 1 \qquad (3a)$$

$$Regime\ 2\colon Y_{2i} = \beta_2 X_i + \varepsilon_{2i} \quad if\ I_i = 0 \qquad (3b)$$

Y_{1i} and Y_{2i} are the dependent outcome variables determined by the exogenous variables X_i, $\beta 1$, and $\beta 2$, are parameters that show the direction and strength of the relation between the outcome variable and the independent variables. $\varepsilon_{1i}$and ε_{1i} are error terms.

Several approaches are available for use in estimating the endogenous switching model. Two-step least square or maximum likelihood estimation can be used through estimating one equation at a time (LOKSHIN & SAJAIA, 2004). These approaches, however, are mentioned to be inefficient and resulting in heteroskedastic residuals in that they need 'cumbersome adjustments' to drive consistent standard errors (ABDULAI & HUFFMAN, 2014). This drawback can be tackled by simultaneously estimating the model using the Full Information Maximum Likelihood (FIML) technique.

Empirical Model Specification

Farmers decide to irrigate if they assume that the net benefits in the form of farm income from irrigating is higher than that of not irrigating. Several types of unobservable factors also determine the farmers' decision to irrigate resulting in a selection bias. A selection bias arises if unobservable factors affect both error terms in the selection equation U_i and the outcome equation (ε). This results in a correlation between the error terms of the selection and continuous equation: $\operatorname{corr}(\varepsilon, u) = \rho \neq 0$ This correlation between the error terms witnesses the existence of an endogenous switching (MADDALA, 1986). The current study assumes the existence of selection bias mainly because of the role of the WUA in the access to irrigation water. The absence of good governance results in over abstraction by favored households, which in turn may affect the decision to irrigate by the other households.

The unobservable factors may fall under personal, social or institutional characteristics. They can include natural managerial and technical skills, the farmer-to-farmer networks and informal associations to formal institutions like water user associations. They can also include transaction costs incurred by the farmers because of poor infrastructure (ABDULAI & HUFFMAN, 2014). Provided that different farm and farmer characteristics determine whether the farm household decides to irrigate or not the following specification gives the outcome regression equations for the two regimes:

$$users:\ Y_{1i} = \beta_1 X_i + \varepsilon_{1i} \quad if I_i = 1 \qquad (4a)$$

$$non-users: Y_{2i} = \beta_2 X_i + \varepsilon_{2i} \quad if\ I_i = 0 \qquad (4b)$$

Assume that the error terms ε_{1i}, ε_{2i}, and u_i have a trivariate normal distribution, with mean vector zero and covariance matrix (LEE *ET AL*., 1982),

$$Cov(\upsilon_i, \varepsilon_{1i}, \varepsilon_{2i}) = \begin{bmatrix} \sigma_\upsilon^2 & \cdot & \cdot \\ \sigma_{\varepsilon 1 i \upsilon} & \sigma_{\varepsilon 1 i}^2 & \cdot \\ \sigma_{\varepsilon 2 i \upsilon} & \cdot & \sigma_{\varepsilon 2 i}^2 \end{bmatrix} \qquad (5)$$

Where σ_u^2 variance of the error term in the selection equation, $\sigma_{\varepsilon 1i}^2$ and $\sigma_{\varepsilon 2i}^2$ are variances of the error terms in the continuous equations. $\sigma_{\varepsilon 1iu}$ and $\sigma_{\varepsilon 2iu}$ are covariance of ui and ε1i and ε2i respectively. Since Y_{1i} and Y_{2i} are not observed simultaneously a covariance of the corresponding error terms is not defined (MADDALA, 1983). This structure of the error terms indicates that the error terms of the outcome equation and the error term of the selection equation are correlated which results in non-zero expected value of ε_{1i} and ε_{2i} given u_i- error term of the selection equation (ABDULAI & HUFFMAN, 2014).Therefore, the expected values of the truncated error terms $E(\varepsilon_1 | I = 1)$ and $E(\varepsilon_2 | I = 0)$ are given below.

$$E(\varepsilon 1 | I = 1) = E(\varepsilon_1 | u > -Z\alpha)$$

$$= \sigma_{\varepsilon 1u} \frac{\varphi(\frac{Z\alpha}{\sigma})}{\Phi(\frac{Z\alpha}{\sigma})} \equiv \sigma_{\varepsilon 1u}\ \lambda_1 \qquad (6a)$$

and,

$$E(\varepsilon_2 | I = 0) = E(\varepsilon_2 | u \leq -Z\alpha)$$

$$= \sigma_{\varepsilon 2u} \frac{-\varphi(\frac{Z\alpha}{\sigma})}{1 - \Phi(\frac{Z\alpha}{\sigma})} \equiv \sigma_{\varepsilon 2u}\ \lambda_2 \qquad (6b)$$

φ and Φ are the probability density and cumulative distribution function of the standard normal distribution, respectively. The ratio of φ and Φ evaluated at Zα is referred to as the inverse Mills ratio λ_1 and λ_2 (selectivity terms). If the estimated covariance $\sigma_{\varepsilon 1u}^2$ and $\sigma_{\varepsilon 2u}^2$ are significantly different from 0 the decision to irrigate and the outcome variable (farm income) are correlated. This implies endogenous switching and the presence of a sample selectivity bias (MADDALA, 1986; MADDALA & NELSON, 1975).

Full Information Maximum Likelihood method is suggested as an efficient method for estimating the model. Following this argument and considering the assumption regarding the distribution of the disturbance terms, the logarithmic likelihood function for the system of equations 5a and 5b is given below.

$$lnL_i = \sum_{i=1}^{N} I_i \left[ln\varphi \quad \langle\frac{\varepsilon_1}{\sigma_{\varepsilon 1}}\rangle - ln\sigma_{\varepsilon 1} + ln\Phi(\rho_1) \right] \\ + (1 - I_i) \left[ln\varphi \quad \langle\frac{\varepsilon_2}{\sigma_{\varepsilon 2}}\rangle - ln\sigma_{\varepsilon 2} + ln(1 - \Phi(\rho_2)) \right] \qquad (7)$$

Where ρ_1 and ρ_2 are correlation coefficients between the selection equation error term u_i and the error terms of the outcome equations ε_1 and ε_2.

Further, estimations of treatment effects were made. Average Treatment effect on the Treated and Untreated (ATT and ATU) are computed using the results for expected values of the dependent variable for users and non-users in actual and counterfactual scenarios.

$$E(Y_{1i} \mid I_i = 1, X_{1i}) = \beta_1 X_{1i} + \sigma_{\epsilon 1u} \rho_1 \frac{\varphi(Z\alpha)}{\Phi(Z\alpha)} \qquad (8)$$

$$E(Y_{2i} \mid I_i = 0, X_{2i}) = \beta_1 X_{2i} - \sigma_{\epsilon 2u} \rho_1 \frac{\varphi(Z\alpha)}{\left(1 - \Phi(Z\alpha)\right)} \qquad (9)$$

$$E(Y_{2i} \mid I_i = 1, X_{1i}) = \beta_2 X_{1i} + \sigma_{\epsilon 2u} \rho_2 \frac{\varphi(Z\alpha)}{\Phi(Z\alpha)} \qquad (10)$$

$$E(Y_{1i} \mid I_i = 0, X_{2i}) = \beta_2 X_{2i} - \sigma_{\epsilon 1u} \rho_2 \frac{\varphi(Z\alpha)}{\left(1 - \Phi(Z\alpha)\right)} \qquad (11)$$

ATT is the difference between the expected value of the outcome variable from equations (8) and (10), i.e., it measures the difference in the expected value of the dependent variable for users with and without the use of irrigation. ATU is the difference between equations (9) and (11) estimating the difference in the expected value of the outcome variable for non-users had they became irrigation users.

4.4. Bio economic household model

4.4.1. Model Structure and Parameters Estimation

The basic model draws from the conventional Farm Household Models of SINGH *ET AL*. (1986). The empirical model combines econometrically estimated production functions for the different crops with the respective functions representing biophysical process in simultaneously solving for maximum utility. Other socio-economic constraints, which are expected to limit the economic activity of the households are as well captured in the model. Three different household groups were identified during the study: Upstream, Middle-stream, and downstream. The farm households, which are located in the upstream have a better access to irrigation water since they are closer to the source of the water. The households located in the middle have access but relatively more constrained than the upstream households. The far downstream households do not get irrigation water currently even though the scheme was developed to reach them as beneficiaries. The crops that are included in the model are the most common cash crops sugarcane and *khat*, and food crops maize and *enset*.

The optimization model was developed for the three more homogeneous household categories stated above. Crop and technology choice is endogenized in the proposed optimization model by considering different crops and both irrigated and rain fed farming. The proposed model shows both the interaction occurring between the households as socio-economic segment and the irrigation water as the biophysical component as well as interaction between the household categories. The welfare and sustainability effects of the production and consumption decisions of the households are solved simultaneously.

4.4.2. Biophysical process

Biophysical process can be integrated into bioeconomic models in ways ranging from complex biological process models to sustainability indicators in economic optimization models (BROWN, 2000). This study considers economic optimization model with a biophysical component. The variable used to capture the biophysical component of the bioeconomy is irrigation water. The following sections present the function representing the biophysical process and important biophysical variables.

Water use (availability) function

Non-statistical considerations lead to the assumption that changes in water use is function of various variables as stated below. Theoretical considerations of crop water relationships, empirical data gathered, and inputs from other relevant previous studies were used in specifying the conceptual relationship between water available for irrigation with scheme discharge, crop water requirement, and available effective rainfall.

$$Wu_i = g(SD, EC, CWR_i, ER) \qquad (12)$$

Where Wu_i is the irrigation water used (available for use) by household i, SD is total scheme discharge, EC is conveyance efficiency of the scheme, CWR_i is crop water requirement for household i, and ER is effective rainfall available for the crops. The decision of the households on the crop mix is captured by the crop water requirement. The quantity of crop water requirement for a given farm strongly depends on the decision of the farmers on the share of the irrigated crops from the whole farm size. The theoretical level of crop water requirement for each crop coupled with the household's cropping decision and corrected for the conveyance efficiency of the canals gives room for simulating the trade-off between households' production decision and water availability and use. Therefore, the per ha effect of the production decision (the type of crop produced) on water use is captured by the crop water requirement. This parameter is one of the factors in the water use function representing the biophysical constraint.

Biophysical variables (SD, CWR, CE)

I. Total water available for use by household: Scheme Discharge (SD)

The total of the canal discharges that entered to the fields of each farmer in the survey is used as a proxy variable for the total water available for use by households at the base line situation. Discharge refers to the volume of water transported by a canal per second and is expressed in liters or cubic meters per second (BOSCH *ET AL*., 1992) . The data for constructing this variable was collected during the 2015 cropping year from each farm of households who were included in the study and use irrigation water. Out of 240 households involved in the study, 160 households are currently irrigators. The collection of the water data was undertaken by individuals with relevant training and experience in the area using Area-Velocity method. There are several techniques that can be used to measure discharge depending on the situation. Some methods use discharge measurement structures and some others do not require structures (BOSCH *ET AL*., 1992). The purpose of the data requirement, the availability of required equipment and trained personnel determines the selection of a technique. Area-Velocity method using float technique was utilized for this study for its simplicity and relative better experience of the data collectors on this method. The float method is quick and cheap way with expected measurement error of ±10 percent (BOSCH *ET AL*., 1992)

The volume of water that enters each plot per second was measured from the appropriate section of the canal transporting water to the field canals. The following formula shows how the volume of water denoted by ‘Q’ is calculated from area ‘A’ of an irrigation canal and ‘V’ average water flow velocity.

$$Q = A * V \tag{13}$$

Cross section area of 10 meters long part of the canal feeding the field canals is first determined using average value for depth and width of the canal taken from three different points over the 10 meters length. The team made sure that the canal under consideration is straight and uniform to get relatively better measurement. The shape of the canals in the study area is mostly rectangular but exhibits irregularities specially the tertiary canals, which are earthen canal. To minimize measurement errors because of the irregular shape of the canals the cross-section area is calculate from average measures of water width and depth taken from three different points as follows:

$$A = W * D \tag{14}$$

Where W is the average surface water width and D is the average water depth.

Similarly, the velocity of the water is measured based on average time required for a light commonly used object – a plastic bottle cap set upside down to float over the predetermined and marked 10 meters canal. The object was put at the beginning of the marked canal section four times and average time was then calculated to be used in the following formula to compute the velocity.

$$V = \frac{s}{t} \tag{15}$$

S is distance of the canal under consideration and t=average time required for the object to float through the canal. The surface velocity must be adjusted by a correction factor to account for the difference in flow velocity of surface and subsurface water. Surface water flows faster than subsurface water (BOSCH *ET AL*., 1992). Accordingly, the surface velocity which is calculated using the above formula is then adjusted by a constant reduction factor of 0.75 to get the average flow velocity for this study.

II. Crop Evapotranspiration (CWR)

Crop water requirements depend on biophysical factors like climate, physio-chemical characteristics of the soil, and the crop under consideration. In this study the reference crop evapotranspiration was first calculated using CROPWAT software of FAO. Then the crop water and irrigation requirement was calculated using by the Penman-Monteith method by incorporating the required climate, rainfall, soil, and crop coefficients data in the software. Other parameters related to the respective crops including crop coefficients is adopted from the FAO guideline and other related studies undertaken on same crops. Crop coefficient for sugarcane was found in several studies undertaken in the area and elsewhere. The Kc for *Khat*, however, was approximated by the Kc of Citrus because the crop parameters are not found on published documents. Similar study by (SETEGN *ET AL*., 2011) used Kc of citrus to approximate for *Khat*. *Khat* and Citrus plant exhibit similar characteristics: evergreen perennial shrubs, tolerance of drought, growing under wide climatic and soil condition, have extensive root system, need fast drainage, and poor performance in rich moist soils (SETEGN *ET AL*., 2011). In addition, soil properties and related data were adopted from the Woreda Agricultural and rural development office working documents.

III. Conveyance Efficiency (CE)

Conveyance efficiency is one of the measures of performance of an irrigation scheme. It measures the efficiency of the canal in transporting water to the required point. In other words, it indicates the amount of water lost during transportation (AWULACHEW & AYANA, 2011). Records obtained from the irrigation development section of the district agriculture and rural development office indicates an average conveyance efficiency of canals in the study area to be 65 percent.

IV. Effective Rainfall (ER)

Effective Rainfall (or precipitation) is measured by subtracting the actual evapotranspiration from the total rainfall. Effective rainfall refers to the utilizable part of the rainfall that reaches the storage reservoir from the rain in the surrounding area. It can be calculated directly from the climatic parameters and the useable ground reserves.

4.4.3. Objective Function: Utility Maximization

The study assumes that the farm household maximizes utility, which is function of consumption of goods and leisure. The specification of the utility maximization function from the demand for commodities and leisure is given below.

$$u = f(Xi, Xj, l) \tag{16}$$

Where *u* refers to utility, *Xi* consumption of food items (Enset, Maize), *Xj* consumption of purchased commodities (clothing, services etc.), and *l* leisure. The utility function includes arguments that have two sources of food consumption; own and purchased. These two sources of utility can be combined in one argument. Consumption of leisure is also included in the argument. There are differing views as what constitutes leisure. KOWALSKI (2017), for instance, consider leisure to include: 1) Time spent for relaxation and family; 2) time spent to meet social obligation. Generally, leisure includes time spent on activities that compete with the classical productive activates like crop production in this case. There are different utility functions. In this study, a

Cobb-Douglas form of utility function is used. Since each household (upstream middle stream and downstream) has its own unique consumption pattern and utility is additive, the objective function for utility of households is given below.

$$U = \sum_{j=1}^{3} \prod_{i=1}^{n} X_{ji}^{\alpha_{ji}} \qquad (17)$$

Where X_{ji} is the amount of consumption of good i (Enset, Maize from own production , clothing, services etc. from purchased items) by households j (upper-stream, middle-stream and downstream) and α_{ji} is the share of good i from the total consumption expenditures by household j (these parameters are computed from the survey data). It the model it is depicted in the equation AnnualUtility (household). In the entire model, the upstream households are optimized first and have first access to water and downstream households can use the part of the water that has been left over from the upper stream.

4.4.4. Constraints

Production technology

The farm household is assumed to maximize utility subject to the existing production technology represented by the production function.

$$Q = f(A, L, Wu_t, K, V) \qquad (18)$$

The typical advantage of bioeconomic modeling is its ability to allow the interface between the natural system and the socio-economic system. In this regard, proper specification and estimation of the production function is crucial. The production function, which is estimated for this model serves to capture the aforementioned interface by including the amount of water use as one of the factors of production. It is now that production function is defined as a function that specifies 'the maximum possible output which can be produced from a given quantities of a set of inputs.

Similar definition was given by AIGNER *ET AL*. (1977) explicitly adding the assumption that the maximum possible output is specified under a 'fixed technology' setting. The above definition emphasizes the concept of maximality implying the possibility of range of different levels of combinations of inputs. In this regard, some points may fall on the production frontier while others fall below the frontier. Before FARRELL (1957) who introduced the possibility of estimating frontier production functions scholars have been estimating the average production functions. He argues that although theoretically attainable function is valid it receives several objections for failing to hold in complex empirical situations. He rather considers estimation of production function from observed combination of inputs and corresponding outputs. FORSUND *ET AL*. (1980) pointed out possibility of various specifications and estimation for any frontier including production function. In this regard, parametric versus non-parametric functions, specifications of explicit statistical model of input output relationship or otherwise, and finally deterministic and stochastic frontier options were mentioned.

Deterministic frontiers could be estimated through parametric or non-parametric approaches. The non-parametric frontiers do not impose specific functional form on the data which can be considered as an advantage as stated by FORSUND *ET AL*. (1980). But these frontiers also have a restricting assumption of constant returns to scale. In addition, because such frontiers are constructed from a sub-set of observations from a sample, they are highly affected by extreme observations and measurement errors. Deterministic parametric frontiers have come into picture with the advantage of specifying a frontier with a simple mathematical form and options to allow the assumption of other levels of returns to scale in addition to constant returns. However, in previous works in this area of like AIGNER AND CHU (1968) used mathematical programing and results in estimates without statistical properties like standard errors and t-values. This, in turn, makes the results of such approach of no use for statistical analysis (FORSUND *ET AL*., 1880; AIGNER *ET AL*., 1977). The shortcomings of the deterministic parametric approach were later improved to make statistical inferences possible. This improved statistical frontier model is estimated with specific assumptions about the regressors and the distribution of the disturbance term. This later deterministic statistical frontier model can be estimated by maximum likelihood or ordinary least squares method (FORSUND *ET AL*., 1880; AIGNER *ET AL*., 1977).

Production frontier models can also be stochastic as mentioned above. In the deterministic approach it is assumed that all farm households share the same production function. The difference between the performances of the farms is attributed to only their efficiency. This is, however, empirically unjustifiable because performance of farm households can be affected by both own efficiency as well as factors outside its control like weather (FORSUND, 1980). AIGNER *ET AL*., (1977) reinforced this argument by giving 'the economic logic behind' stochastic specification as 'production process is subject to two economically distinguishable random disturbances, with different characteristics.

Hence, the stochastic frontier modeling assumes that error term is composed of two parts; a non-positive disturbance, which is attributable to factors under the farmer's control and a disturbance which can take any value resulting from 'favorable' or 'unfavorable' external shocks AIGNER *ET AL*. (1977). This allows for random variation of the frontier across households. Stochastic production frontier model can be estimated by maximum likelihood method or OLS with correction. Even though the estimation using OLS is simple, it is less efficient (FORSUND, 1980).

Considering the pros and cons of the approaches and theoretical considerations above the stochastic frontier approach is used to estimate the production function for this study. The production function was estimated using maximum likelihood method. The estimation was based on the linearized Cobb-Douglas function of the following form (see the values of the coefficients on Table A. 1).

$$lnQ = \alpha + \beta_1\, lnlabor + \beta_2\, fertilizer + \beta_3\, compost + \beta_4\, pesticide + \beta_5\, wate \quad (19)$$

Where Q refers to farm output. The production function is estimated for each crop using econometric technique based on the collected farm level cross-section data. Empirical quantity of crop water use was collected for each irrigated crop and this value is included as one explanatory variable in the production function.

Biophysical constraint

Water used by the crops in each field should not exceed the crop water requirement. Similarly, the total water used by the farmers for their field should be less than or equals to the total scheme discharge corrected for the conveyance efficiency of the scheme canals.

$$Wu_t \leq CWR \quad (20)$$

$$\sum Wu_t \leq SD \quad (21)$$

Where Wut is crop water use (it is presented by equation Qcrop_wat_req in the GAMS code), SD is total water discharge of the Scheme, and CWR is crop water requirement

Time endowment constraint

Labor time is one of the important variables in the utility function included in the form of consumption of leisure time. It is also one of the explanatory variables in the production function, which determines the activity level for each crop. Because it is one of the scarce resources in a household, it is considered as one of the constraints in the production and consumption decisions of farm households. This in turn implies the existence of clear trade-off between time allocated for different productive activities and time consumed as leisure. Accordingly, this trade-off should correctly be recognized in the model and should be theoretically justified

The time allocated to different productive activities was collected during the survey from each member of the household. Further, the labor time invested for the farming activities were also collected. The questionnaire included sections for: 1) Land Preparation, 2) Planting, 3) Fertilizing, 4) Crop Protection, 5) Irrigation, 6) Weeding, Harvesting and Post Harvesting. Both own and hired labor involved in all the listed activities was collected. This was used in the estimation of the production frontier to represent the production technology.

Based on the aforementioned description, utility maximization objective of the farm households in the area is also constrained by the availability of time which is expressed below.

$$l + H + N \leq \mathrm{T} \qquad (22)$$

Where T = total time endowment, l = leisure, H = Time allotted to own farm work, and N = time allocated to off farm employment.

Full income constraint

Finally, the objective of utility maximization is also constrained by cash income, which is set by equating household net earnings to income available for expenditure on purchased consumer goods.

$$pQ + wL_f + I_{nf} = PX_i + wL_h + rV + iK + mX_j + E \qquad (23)$$

Where pQ Cash from crop sale, wLf = Cash from labor invested on other farm for wage, I_{nf} = cash from non-farm activities, Px_i = cash needed for purchase of food items, wL_h = Cash needed for hired labor, rV = Cash needed for fertilizer, iK = cash needed for pesticide, mX_j = cash needed for purchase of non-food commodities, and E = cash surplus.

Minimum Food Requirement

Safety first criterion is considered as a means to account for risk in the model. To this end, minimum food requirement expressed in kcal per adult equivalent per day has to be met by each household in the current optimization model.

$$M_{kcal} < X_{kcal} \qquad (24)$$

Where X_{kcal} is food consumed in each household in Kcal, and M_{kcal} is minimum food requirement by each household in Kcal.

Land size Constraint

In order to carry out policy simulation related to land allocation between sugar cane and Khat the following equation has been included.

$$Aa_{khat} = \alpha_i A_{sugarcane} \tag{25}$$

Where Aa_{khat} and $A_{sugarcane}$ refer to the amount of land allocated to khat and sugarcane, respectively and α_i is going to take different values as per the simulation indicated in section 3.9. The expression is captured by equation QAllocatedLandSizec in the GAMS code.

4.5. Risk and production choice of farmers

Understanding what influences the production decisions of a farm household in a developing country requires evaluation of the typical and contextual influencing factors. Influence comes from uncertainties in several environments both internal and external to the farmer including socio-economic, natural, and institutional. Insurance against the risk entailed by these uncertainties is priority for poor farmers. The existence of strong institutional settings that can assist risk-bearing capacity of the farmers play great role in this regard. In the absence of such institutions and perfect markets, which happens to be the case for developing countries, households tend to make production decisions with high weight to self-protecting the household. This is evidenced by the behavior of farmers in poor countries where they prefer to give up profits for greater self-protection (MENDOLA, 2007).

This important issue has been given due consideration and incorporated in to farm household models through several ways. Some approaches are data intensive and require specific type of empirical data. Risk can also be considered in the model through approaches that require moderate amount of data. KOWALSKI (2017) for instance incorporated risk in his model by attaching safety first criterion which puts the constraint that the model should allow for the production of sufficient amount of food for ensuring the minimum consumption by the household.

Similarly, the water scarce farmers included in this study tend to cover less of their land with irrigated crops than the relatively better off farmers. They tend to grow more of food crops like *Enset* and maize than non-food cash crops. Accordingly, risk considerations in this study follow safety first criterion through putting minimum consumption requirement as a constraint in the model.

4.5.1. Integration of household model

The model has three distinct household categories such that the constraints related to water, labor, land and the utility function should be integrated depending on the nature of the production factors. In this regard, it is assumed that labor is immobile across upstream middle stream and downstream villages in the short run. Apart from this, the total land allocated to each crop should not exceed the already available total land endowment. In other words, land cannot expand at least in the short run. Cognizant to this, the demand for labor and land in each household category is less than or equal to the total labor and land available. Hence, the labor and the land constraints are given below.

$$\sum_{i=l}^{n} L_{ij} \leq L_{Ai} \tag{26}$$

$$\sum A_{ic} < A_{\max} \tag{27}$$

Where L_{ij} is the labor allocated for crop production in each household category, and L_{Aj} is the total labor available in the village. This expression is presented by equation QAllocatedLandSize in the GAMS code. A_{max} is the maximum total land area available for crop production, and A_{ic} is land size allocated by each household i for each crop c.

Since water is mobile across all villages, the total water demand in all the three streams is equal or less than to the total water that flows in the river. It is known that the demand for water for each crop in each household category is determined by the respective production functions. Hence the water constraint is given in the following way:

$$\sum_{j=1}^{3} \sum_{i=l}^{n} W_{ij} \leq W_A \tag{28}$$

Where W_{ij} is the demand of water for crop I in household category j. W_A is the total water in the stream.

There are other linear equations which are used in the model including the constrains set on the maximum amount of yield per crop per ha in each region. Apart from this, the total amount of production of each crop is assumed to be either consumed or sold to the market. Thus, own consumption is equal to the amount left over after the household sold some portion of the total production. The total calorie intake of the household is equal to the sum of food consumption multiplied by the calorie content of the food items. Cost of purchasing inputs is equivalent to sum of the total amount of inputs used by each crop multiplied by the unit price of each input.

4.6. Estimation of parameters

The descriptive analysis of the collected data was presented in the subsequent sections. This data has been reorganized such that some of the parameters pertaining to the relevant variables have been estimated using econometrics approach. Others were computed directly from the survey data. For instance, the most significant variables, notably, share of consumption of goods and services by households, the water use constraints, land constraints, maximum output per ha per crop have been computed from the collected data and are presented in the appendix at Table A.1, Table A.2, and Table A.3.

4.7. Scenario

Policy can influence economic and environment link in two ways: one through conditioning the way farmers use natural resources for instance thorough imposing standards and minimum/maximum requirements; and two through promoting sustainable technologies (BORNER, 2005). Right mix of policies relevant to ensure technology and institutional change and transformation are prerequisite to ensuring sustainable development where by current production, income, and food security are improved without compromising the ability of future generation to meet their own needs (KRUSEMAN & BADE, 1998). Accordingly, after the baseline optimization model was developed and solved, several scenarios were considered to simulate the effect of different policy instruments on the water use behavior of the farmers. Specifically, analysis was done on different policy instruments and farming plans as per their likely result in water saving behavior and action of the smallholders in the study area.

This analysis is based on the empirical information collected from the area and related literature review. Accordingly, three different scenarios based on different policy options to influence farmers' decisions on crop mix, reallocation of water across different course of the river, and introduction of water fee were considered in undertaking a simulation analysis. The three scenarios are built on the following three hypothetical interventions (Table 4.1). These are: 1) controlling the expansion of *khat* cultivation through fiscal policies, 2) water pricing, and 3) land allocation. This way the analysis will help to come up with the right incentives and interventions to bridge the gap between the baseline situation and more sustainable economic activity.

Scenario I: Controlling the expansion of khat cultivation through fiscal policies

Khat is a major agricultural cash crop with high return for the producers (ATROOSH & AL-MOAYAD, 2012). It is a psychoactive leaf consumed heavily in northeastern Africa and has become export cash crop. This situation coupled with huge yield gap under rain-fed agriculture of about 40 percent of the people is resulting in increased cultivation of irrigated *khat* in Eastern Hararge (SETEGN *ET AL*., 2011). The data from the current study also show that farmers who have cultivated *khat* under irrigation harvest this 'cash crop' at least two-three times per year. Hence, they tend to opt for irrigating their *khat* fields though it results in several environmental and social ramifications in the areas it is grown and consumed. For instance, irrigated *khat* expansion has brought about significant negative implications on the sustainability of Lake Haromaya because of withdrawal of large volume of water for irrigation (SETEGN *ET AL*., 2011).

Further problems of sustainability were identified in connection with *khat* irrigation practice in the area as indicated by several irrigation performance indicators of the scheme. The increasing expansion of *khat* is negatively impacting and causing intrusion and permanent settlement in the forest in the current study area (DESSIE & KINLUND, 2008) further resulting in the replacement of food crops.

Secondly, khat has been controversial at a global scale regarding its health and socio-economic impacts. Some users consider it as having a positive social value in keeping families together while others mention it as a drug, which destroys families by keeping especially men away from home and job (The Economist, 2012). Khat is banned in the USA, Canada and most of European countries including Germany, Sweden, the Netherlands, and later the UK (The Economist, 2012; The Guardian, 2015). Several studies indicated that it has negative health and socio-economic impacts. In Yemen, for instance, the widespread use of khat by the population has caused great deal of problem (HASSAN *ET AL*., 2007). Generally, chewing khat causes mild level of euphoria and excitement which facilitates social interaction (HASSAN *ET AL*., 2007; KALIX & BRAENDEN, 1985; KALIX, 1987). There is a claim that the chewer feels achievement of increased alertness, energy, and improved level of perception (KALIX, 1990). This feeling, however, will ultimately be followed by 'mild dysphoria' (NENCINI & AHMED, 1986) anxiety, reactive depression, and insomnia (HALBACH, 1972; HASSAN *ET AL*., 2007). *Khat* related psychosis is commonly reported and the risk is higher in predisposed individuals (HASSAN *ET AL*., 2007).

The above evidence and own data led to the consideration of a scenario of setting a control on the cultivation and expansion of *Khat* in Wondo Genet. To do so, different policy options have been considered. In one hand, the government can levy production tax on *Khat* and can invest the money to enhance the productivity of sugarcane production. These two initiatives enable farmers to produce more of sugarcane and less of *Khat* without encountering a significant loss on their level of income. Three sub-scenarios are considered, namely: 1) introduction of production tax on khat cultivation (levying 10 percent of production tax on the volume goods produced); 2) enhancing the efficiency of other competing agricultural crops (10 percent increase in the total factor productivity of sugarcane); and 3) enhancing the efficiency of water usage by sugarcane production by 10 percent.

Scenario II: Water Pricing

The most serious problem of an irrigation system is inefficient use of water and is mostly attributable to water leakage in the network (YANG *ET A*L., 2003). Empirical studies indicate inadequate technology: like use of earthen canals and lack of regular maintenance resulting in significant amount of water loss (AMEDE, 2015). Similarly, the average conveyance efficiency of the canals in the study area is 64.25 percent indicating significant amount of water loss during transportation (MAMO & WOLDE, 2015). On the contrary, the ideal irrigation system would cover the targeted command area without loss (SETEGN *ET AL*., 2011). Efficiency of an irrigation system, on the other hand, heavily depends on economic factors like the value of water for different uses and users (ESMAEILI & SHAHSAVARI, 2015; LATINOPOULOS *ET AL*., 2004).

As the increasing scarcity of water is posing immense challenge on agricultural production and food security proper policy should be drawn to mitigate the problem. In this regard, water pricing has been suggested by many studies as an important policy instrument in achieving water use efficiency and reduce waste (ESMAEILI & SHAHSAVARI, 2015; OUDA, SHAWESH, AL-OLABI, YOUNES, & AL-WAKED, 2013; YANG *ET AL*., 2003;VARELA-ORTEGA *ET AL*., 1998).

Governments, however, mostly favor agricultural use of water and farmers pay little or no for using water for crop production. Similarly, farm households in the study area do not pay for using irrigation water at the moment like most countries in the world. This problem of valuation of water significantly contributed towards inefficient systems and no incentive to conserve it (ESMAEILI & SHAHSAVARI, 2015; JOHANSSON, 2000; YANG *ET AL*., 2003). A study undertaken in Saudi Arabia, for instance, concluded that low price of water is the major reasons for improper and wasteful utilization of the scarce resource (OUD *ET AL*., 2013).

Therefore, it is imperative to price water in a balanced way reflecting the scarcity level and the real economic value for it (ESMAEILI & SHAHSAVARI, 2015). In this regard, it is important to note that demand elasticity of water responds differently at differing levels of water price and there is a threshold below which water demand is inelastic. The increase in water price up to this threshold will not bring about any change on water demand or land allocation decision of the farmers (YANG *ET AL*., 2003). Study by VARELA-ORTEGA *ET AL*. (1998) confirmed the same in Spain indicating that water demand is inelastic for lower prices.

Water charging has also impact on the supply of agricultural products in the market if it results in the change in the land allocation plan of the farmers to different crops. YANG *ET AL*. (2003) for instance projected that food crop production and market supply will particularly decline and lead to rise in food imports on their study in China due to change of land allocation plan. The impacts of such changes are in fact expected to differ depending on the type of irrigated crops. The farmers in the current study area irrigate only cash crops: sugarcane and *khat*. The change in the land allocation plan, if any, will inevitably result in cultivation of non-irrigated/less water requiring food crops and vegetables. This shift will have a general impact on the market supply of the irrigated crops. The change in the production pattern of farmers after charging of water depends on the profitability of the crops.

Nevertheless, the water charging is complicated when dealing with fragmented smallholder systems. Measuring the amount of water that each farmer used is mostly not practical as a base for pricing. The most common used way is charging flat rate based on the farm size involved (YANG *ET AL*., 2003). The price to be set should consider the intended purpose of the policy intervention. Water saving as an objective can be achieved at a different level of charges than increasing public revenue objective. For instance, in surface water irrigated areas price elasticities are usually very low and can lead to high public revenue from high prices at the expense of farmers' welfare without any significant change on water use (YANG *ET AL*., 2003).

For the purpose of this study, the scenario to be considered assumes objective of saving more water which requires setting the appropriate amount of price which serves this purpose. This has to be done with caution because of the absence of appropriate technological facilities in the study area to monitor and control the amount of water use by each farmer. YANG *ET AL*. (2003), for instance, indicated that in the similar irrigated areas in China which depend on surface water payment is determined based on flat rate. The study added that this situation made the farmers less motivated to adopt water saving technologies because water is charged not based on the amount of water used. In addition, lack of non-farm employment opportunities farming remains the most important source of employment in rural areas.

With increasing population pressure and land fragmentation the viable option is intensification mainly through irrigation. Therefore, the farmers have shown no change in the production plan or water use behavior despite the increase in water charges. Similar empirical result was indicated by a study in Spain where water pricing has not result in adoption of water saving technologies. Rather adoption of the technologies depended to the large extent on other factors like 'structural factors', 'agronomic conditions', and 'financial constraints'. Hence, the pricing policy should incorporate other instruments to get the desired goal of water saving as indicated by (VARELA-ORTEGA *ET AL*., 1998). The similarity of the farming system and political economy of Ethiopia to China would lead to expectation of the same responsiveness of farmers to water charges.

The condition of the smallholder farmers in Ethiopia currently is very weak to expect a full taking over of the schemes and taking care of all the maintenance and operation activities (AMEDE, 2015). There is, however, a lot of room for improvement on water conveyance efficiency considering the physical and engineering condition of the irrigation scheme under the current study. The overall conveyance efficiency of the canals is only 64.25 percent. Further, the irrigation scheme was constructed in 1993 and no major renovation has been undertaken on it since then as the information from the local people. Only part of the major canal which is used to divert the river from the head work is constructed with concrete and cement lined; only 1.648 km is lined out of 4.6 km long scheme. The rest of the water way is earthen canal dug by the farmers themselves.

If the collected fee is used for improvement of the irrigation system the impact of the water charging is redistribution of income and does not result in welfare loss of farmers (YANG *ET AL.*, 2003). Empirical results have proved that such strategies which combine pricing with improvement of conveyance efficiency of the network could result in significant amount of water saving (GARRIDO *ET AL.*, 1997; IGLESIAS *ET AL.*, 1998; VARELA-ORTEGA, 1998). Hence, the welfare loss incurred by the farmers because of water charges will be transferred to the currently non-user farmers through the allocation of the water saved in the process to them. It has also equally important environmental impact by saving more water for ecosystem services. The willingness to pay survey of irrigation water in Ethiopia has shown that farmers are willing to pay from 5 to 7.5 per cubic of water. Hence, the simulation (Sim2.1) in this case considered the minimum range (5 birr per cubic meter of water) due to the fact that farmers in the study area have small land size and their paying capacity is low.

Scenario III: Land allocation

Khat is profitable to farmers as compared to sugarcane production. The data from the current study also shows that farmers who have cultivated Khat under irrigation harvest at least two times (mostly three times) during the year. This makes households to opt for Khat production than sugarcane production. The trend of land allocation in the study area has also shown that farmers have been inclining to allocate more water and land to Khat production. Given the fact that Khat consumes more water and causes social and health problems, this trend of allocating resources, in the long-run, weakens the overall competitiveness of the study area. For instance, ADEME *ET AL.* (2017) found out that nearly one-third of Khat producers in Oromia and southern Nation and Nationalities were also consumers. This shows that Khat production is associated to Khat consumption.

One possible intervention to decrease *Khat* production is to reduce the amount of land allocated to *khat* such that the volume of land allotted to sugarcane would increase.

Such intervention has its own effect on the area. In one hand, it reduces the amount of water consumed by *Khat* such that it ensures sustainability of sugarcane production in the long run. On the other hand, the amount of income of households might be reduced as households switch from the most profitable *Khat* production to the less profitable sugarcane production. For instance, HANNA (2016) has shown that *khat* production in the Amhara regional state generates higher incomes for the farmers as compared to the non-producers. ADEME *ET AL.* (2017) also found that *khat* producers converted their land from other crops to *khat* production because of income opportunities and soil infertility.

Therefore, the extent of the impact of land reallocation on income of households depends on the net income loss/gain coming from more production of sugarcane and less production of *Khat* and vice versa in the study area. To know the extent of the loss/gain of income, conducting comparative analysis is very vital. To this end, three possible simulations have been considered. The first simulation (Sim3.1) examines the income gain/loss coming from household decision of allocating equal amount of land to *Khat* and sugarcane production. The second simulation (Sim3.2) tries to examine the impact of allocating more land to *Khat* on income of households while the third simulation (Sim3.3) examines the possible impact of allocating more land to sugarcane production. These enable to compare and contrast the gain/loss in household income.

Table 4.1: Summary of scenarios considered in the model for simulation

Scenario	Scenario Description	Simulation	Description of Scenario
1	Controlling the expansion of khat cultivation through fiscal policies	Sim1.1	1) Introduction of production tax on *khat* cultivation (levying 10 percent of production tax on the volume goods produced) 2) Enhancing the efficiency of other competing agricultural crops (10 percent increase in the total factor productivity of sugarcane) 3) Enhancing the efficiency of water usage by sugarcane production by 10 percent
2	Water Pricing	Sim2.1	Introducing water tax 5 birr per cubic meter of water
3	Land allocation	Sim3.1	Allocating equal land to *Khat* and Sugarcane production
		Sim3.2	Allocating 10 percent more land to *Khat* production
		Sim3.3	Allocating 10 percent more land to sugarcane production

Source: own compilation

4.8. Transmission mechanisms

4.8.1. Controlling the expansion of *khat* cultivation through fiscal policies

Sugarcane production could be promoted through the provision of subsidy to farmers or by levying tax on the Khat. Giving subsidy to farmers who produce sugarcane stimulate farmers to produce more sugarcane and less of Khat. This is because the sales revenue from sugarcane increases while the sales revenue from khat decreases or stays constant. But, the magnitude of the impact depends on the extent to which the amount of pricing incentives is fair enough to bring change in the production decision of households. If the pricing incentive is too small to reduce the production of Khat, i.e., if the price is low enough to reduce their benefits of farmers, farmers tend to produce khat even though there is a change in pricing.

Theoretically, it is believed that subsidy to sugarcane production and taxing khat tends to increase the production of sugarcane and reduce the production of Khat. This increases sales income from sugarcane increases while sales income from Khat decreases. By the same token, when the productivity of sugarcane increases, households allot more land to the production of sugarcane which further induces more demand for labours, land, water and other production factors. Since land is limited, the production of Khat decrease proportionally, which decreases the demand for production factors, water and labour. The increase in production of sugarcane increases household income coming from sales revenue. Appositely, the reduction in Khat decreases the sales revenue from Khat.

Since the production functions of sugarcane is labor intensive as compared to Khat, the amount of labour invested on own farm tend to be higher. This might contribute more job creation to the rural people. If more labor is allocated to own farm production, the amount of labour used for off farm activities might decrease. But, the reduction in Khat production release labour so that the extra labour released might engage in off farm activities or transfer to the production of sugarcane. So, the income from off-farm activities might decrease. The schemata in Figure 4.2 depicts the transmission mechanism in a systematic way. The light green boxes represent an increase/positive impact, the light blue boxes represent a decrease/negative impact while the purple boxes represent indefinite outcome.

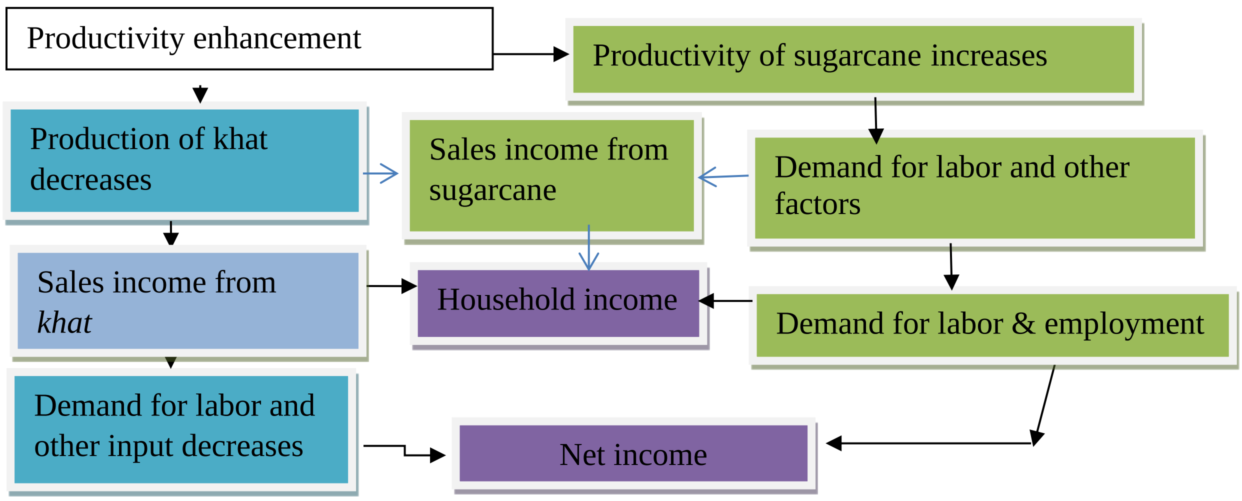

Figure 4.2: Channels of expected impact on productivity of sugarcane

Source: Own depiction

4.8.2. Land reallocation

Land policy could be used to reduce the production of *Khat* in the study area. This increases sugarcane production which ultimately induces more demand for labour and other production factors. On the contrary, the production of *Khat* tends to decrease such that the demand for production factors and labour decreases proportionally. The income of households tends to decrease if they fetch the lion share of their income from sales of K*hat* or their income tend to increase if the increase in sugarcane production ensures more sales revenue.

On the other side of the story, the released labor from *Khat* could engage in the production of sugarcane or else, could engage in off farm activities and earn income. In addition to this, allocating more land to sugarcane changes the input consumption pattern of households. Thus, the net effect depends on the relative power of these effects. The framework in Figure 4.3 shows how allocating more land to sugarcane production affects the production pattern and its effect on income of households.

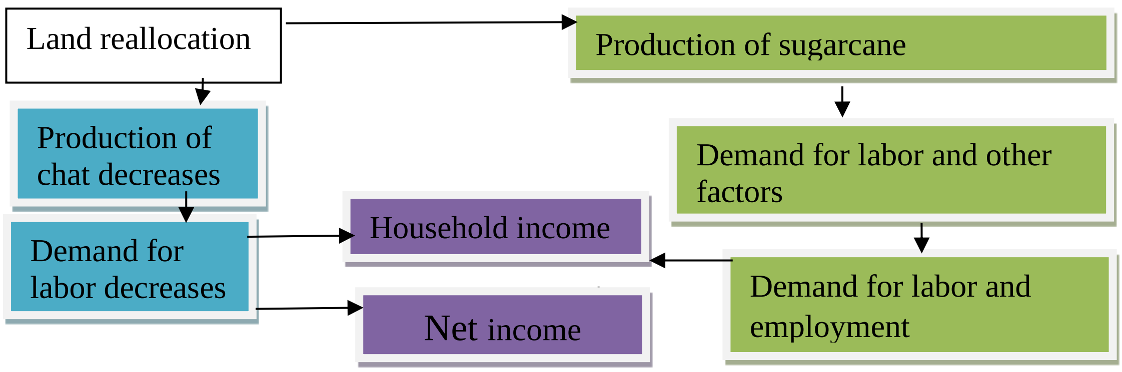

Figure 4.3: Main channels of expected impact of land reallocation

Source: Own depiction

4.8.3. Water Pricing

The government should sustain the provision of irrigation system. One of the most widely methods of it is financing through charging the irrigation water. This will lead households to produce crops that have the highest profit. For instance, if water taxing promotes the production of sugarcane, then the corresponding production of Khat decreases. This induces more demand for labour and other production factors by sugarcane and the corresponding demand for production factors and labor by Khat decreases. The income of households might be reduced if they generate the majority of their income from sales of Khat or their income tend to increase if the increase in sugarcane production ensures more sales revenue that could compensate the loss of income from Khat. On the other side, the released labour from Khat could engage in the production of sugarcane and fetch more income in the form of wage. Or else, the released labour could engage in off farm activities and earn income. In addition, allocating more land to sugarcane changes the input use pattern of households. Thus, the relative power of these interventions determines the net effect. Figure 4.4 shows how allocating more land to sugarcane production affects the production pattern.

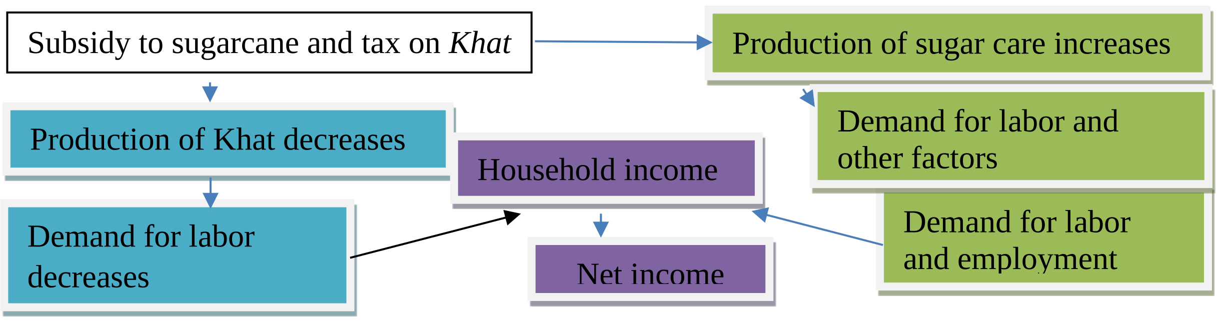

Figure 4.4: Main channels of expected impact of increasing on subsidy and tax

Source: Own depiction

Using the three scenarios considered for analysis and also simulations namely improving the efficiency of water use and taxing Khat production, water tax and allocating more land to Sugarcane, the following can be deduced. Improving efficiency of sugarcane production and taxing Khat improves the production of sugarcane. Water pricing promotes the production of khat, while land allocation promotes the production of sugarcane. The study pinpointed the fact that both institutional and social factors should be given prime attention to ensure fair distribution of water across the course of the river and to instigate farmers to use irrigation. Besides, enhancing the productivity of sugarcane through improved technology should be the main concern of stakeholders. In this regard, a system that tends to enhance the productivity of sugarcane should be in place such that the community would allocate more land to sugarcane which eventually ensures sustainable water use across the course of the river ultimately benefiting users.

5. RESULTS

5.1. Socio-economic characteristics of the study area

The descriptive analyses of socio-economic characteristics of the households included in the current study are presented in this section. Several descriptive analysis tools and tests were applied depending on the variable types and data characteristics to determine how the mean value of the variables differs for the different groups of the households. The descriptive analysis of the data is undertaken from two different perspectives to get adequate understanding of the socio-economic characteristics of the households in line with the requirements of the research objectives. The analysis in the first section pertains to the first objective of the study where we examined the determinants of adoption and impact of access to irrigation on poverty level of the farm households. Accordingly, the observations are organized as households who use irrigation water (n=160) and those who do not (n=80). Based on their location along the irrigation scheme, households were classified as upstream (n=80), middle-stream (n=80), and downstream (n=80) and the descriptive analysis is undertaken accordingly. Most of the variables are common in the analysis except few, which are included only in either of the sub-sections. Moreover, the selected variables are defined and explanations are also included on how the variables were measured and constructed to be included in the analysis.

Our focus group discussions (FGD) revealed that little or no problem was observed when the allocation of irrigation water was administered under the traditional system. Key informants from the local government, however, attribute the current irrigation water problem to water scarcity and population pressure. The households in the study area currently practice irrigation on *khat* and sugarcane fields, on average, for four months (December to March). Results of the descriptive analysis reveal that 92 percent of respondents believe that the irrigation water is not sufficient to meet their current needs. The remaining 8 percent of the households who responded positively are all from the upstream. Despite differing views on the source of the problem, both the FGDs and key informant interviews confirm increasing scarcity of irrigation water in the study area. In one of the FGDS, one participant made a remark that confirms the seriousness of irrigation water scarcity in the area sating "*We are suffering from lack of water seriously affecting our production system. Therefore, the concerned body should do something about it before we fall into the trap of hunger*". As a manifestation of full support to his remarks, he got a big hand from all FGD participants.

5.1.1. Characterization of irrigation users vis-à-vis non-users

This sub-section presents descriptive statistics of the survey data for the relevant variables included in the econometric model estimation (Endogenous Switching Regression). Chi-square test and t-test were used to test (any) statistical differences between irrigation users and non-users on the mean values of the categorical and continuous variables, respectively. The test results are presented in the tables 5.1 to 5.6 under the respective headings.

Household Characteristics

Table 5.1 presents descriptive analysis results for variables selected to capture the household characteristics of the surveyed households. One dummy and four continuous variables relating to demographic and educational characteristics of the households were used for the analysis. Sex of the head of the household is a dummy variable with value of one for male and zero for female. Similarly, the age of the head of the household in years was collected during the survey. The household size of the respondents was constructed using the adult equivalent conversion factor based on consumption calorie intake (EHNRI, 2000). Education level of the head and highest education level completed by an adult member of the household are used to measure literacy level of the respondents. The data for these variables were collected as 1 = illiterate, 2 = read and write, 3 = elementary school completed, 4 = high school completed, 5 = diploma completed, and 6 = first degree completed and above.

Table 5.1: Summary statistics of household characteristics for irrigation users and non-users

Variable and variable definition	Measure	Users (n=160)	Non-users (n=80)	p-value
Head of the household (1=male)	Dummy	0.95	0.98	0.20[1.61]
Age of the household head (year)	Continuous	46.95	43.58	0.038**
Household size in adult equivalent units	Continuous	5.61	5.09	0.024***
Education level of the head	Continuous	2.96	2.73	0.285
Highest education completed by an adult member of the household	Continuous	4.22	3.37	0.038**

****significant at 1 percent level, **significant at 5 percent level, Chi-square in square brackets*
Source: own calculation from survey data

As shown in the table, except for gender and education level of the head of the household there is statistically significant difference between the mean values of the two groups in terms of the age of the head (p = 0.038), household size (p = 0.024), and highest education level completed by an adult member of the household (p = 0.038). It can be concluded from the results that the farm households that have adopted irrigation agriculture are significantly older, have bigger household sizes, and have better literacy levels than the households that do not irrigate.

Farm Characteristics

Farm characteristics are important features to describe the farm households in the study area. In this regard, two variables are selected to represent farm characteristics and used for the analysis. The farm households in the study area grow several crops and accordingly portion their total landholding into different plots. In view of this, average land size per plot of the two household groups is considered for the analysis. To study the adoption and impact of irrigation, it is imperative to assess the land allocation to different crops. In this regard, cash crops namely sugarcane and *khat* are the major irrigated crops in the area. This necessitates the descriptive analysis of the share of the land covered in percentage by these irrigated cash crops as presented in Table 5. 2.

Table 5.2: Summary Statistics of farm characteristics for irrigation users and non-users

Variable and variable definition	Measure	Users (n=160)	Non-users (n=80)	p-value
Landholding per plot (ha)	Continuous	0.172	0.148	0.02**
Land covered by cash crop (percent)	Continuous	0.780	0.613	0.000***

****significant at 1 percent level, **significant at 5 percent level, Chi-square in square brackets*
Source: own calculation from survey data

The result indicates that the surveyed farm households have significant difference in the mean values of the variables selected to characterize their farm. The farm households with access to irrigation water have higher landholding per plot and larger share of their land covered with cash crop with $p = 0.02$ and $p = 0.000$, respectively. The significant difference in mean value of the land covered with cash crop can be attributable to the fact that irrigation agriculture in the area is practiced on cash crops and farmers with access to irrigation water tend to cover most of their land with cash crops.

Endowments and Assets

Labor endowment in adult equivalent units, size of landholding in ha, and household asset value in ETB (Ethiopian Birr) are selected to capture the status of the surveyed households in terms of assets and endowments. The variable labor endowment was constructed by converting all members of the household into adult equivalent units using conversion factors based on age and sex of the member. Landholding refers to the total land that the concerned household is entitled to use with evidence of a certificate from the concerned government office. Regarding the household asset value, the survey instrument included house, household equipment and furniture, jewelries, and car/motorbike etc. Then the values of these assets are aggregated to get the household asset value in ETB. The test results of the descriptive analysis are presented below in Table 5.3.

Table 5.3: Summary Statistics of Endowments for irrigation users and non-users

Variable and variable definition	Measure	Users (n=160)	Non-users (n=80)	p-value
Labor endowment	Continuous	3.86	3.26	0.003***
Landholding (ha)	Continuous	0.436	0.323	0.007***
Household asset value (ETB)	Continuous	66,709	26,928	0.000***

****significant at 1 percent level, **significant at 5 percent level, Chi-square in square brackets*
Source: own calculation from survey data

There is highly significant difference in mean value of the asset and endowments variables between irrigation users and non-users. The irrigation users have significantly higher labor endowment (p = 0.003), Landholding (p = 0.007), and Household asset value (p = 0.000). Field observation during the survey was also made on the housing conditions of the households which confirmed that users of irrigation are relatively better off than the non-users in this regard.

Income and consumption

Income and consumption levels of the surveyed households were also assessed through selected variables including farm income per ha in ETB, non-farm income in ETB, and total per adult equivalent food consumption expenditure in ETB. Farm income per ha was measured by aggregating the value of crops produced by the surveyed households and converting it in to per ha amounts in ETB. Non-farm income was measured by aggregating the income of the farm households' head from sources other than farming. The non-farm activities that were mentioned as the sources of the income include carpenter, guard for a school/factory, school teacher, health extension worker, small trade, and broker. Consumption expenditure was collected during the survey for variety of consumption items. The farm households were asked to retrieve the quantity and prices of the different food items they bought for consumption during the last month. Then the monthly amount is extrapolated into annual total food expenditure aggregated for all food items. Finally, the aggregated amount is divided by the adult equivalent household size (calculated based on conversion factor for calorie intake) to get the per adult equivalent food consumption expenditure for each observation. The test results for comparisons of the mean values of the income and consumption variables are presented in Table 5.4.

Table 5.4: Summary Statistics of income and consumption levels for irrigation users and non-users

Variable and variable definition	Measure	Users (n=160)	Non-users (n=80)	p-value
Farm income per ha (ETB)	Continuous	432,507	101,689	0.000***
Non-farm income (ETB)	Continuous	3,166	4,033	0.230
Food consumption expenditure (ETB)	Continuous	3965	2848	0.000***

****significant at 1 percent level, **significant at 5 percent level, Chi-square in square brackets*
Source: own calculation from survey data

As reported in the table, the farm households with access to irrigation water have significantly higher farm income with p = 0.000 than the non-user households. This significant difference has to do with the access to irrigation, which made the user households have multiple harvests (at least two) per year of the most lucrative cash crop named *Khat*. In addition, the access to better agricultural water also makes better quality harvest for the other crops like sugarcane resulting in better price at the market. Similarly, the total per adult equivalent food consumption expenditure is also higher for irrigation users than the non-users with p = 0.000. With farming being the main source of income in rural families, the possibility that the level of farm income translates into the level of consumption in the household is high.

Access to market and modern technology

The farm households' access to market and modern technology was also considered to be important factor to characterize the household groups for the purpose of this study. Three variables were selected to describe the surveyed households in this regard. Access to market was captured by the average distance of the nearest input/output market in km from the homestead of the surveyed households. Similarly, the access to modern agricultural technology was assessed through the aggregate amount of chemical fertilizer applied in kg per ha and the total cost of insecticide/herbicide used in ETB per ha. The test results are presented in Table 5.5.

Table 5.5: Summary Statistics of access to market and modern technology

Variable and variable definition	Measure	Users (n=160)	Non-users (n=80)	p-value
Distance of the local market (km)	Continuous	5.29	5.74	0.060**
Chemical fertilizer use per ha (kg)	Continuous	929.5	621.8	0.000***
Insect/herbicide use per ha (ETB)	Continuous	21.5	12.7	0.002***

****significant at 1 percent level, **significant at 5 percent level, Chi-square in square brackets*
Source: own calculation from survey data

As indicated in the table, the non-user households are relatively far from the market compared to the user households with p = 0.060. Chemical fertilizer applied per ha and cost of insecticide/pesticide applied per ha, on the other hand, is significantly higher for irrigation user farm households with p = 0.000 and p = 0.002, respectively. This is justifiable considering the general understanding that access to better water supply encourages the use of productivity enhancing inputs like fertilizer and insecticide/herbicides.

Institutional and information access related variables

The economic behavior of farm households can also be influenced by the ease of access for information and institutional setting that they operate in. To get full understanding of these aspects several variables were selected and included in the analysis (Table 5.6). Visit by extension agents during the last 6 months was included as a dummy variable to have idea on the access to important information on improved technology, weather condition, and better way of doing things. Moreover, dummy variables representing ownership of radio and mobile phone are also included in this category to have understanding of the level of access of the households for networks and information. The level of scarcity as perceived by the surveyed households was another factor which is included as a variable to capture the level of water scarcity faced by the different groups of the households. Similarly, households were asked several questions regarding the current management and governance of the irrigation scheme. (1) How much they agree/disagree that the prevailing water scarcity is created mainly by mismanagement, (2) what measures they are taking to get more water, (3) what is the role of WUA committee in this regard.[4] The first variable is measured on Likert's scale while the other two are constructed by grouping responses of the farmers in to five/four and assigning score depending on the level of implication to the existence of poor governance.

Table 5.6: Summary Statistics of institutional and information access related variables for irrigation users and non-users

Variable and variable definition	Measure	Users (n=160)	Non-users (n=80)	p-value
Visit by extension agent during last 6 months (Yes = 1, No = 0)	Dummy	0.88	0.87	0.776[0.08]
Ownership of radio (Yes=1, No = 0)	Dummy	0.63	0.46	0.013[6.21]***
Ownership of mobile phone (Yes = 1)	Dummy	0.66	0.35	0.000[21.12]***
Level of scarcity (highly scarce = 1, Not scarce = 0)	Dummy	0.50	0.97	0.000[52.41]***
Mismanagement of the scheme	Ordinal	4.3	4.9	0.000[33.68]***
Measures/Actions to get more water	Ordinal	3.41	3.3	0.000[42.99]***
Role of WUA committee	Ordinal	3.5	3.7	0.12[5.71]

****significant at 1 percent level, **significant at 5 percent level, Chi-square in square brackets*
Source: own calculation from survey data

[4] *Please look at the codes in the appendix*

As presented in Table 5.6, except for visit by extension agents all the other variables have significantly different values for irrigation users and non-user groups. Significantly a greater number of farm households from those who use irrigation water own radio and mobile phones implying better access to information and networking with fellow farmers. Regarding water scarcity, significantly higher numbers of non-user farm households perceive that there is high water scarcity compared to the users.

The last three variables are included to assess the institutional setting and governance situation of the scheme. Accordingly, for the first variable both groups agree that the prevailing water scarcity is mainly created by mismanagement. However, the households who currently do not have access to irrigation water strongly agree on the claim; there is highly significant difference on the mean value of the score to the variable. The test for the second variable also shows highly significant difference between users and non-users. The mean value of the score for this variable is higher for users implying that they are getting water through actions that indicate existence of poor governance like bribing the committee. The responses for third variable are measured on a scale of one to four and the highest score is assigned to the category of responses, which implied the highest relevance to the existence of poor governance. The mean result for the variable is closer to four for both the users and non-users indicating existence of poor governance. It is worth to mention that a score of 4 is given to responses which finally are rephrased in to “Distribute the existing water fairly and avoid corruption. It is important to note that the same situation was aired in the FGDs undertaken for additional data (see section 4.1: study context). A similar result was found by a study undertaken in Southern Ethiopia where farmers rated fairness of water allocation by WUA as ‘poor' (YAMI, 2013).

5.1.2. Characterization of upstream, middle-stream, and downstream households

One-way ANOVA test using Tukey post hoc test was undertaken to determine if there is significant difference in the mean of the variables of interest among the three household groups. Besides, to verify the results of the one-way ANOVA test we also undertook a non-parametric test using Krushkal-Wallis test. We found out that there is no difference in the results regarding the significance of the test for all the variables except for variable distance to the nearest input/output market. The results of the one-way ANOVA test and other tests are presented in tables under each sub-section.

Household Characteristics

Household characteristics of farmers are important in understanding their production, consumption, and resource allocation behavior. It would also be vital in guiding policy recommendation later in the process. To this end, important continuous variables were used to shed light on the demographic characteristics of the three household groups. Table 5.7 presents the results of a one-way ANOVA test for the three groups of households.

Table 5.7: One-way ANOVA test result for household characteristics

Variable	Total Sample Mean (SD)	Mean (SD)			ANOVA test F(p)
		U (n=80)	M (n=80)	D (n=80)	
Age	45.82(13.9)	45.52(15.02)	48.37(12.5)	43.58(13.8)	2.42(0.09)*
Level of Schooling completed by head	2.88(2.9)	2.7 (3)	3.22(2.8)	2.73(2.9)	0.81(0.44)
Highest schooling completed by adult member	3.94(3.5)	3.65(3.52)	4.8(3.6)	3.37(3.28)	3.79(0.02)**
Household size in Adult Equivalent	5.44(1.9)	5.32(1.82)	5.90(2.1)	5.09(1.72)	3.88(0.02)**

Note: standard deviation in parenthesis

**Significant at 10 percent level, ** Significant at 5 percent level, ***Significant at 1 percent level*

Source: Own calculation using survey data

The total sample mean age, level of schooling by the head, highest level of schooling by an adult member, and family size in adult equivalent unit are 45.82 years, elementary school completed, high school completed, and 5.44 persons, respectively. As presented in Table 5.7, there is statistically significant difference in the mean value of the age, level of literacy of an adult member, and size of the households among the three groups with ANOVA test result of $F = 2.42$ ($p = 0.09$), $F = 3.79$ ($p = 0.02$), $F = 3.88$ ($p = 0.02$).

It is also important to determine how the mean value of the variables for each group differs from the other. To this end, Tukey post hoc test has been carried out and the result is presented in Table 5.8.

Table 5.8: Tukey post hoc test for household characteristics

Variable	Tukey t(p)		
	M vs U	D vs U	D vs M
Age	1.30(0.395)	-0.89(0.650)	-2.19(0.075)*
Level of Schooling completed by head	1.14(0.493)	0.07(0.997)	-1.06(0.540)
Highest schooling completed by adult member	2.10(0.093)*	-0.50(0.871)	-2.60(0.027)**
Household size in Adult Equivalent Units	1.95(0.127)*	-0.74(0.738)	-2.70(0.021)**

**Significant at 10 percent level, ** Significant at 5 percent level, ***Significant at 1 percent level*

Source: Own calculation using survey data

Households located in the middle-stream section of the scheme have significantly higher age, highest education level of an adult member, and family size compared to the households located in upstream and downstream as indicated by the Tukey test result in Table 5.8. All the three household groups, however, have no significant difference on level of schooling completed by the head of the household.

Farm characteristics

Table 5.9 shows two continuous variables used to characterize the farm of the surveyed households. The total sample mean for landholding per plot and percentage share of landholding covered with cash crop is 0.16 ha and 72 percent, respectively.

Table 5.9: One-way ANOVA test results for variables of farm characteristics

Variable	Total Sample Mean (SD)	Mean (SD)			ANOVA test F(p)
		U(n=80)	M(n=80)	D(n=80)	
Landholding per plot (ha)	0.16(0.91)	0.15(0.06)	0.18(0.11)	0.14(0.07)	4.23(0.01)***
Percentage share of cash crop from total land	0.72(0.31)	0.81(0.22)	0.74(0.19)	0.61(0.43)	8.96(0.0002)***

*Note: standard deviation in parenthesis. ***Significant at 1 percent level*
Source: Own calculation using survey data

The one-way ANOVA test results in Table 5.9 show that the three household groups have significant difference among each other in the mean value for Landholding per plot and percentage of their landholding covered with cash crop as evidenced by ANOVA test result of F = 4.23 (0.01) and F = 8.96 (0.0002), respectively.

Further post hoc test was undertaken to identify how the mean value of the variables of each household group differs from the other group. The results of the tests are presented in Table 5.10.

Table 5.10: Tukey post hoc test result of farm characteristics variables

Variable	Tukey t(p)		
	M vs U	D vs U	D vs M
Landholding per plot (ha)	2.09(0.09)*	-0.71(0.757)	-2.80(0.01)***
Percentage share of cash crop from total land	1.30(0.394)	-4.14(0.000)***	-2.84(0.014)***

**Significant at 10 percent level, ** Significant at 5 percent level, ***Significant at 1 percent level*
Source: Own calculation using survey data

As reported in the table, households in the middle-stream have significantly higher land size per plot compared to both households in the upstream and downstream. Regarding percentage share of land covered with cash crop, the downstream households have significantly lower mean value compared to both upstream and middle-stream households. It is important to note that irrigated agriculture in the area is mainly practiced on the cash crops. The households that have access to irrigation water, on the other hand, are from the upstream and middle-stream part of the scheme. Hence, the downstream households who do not have access to irrigation water prefer to cover larger share of their land with other crops as compared to households who have access to irrigation water.

Endowments and assets

In this section three continuous variables are selected to characterize the farm households in terms of their endowments and assets. As reported in Table 5.11, the total sample mean for landholding, labor endowment, and household assets value is 0.39 ha, 3.66 adult equivalent units, 53,448 ETB, respectively.

Table 5.11: One-way ANOVA test result for Variables of Endowment

Variable	Total Sample Mean(SD)	Mean (SD)			ANOVA test F(p)
		U(n=80)	M(n=80)	D(n=80)	
Landholding (ha)	0.39(0.34)	0.33(0.19)	0.53(0.48)	0.32(0.21)	11.1(0.000)***
Labor endowment	3.66(1.6)	3.68(1.66)	4.05(1.80)	3.26(1.41)	4.64(0.01)***
Household assets	53448(38432)	64503(35330)	68914(40434)	26927(22520)	3.88(0.02)**

Note: standard deviation in parenthesis
**Significant at 10 percent level, ** Significant at 5 percent level, ***Significant at 1 percent level*
Source: Own calculation using survey data

As evident from Table 5.11, there is statistically significant difference in mean values of the variables among the three household groups. The ANOVA test result shows $F = 11.14$ ($p = 0.000$), $F = 4.64$ ($p = 0.01$), and $F = 3.88$ ($p = 0.02$) for landholding, time endowment, and household asset value, respectively.

We also undertook a further post hoc test to see how the mean value of the variables for each group differs from the other. Table 5.12 reports the Tukey post hoc test results for the three variables.

Table 5.12: Tukey post hoc test results for endowment variables

Variable	Tukey t(p)		
	M vs U	D vs U	D vs M
Landholding (ha)	3.98(0.000)***	-0.21(0.977)	-4.19(0.000)***
Labor Endowment	1.41(0.338)	-1.64(0.233)	-3.04(0.007)***
Household assets	0.83(0.685)	-7.07(0.000)***	-7.90(0.000)***

**Significant at 10 percent level, ** Significant at 5 percent level, ***Significant at 1 percent level*
Source: Own calculation using survey data

Regarding landholding the middle-stream household groups have significantly higher land holding than the other two. Similarly, the middle-stream households have significantly higher time endowment when compared to downstream household groups. The other variable is the household asset value for which the downstream household groups have significantly less mean value as compared to both upstream and middle-stream households. As mentioned in the previous sections direct observation during field visit also confirmed the same where we had witnessed the housing conditions of the upstream and middle-stream households to be way better than downstream households.

Income and Consumption

Several income and consumption variables were also considered in the characterization of the farm household groups included in the study. In this regard, farm income per ha, non-farm income, and per adult equivalent consumption expenditure were selected as relevant variables. The results of the one-way ANOVA test for the three variables are presented in Table 5.13. The total sample mean for farm income per ha, non-farm income, and food consumption expenditure are 322,234 ETB, 3,454 ETB, and 3,592.58 ETB, respectively.

Table 5.13: One-way ANOVA test results for variables of income and consumption (ETB)

Variable	Total Sample Mean (SD)	Mean (SD)			ANOVA test F(p)
		U(n=80)	M(n=80)	D(n=80)	
Farm income/ha	322234(259381)	480154(289080)	384859(194165)	101688(61565)	74(0.000)***
Non-farm income	3454(8559)	2857(9352)	3473(8386)	4033(7947)	0.38(0.68)
Food consumption expenditure	3592(1233)	3985(984.99)	3944(1257)	2848(1079)	26(0.000)***

Note: standard deviation in parenthesis

**Significant at 10 percent level, ** Significant at 5 percent level, ***Significant at 1 percent level*

Source: Own calculation using survey data

As reported in Table 5.13, there is statistically significant difference in the mean values of farm income per ha and per adult equivalent food consumption expenditure among the three household groups with test result of F = 74.37 (p = 0.000) and F = 26.54 (p = 0.000), respectively. The households, however, do not have significant difference in mean value of non-farm income.

It is also an important input in the analysis to identify how the mean values of the variables for one household group differs from the other. The post hoc test result is presented in Table 5.14.

Table 5.14: Tukey post hoc test results for income and consumption variables

Variable	Tukey t(p)		
	M vs U	D vs U	D vs M
Farm income per ha	-2.95(0.010)***	-11.72(0.000)***	-8.77(0.000)***
Non-farm income	0.45(0.893)	0.87(0.662)	0.41(0.911)
Consumption expenditure	-0.23(0.971)	-6.42(0.000)***	-6.19(0.000)***

**Significant at 10 percent level, ** Significant at 5 percent level, ***Significant at 1 percent level*

Source: Own calculation using survey data

As presented in Table 5.14, the Tukey post hoc test indicates that upstream household groups have significantly higher farm income compared to the other two while downstream household groups have significantly lower farm income compared to both upstream and middle-stream household groups. Similarly, the downstream farm household groups have significantly lower per adult equivalent consumption expenditure compared to both upstream and middle-stream household groups.

Access to market and modern technology

The level of access to market and modern technology plays important role in shaping production, consumption, and resource allocation decisions of farm households. To this end three variables were selected to describe the farm household groups including distance of local markets from the homestead in km, amount of chemical fertilized applied in kg, and cost of insecticide/herbicide used in ETB. The total sample mean for Distance of the local market, amount of chemical fertilizer applied per ha, and cost of insecticide/herbicide applied per ha is 5.44 km, 826.92 kg, and 90.29 ETB, respectively. The one-way ANOVA test result for the three variables is presented in Table 5.15.

Table 5.15: One-way ANOVA test results for variables of access to market and modern technology

Variable	Total Sample Mean (SD)	Mean (SD)			ANOVA test F(p)
		U (n=80)	M (n=80)	D (n=80)	
Distance of the local market (km)	5.44(2.14)	5.07(1.76)	5.50(2.30)	5.74(2.28)	2.01(0.136)
Chemical fertilizer use per ha (kg)	826 (580.7)	808(639.7)	1050(582.9)	621(421)	11.98(0.000)***
Insect/herbicide use per ha (ETB)	90(120.25)	101(109.3)	94(147.97)	75(97.6)	1.00(0.368)

Note: standard deviation in parenthesis

**Significant at 10 percent level, ** Significant at 5 percent level, ***Significant at 1 percent level*

Source: Own calculation using survey data

As presented in Table 5.15, there is significant difference among the farm household groups in the amount of fertilizer applied with one-way ANOVA test result of F = 11.98

(p = 0.000). There is, however, no significant difference in the mean value of the other two variables among the farm household groups.

Tukey post hoc test was also undertaken to see how the mean value of the variables for each household differs from the other. Table 5.16 reports the results of the analysis.

Table 5.16: Tukey post hoc test results for access to market and modern technology variables

Variable	Tukey t(p)		
	M vs U	D vs U	D vs M
The distance of the local market (kms)	1.26(0.419)	1.98(0.119)	0.72(0.751)
Chemical fertilizer use per ha (kg)	2.76(0.01)***	-2.12(0.08)*	-4.88(0.000)***
Insect/herbicide use per ha (ETB)	-0.38(0.922)	-1.37(0.357)	-0.99(0.586)

**Significant at 10 percent level, ** Significant at 5 percent level, ***Significant at 1 percent level*
Source: Own calculation using survey data

The Tukey post hoc test also confirms that there is significant difference in the mean value of the amount of chemical fertilizer applied among the farm household groups. It also helped us determine how each group differs from the other. As presented in Table 5.16, the households from the middle-stream on average applied significantly more chemical fertilizer than both the upstream and downstream households. The amount of chemical fertilizer applied by downstream household groups, on the other hand, is significantly lesser when compared to the other two household groups.

Other agricultural inputs used

Understanding how farm households allocate resources for crop production helps to later see the impacts of different policy scenarios on their allocation decision. In addition to the inputs described in the previous sections four more variables are selected to create better understanding of the study context. One of the important inputs in agricultural production is labor which may come from own family or hired. In view of this we have collected labor hours invested in crop production both hired and own of the surveyed households. The labor hour data was collected for all crop production steps including land preparation, planting, fertilizing, crop protection, irrigating, weeding and harvesting, and post-harvest. For all the steps both own labor and hired labor invested data was collected separately and converted in to per ha amounts. Another important variable considered for this study is crop water use in cubic meters. The data for this variable was collected by directly measuring the quantity of water applied to each farm during the actual irrigation season. The quantity of the water applied to each farm was measured using appropriate techniques by qualified individuals. The other important input used in crop production is organic fertilizer called compost. Farm households in the study area apply compost to all the crops except for maize. Accordingly, the aggregated quantity of compost applied by each household group is described below.

Table 5.17: One way ANOVA test result for other agricultural inputs

Variable	Total Sample Mean (SD)	Mean (SD)			ANOVA test F(p)
		U(n=80)	M(n=80)	D(n=80)	
Hired labor hour per ha	774(887.8)	979(822.2)	880(934.37)	432(792)	20.5(0.000)***
Own labor hour per ha	1812(843.2)	1883(713)	1967(944.60)	1544(764)	13.7(0.000)***
Water applied (m^3/ha)	4417(4853)	7282(4404)	5614(4706)	0.00	177(0.000)***
Compost applied per ha	12634(16478)	15365(18565)	13996(18511)	8143(8942)	9.9(0.000)***

Note: standard deviation in parenthesis
**Significant at the 10 percent level, ** Significant at 5 percent level, ***Significant at 1 percent level*
Source: Own calculation using survey data

The one-way ANOVA test was undertaken to determine if there is significant difference on mean value of the aforementioned variables and the test results are given in Table 5.17 above. The total sample mean hired labor hours, own labor hours, water applied, and compost applied is 774.63 hrs. per ha, 1,812.85 hrs. per ha, 4,414.84 m^3 per ha, and 12,634 kg per ha, respectively. As indicated in table, the ANOVA test results show that the mean value of all the four variables is significantly different among the three household groups. The mean value of hired labor hours, own labor hrs., quantity of water applied, and quantity of compost applied differ significantly among the three groups of households with F = 20.50 (p = 0.000), F = 13.75 (p = 0.000), F = 177.1 (p = 0.000), and F = 9.94 (p = 0.000), respectively.

It is also important to know how each household group differs from the other in mean values of these relevant variables. To this end, Tukey post hoc test has been used and the results of the analysis are presented in Table 5.18.

Table 5.18: Tukey post hoc test results for other inputs used

Variable	Tukey t(p)		
	M vs U	D vs U	D vs M
Hired labor hour per ha	-1.14(0.493)	-5.96(0.000)***	-5.15(0.000)***
Own labor hour per ha	1.01(0.570)	-3.84(0.000)***	-5.06(0.000)***
Water use in m^3 per ha	-4.33(0.000)***	-17.85(0.000)***	-14.52(0.000)***
Compost use in kg per ha	-0.84(0.681)	-4.16(0.000)***	-5.56(0.001)***

**Significant at 10 percent level, ** Significant at 5 percent level, ***Significant at 1 percent level*
Source: Own calculation using survey data

The Tukey post hoc test result for hired labor hrs. indicates that the downstream household groups hire significantly less labor than the other two groups. Similarly, the downstream households invest significantly less own labor hours than both upstream and middle-stream households.

Production patterns and water consumption characteristics

Characterizing the production and water consumption patterns based on the survey data enables us to envision the effects of different simulation on the productions of Khat and sugarcane and so on. It is known that the amount of irrigation water used in the upper and lower stream households depends on the type of crop produced, the size of available irrigated land and the relative power of accessing water. Households, as rational economic entity, decide what to produce taking into account their location, water availability, nature of their land and profitability of the crop. In the same token, the availability of irrigable land determines the amount of irrigation water used by households across the course of the stream.

The results from the baseline data shows that the total land size allocated for different crops in the three basin of the river differs. From the total land, nearly half of it goes to the production of Khat in the upper basin while the figure goes as low as 24 percent in the downstream part of the river while the 30 percent of the land has been allocated to Khat in the middle part of the river. Comparably, the amount of land allocated for irrigation is the highest in the upper parts of the river where the share of irrigated land from the total land goes as high as 82 percent but the figure is only 36 percent in the lowest part of the river. In the meantime, from the total irrigated land, the share of land allocated to Khat decreases along the course of the river. This is related to the ease availability of water. Table 5.19 summarizes patterns of land allocation to different crops along the course of the river.

Table 5.19: Pattern of land in ha and crop allocation

	Sugarcane	*Khat*	Maize	Enset	Total land
Upper	0.35	0.47	0.08	0.10	25.96
Middle	0.43	0.30	0.16	0.11	40.4
Down	0.12	0.24	0.17	0.09	25.26

Source: Own computation (own survey)

Water allocation

Water is a scarce resource and its allocation across different crops differs depending on the water requirement of the crops. As shown in Table 5.20, from the total water allotted for irrigation, 72 percent of it goes to sugarcane in the upper stream while the rest 28 percent goes to Khat. The figure is more or else the same in the middle stream where the amount of irrigation water goes to sugarcane is 74 percent and the rest 26 percent is allocated to Khat. Those households living in the lowest part of the stream, they do not have water left for irrigation.

Table 5.20: Pattern and share of Water allocation

	Sugarcane	***Khat***	**Maize**	**Enset**
Upper	0.72	0.28	-	-
Middle	0.74	0.26	-	-
Down	-	-	-	-

Source: Own computation (2018)

The other issues related to water allocation is fairness of water availability across the stream of the river. This is basically linked to the amount of water distributed to the three parts of the river. It is clear that those households on the upper parts of the stream have advantages of using more water because of their location. The rest of the farmers in the middle and lower part of the scheme can only use what is left from the upstream farmers if there is no any established rule of law that governs the way the irrigation water is used along the courses of the river. The results reveals that the distribution of water is different across the streams. From the total water allocated for sugarcane, 74 percent of it has been used in the upper stream households while the remaining 26 percent has been used by middle stream households. The same also holds true for *Khat*. From the total water allocated to *Khat*, 78 percent of it has been consumed by upstream households while the rest 22 percent has been used by middle stream households. In all cases, no water has been used by downstream households.

Table 5.21 depicts that the amount of water allotted per ha varies across the courses of the stream. The amount of water in a ha of land for sugarcane production for upper stream households is 28.87 thousand litters while the figure is as low as 4.74 for the middle stream households. The same pattern has been observed for *Khat* production. The amount of water allocated for sugarcane production in the middle stream households is 8.3 thousand litters. The amount of water allocated for a ha of land for *khat* production is 2.38 thousand litters of water. The cases mentioned so far have clearly indicated that the upper stream households use more water per ha than the lower stream households in both agricultural activities. This entails that the upper stream households use their location advantage to use more water.

Table 5.21: Water allocation in thousands of cubic meters per ha per crop

	Sugarcane	Khat
Upper stream	28.87	8.30
Middle stream	4.74	2.38
Down stream	-	-

Source: Own computation

5.2. Results of the ESR model [5]

This section presents the results of the ESR model. We believe that it is worthwhile to examine the poverty situation of the surveyed households and to that end we undertook poverty analysis using Foster-Greer-Thorbecke (FGT) indices. The determinants of adoption of irrigation and the impact of irrigation on welfare of the surveyed households were estimated considering to outcome variables: Farm income per ha and per adult equivalent annual food consumption expenditure.

5.2.1. Poverty Analysis

The level of poverty between irrigation water users and non-users was tested using Foster-Greer-Thorbecke (FGT) indices. Based on the recommended daily energy requirement of the 2,100 Kcal Poverty line (Z) of Birr 3,329.27 (= USD 123.30) per adult equivalent per year is used to estimate the FGT indices of poverty. The poverty line was constructed using food and non-food per adult equivalent consumption expenditure of the households. Table 5.22 shows the results.

Table 5.22: FGT indices on consumption

Poverty estimates	Groups	
	Users	Nonusers
Incidence	0.28	0.67
Depth	0.03	0.18
Severity	0.008	0.06

Source: computation from own survey date

Note: α=0, 1, and 2 and Z= ETB 3,329.27

The incidence of poverty is measured by the headcount index and shows that 67 percent of the households who do not have access to irrigation fall below the consumption-based poverty line (Z) of ETB 3,329. On the other hand, only 28 percent of the farmers who irrigate are below the poverty line. This result reinforces the claim by several studies that prevalence of poverty is higher in rainfed areas than irrigated areas (BACHA *ET AL*., 2011; HANJRA *ET AL*., 2009; WOOD *ET AL*., 2004). The depth and severity of poverty are also higher among the non-users. The consumption expenditure of the non-users should be pushed up by 18 percent of its current amount if they have to be lifted out of poverty while it takes only 3 percent for users. These results are in

5 The result of this part of the manuscript has been published as Adela, Aurbacher and Gumatawu (2019) entitled "Small-scale irrigation scheme governance poverty nexus: Evidence from Ethiopia" in "Food Security: The science, Sociology and Economics of Food production and Access to Food" 2019, vol 11, issue 4, No 10,897-913.

line with most micro level empirical studies on poverty and irrigation linkage. BACHA *ET AL*. (2011), for instance, found out that depth of poverty among non-irrigation users in Ambo district (Western Ethiopia) at 21 percent while it is only 10 percent among users.

5.2.2. ESR model estimation results

Consistent with the descriptive and poverty analysis above there is a significant difference between the users and nonusers in several relevant variables and welfare indicators. These differences could be due to several observable and unobservable factors in addition to differential access to irrigation. Two outcome variables were used as a proxy for the welfare of the households: Farm income per ha and/or per adult equivalent food consumption expenditure. Such indicators have been frequently used in past studies to measure welfare (AMARE *ET AL*., 2012; BRAVO-URETA *ET AL*., 2006; SHIFERAW *ET AL*., 2014).

Table 5.23 presents the estimation results for the model with farm income per ha as the outcome variable. The second column of the table reports the estimates for the determinants of the decision to irrigate. Education and age have a positive non-significant association with the irrigation decision of the farmers. Generally, education tends to have a positive association with new technology adoption among farmers because of better access to and comprehension of information on the technologies (NORRIS & BATIE, 1987).Studies have indicated a positive relationship between education and age and adoption of a new technology (DERESSA, HASSAN, RINGLER, ALEMU, & YESUF, 2009; LIN, 1991; NHEMACHENA & HASSAN, 2007) while others found out a negative association between these variables (SHIFERAW & HOLDEN, 1998). HUFFMAN (2001), however, argues that when an intervention has been there for relatively long time, education and experience may not significantly affect the decision to participate. This reinforces the above positive but non-significant result considering irrigation has been practiced in the study area for at least the last 30 years.

Table 5.23: Full information maximum likelihood estimates of the switching regression model for farm income per ha

Variables	Model Estimates		
	Irrigation 1/0	Users	Non-users
Highest education of adult member	0.023(0.64)	-0.018(1.58)*	0.004(0.21)
Age of the household	0.011(1.23)	-0.003(0.89)	0.002(0.33)
Log of distance to the nearest market	-0.001(0.03)	-0.021(1.09)	-0.040(1.21)
Visit by extension workers	0.078(0.24)	0.198(1.61)*	0.178(0.84)
Log of landholding	0.434(1.34)	0.415(3.73)***	0.578(2.45)***
Log of landholding per plot	-0.441(1.08)	-0.267(1.95)**	-0.652(2.33)***
Log of percentage of land covered by cash crop	1.27(3.48)***	0.423(3.10)***	-0.295(1.39)
Log of time endowment in adult equivalent units	-0.003(0.01)	0.019(0.19)	0.110(0.53)
Log of non-farm income	-0.096(2.80)***	-0.001(0.09)	0.046(2.51)***
Log of chemical fertilizer applied	0.115(0.86)	0.202(3.81)***	0.095(1.18)
Log of pesticide applied	0.092(1.09)	0.149(4.09)***	0.142(2.61)***
Owned radio(Yes=1)	0.594(2.50)***		
Owned mobile phone (Yes=1)	0.959(4.02)***		
Perceived water scarcity (High=1)	-1.911(5.10)***		
Mismanagement of the scheme	-0.846(3.35)***		
Measures/Actions to get more water	0.149(1.85)**		
Role of WUA committee	-0.330(2.12)**		
Constant	4.49(2.48)***	11.40(27.15)***	9.31(12.51)***
ρ_1, ρ_2		-0.822[0.115]	-0.518[0.232]
Model diagnosis			
Wald x^2	115.40**		
Log-likelihood	-255.09		
LR test of independence	19.76***		

Note: Absolute value of z statistics in parenthesis standard errors in square brackets
**Significant at 10 percent level, ** Significant at 5 percent level, ***Significant at 1 percent level*
Source: Own calculation using survey data

Land covered by cash crops has a positive impact on the decision to irrigate. Therefore, households with a larger share of their land covered by cash crops are more likely to irrigate than others with less proportion of land covered by cash crops. In fact, the most important cash crops in the study area, sugarcane and *Khat*, are the ones that irrigation is widely practiced on. Land size per plot, on the other hand, has a negative effect on the decision to irrigate. This is possibly because farmers with smaller plots can only increase their production through intensification such as the adoption of irrigation. Previous studies find mixed results on the association of land size and agricultural technology adoption (BRADSHAW *ET AL*., 2004; DERESSA *ET AL*., 2009; KHONJE *ET AL*., 2015).

Similarly, time endowment shows a negative association with the decision to irrigate. This can be attributable to the high population density and land fragmentation in the study area. This result is consistent with a study in Ethiopia (TIZALE, 2007) but different from another study that showed a positive association between labor endowment and adoption decision (DERESSA *ET AL*., 2009). In southern Ethiopia, however, the rural youth is forced to search for other livelihood options because of the scarcity of agricultural land (Bezu & Holden, 2014). It is worth noting that, the average land holding of the surveyed households is 0.4 ha which is significantly less than the national Average of 1.37 ha (CENTRAL STATISTICAL AGENCY & WORLD BANK, 2013).

Non-farm income has a negative and significant impact on the practice of irrigation. This result is reinforced by the findings of WOZNIAK (1984) that participation in non-farm activities may constrain the amount of labor hour available for farm activities. The variables representing the amount of chemical fertilizer and pesticide applied show positive relationship. This is because farmers who irrigate tend to use modern inputs to enhance productivity. It is commonly argued that stable supply of agricultural water would encourage farmers to invest on productivity-enhancing inputs (ABERRA, 2004).This result is in keeping with previous studies(GEBREGZIABHER *ET AL*., 2009; NAMARA *ET AL*., 2010; SMITH, 2004). Variables for access to information and networks (proxied by ownership of a radio and mobile phone), perceived level of scarcity, and scheme governance (proxied by three variables) were used in the selection equation but not in the outcome equation. This is because a correct specification of the model requires the inclusion of at least one explanatory variable in the former which directly affects the irrigation decision but not the outcome variable (ABDULAI & HUFFMAN, 2014; KHONJE *ET AL*., 2015). Estimates for ownership of radio and mobile phone variables are positive and significantly different from zero. BANDIERA & RASUL (2006) found out similar result in their study that farmers' decision to participate in an intervention is influenced by family and friends. Interestingly, farmers' perception about the scarcity of water in their area is negatively and significantly correlated with the likelihood of irrigation water use. This is also supported by previous studies from developing countries, including Ethiopia (HANJRA *ET AL*., 2009B; NAMARA *ET AL*., 2010).

Institutional related variables are the main focus of this study and are used to capture issues related to scheme governance and allocation of water in the area. These variables were constructed based on responses of households to three questions. All the three variables are measured in an ordinal scale. One of these variables is measured by the

Likert's scale. For the remaining two the responses to the open-ended questions were categorized in to similar groups of five and four each. Then, the responses were given a score depending on the level of implication to the poor governance. For instance, score of five is assigned for a response with relatively highest indication of poor governance. The first variable in this category is a direct question inquiring how much the respondents agree/disagree on the claim that the water scarcity that the farmers are facing is created more of by mismanagement of the scheme as opposed to physical scarcity of water. As indicated in the table, the variable has a strong negative association with the decision to irrigate implying that mismanagement of the scheme is creating more scarcity and is excluding some farmers from being users of the irrigation water.

Similarly, the second variable 'actions/measures to get more water was constructed from responses of farmers to the question how they are adapting to the water scarcity. As reported in the table, the adaptive mechanism has strong and positive impact on the decision to irrigate. The more the adaptive mechanism or action to get more water relate to poor governance (like bribing the committee) the more the farmers tend to irrigate. The third variable in this group probes respondents on the role of the WUA's committee in this regard. The result indicates that the role of WUA's committee has a strong negative impact on the decision to irrigate. The descriptive analysis also confirms the same regarding the issue of scheme governance. Hence, mismanagement of water by WUA, unfair distribution, corruption, and inefficient use of water by upstream users are the key sources of poor irrigation scheme governance in the study area. The farmers' decision to irrigate is highly affected by their perception about the irrigation scheme governance. This is also in keeping with past studies that show poor governance as key factor for most of the water scarcity problem in SSA (BELAY & BEWKET, 2013; CTA, 2011; DUDU & CHUMI, 2008). One such a problem is excessive abstraction of water by upstream users (ABERRA, 2004; AMEDE, 2015). Indeed, the econometric analysis has confirmed the findings from the FGDs.

The correlation coefficients ρ_1 and ρ_2 show that they are statistically significant for both users and non-users, indicating the existence of self-selection. The estimate is also negative for both users and non-users indicating positive selection bias such that farmers with above-average farm income tend to decide to irrigate. The likelihood ratio test is also significant indicating the existence of joint dependence between the outcome and selection equation between users and non-users.

The model estimates of the variables against farm income per ha for users and non-users are presented in the third and fourth column of Table 5. 23. Education shows a negative and statistically significant result for users. DI FALCO *ET AL*. (2011) found similar results for literacy and production per ha in Ethiopia. The adult members of the households with a higher level of education tend to involve in nonfarm employment.

This, in turn, suppresses the farm income because the time allocated to farm activities will be less. Distance to local markets also negatively and significantly affects the farm income per ha for both users and non-users. The proxy variable measuring advice and information received from agricultural extension agents shows a positive association with farm income for both users and non-users. This is in line with the theory that farmers with better information and advice from extension agents are likely to have better productivity (ABDULAI & HUFFMAN, 2014).

Landholding has a positive and significant impact on the outcome variable for both users and non- users. This is consistent with an earlier study in Ethiopia (BELAY & BEWKET, 2013). On the contrary, landholding per plot has a negative and significant impact on farm income per ha for both users and non-users. This may be due to an inverse farm size-productivity relationship. Past studies have proved that small farms are more productive than big farms (ABDULAI & HUFFMAN, 2014). A study in Ethiopia also found that land pressure is strongly associated with crop yield and income proving the holding of Boserup's hypothesis (HEADEY *ET AL*., 2014). The amount of non-farm income has a positive and significant impact on the farm income of the non-users. This is because the income from non-farm sources can be invested to purchase productivity-enhancing inputs like fertilizers and improved crop varieties (ABDULAI & HUFFMAN, 2014). The amount of chemical fertilizer and insect/herbicide applied has a positive association with farm income of both users and non-users, with highly significant impact on farm income of only users.

The proportion of farm covered by cash crops also has a significant positive and non-significant negative impact for users and non-users, respectively. Users harvest *khat*, one of the most traded cash crops in the area, at least twice per year (mostly three times). The non-users, on the other hand, harvest this crop only once per year because they rely on rainwater. Regarding sugarcane, the non-users complain about quality and yield compared to those exposed to adequate water. Since these two crops are cash crops and the main source of farm income, as the share of farm covered by cash crops increase the farm income per ha of the non-users decreases significantly while it increases for the users. The strong correlation between the share of irrigable land and cash income was also confirmed by a study on small-scale irrigation in other parts of the country (AMEDE, 2015). Model estimation was also carried out using the total per adult equivalent food consumption as the dependent variable. Table 5.24 presents the model estimates.

Table 5.24: Full information maximum likelihood estimates of the switching regression model for the total per adult equivalent food consumption

Variables	Model Estimates		
	Irrigation 1/0	Users	Non-users
Log of farm income	1.55(5.75)***	0.075(2.16)**	0.061(0.87)
Highest education in the household	-0.013(0.28)	0.001(0.23)	0.002(0.29)
Age of the household head	0. 013(0.91)	2.6 e-05 (0.02)	4.2-04(0.16)
Log of landholding	-0.919(2.07)**	0. 033(0.65)	0. 060(0.83)
Log of land allocated to cash crop to food crop	0. 394(1.20)	0. 032(0.93)	0. 056(1.15)
Log of adult equivalent household size	-0.559(1.23)	-0.36(7.26)***	-0.59(5.81)**
Log of productive adult equivalent labor to total adult equivalent household size	-0.123(0.17)	-0.21(2.69)***	-0.157(0.94)
Log of non-farm income	-0.036(0.90)	-0.001(0.25)	0. 02(2.26)**
Log of value of household asset	0.19(2.63)***	0.034(3.13)***	0. 029(1.73)*
Log of number of visit by extension officers	-0.254(1.68)*		
Owned radio (Yes=1)	-0.208(0.65)		
Owned mobile phone (Yes=1)	0. 575(1.70)*		
Scarcity level (high= 1; Low=0)	-.355(2.86)***		
Mismanagement of the scheme	-.18(3.34)***		
Measures/Actions to get more water	0.145(1.17)		
Constant	-.609(3.58)***	7.66(15.60)***	8.06(9.92)***
ρ1, ρ2		0. 35[0.250]	0. 34[0.459]
Model diagnosis			
Wald x2	81.59***		
Log-likelihood	-35.77		
LR test of independence	2.03*		

Note: Absolute value of z statistics in parenthesis and standard errors in square brackets
**Significant at 10 percent level, ** Significant at 5 percent level, ***Significant at 1 percent level*
Source: Own calculation using survey data

The results of the selection equation with food consumption considered as outcome variable are presented in the second column (Table 5.24). The direction of relationships between the variables measuring the decision to irrigate in Table 5.24 and that are common with the previous model in Table 5.23 are similar for both models with some variation on the significance level. New explanatory variables such as farm income and the value of household assets have a positive and highly significant effect on the farmers' decision to irrigate. BACHA *ET AL*. (2011) and DERESSA *ET AL*. (2009) have also reported similar findings.

The factors that affect the outcome variable, food consumption, are reported in the third and fourth column of the table. The estimates for household size-related variables are negative and significantly different from zero for both users and non-users. This situation holds in most cases because large household size means less per-head consumption other things kept constant. The same results are reported by KHONJE *ET AL*. (2015)AND BACHA *ET AL*. (2011) for impact studies in Eastern Zambia and Western Ethiopia, respectively. The model estimates for the amount of non-farm income show positive and significant impact on the consumption of non-users. Mostly non-farm income is used to augment the household income and cover for consumption expenditure shortfall (DORWARD *ET AL*., 2004). Similarly, the variable measuring the total value of household asset is positively and significantly correlated with consumption expenditure for both groups of farmers; this is in keeping with earlier findings of (BACHA *ET AL*., 2011). Finally, the average treatment effect on the treated (ATT) and untreated (ATU) are presented in Tables 5.25 and 5.26.

Table 5.25: Impact of irrigation on farm income and consumption-ATT

Outcome variable	Mean outcome		ATT		t-value
	I=1	I=0			
Log of farm income per ha	356,407	204,916	151,419	42 percent	7.73***
Log of total per adult equivalent consumption	3,817	2,479	1,338	35 percent	18.47***

Table 5.26: Impact of irrigation on farm income and consumption-ATU

Outcome variable	Mean outcome		ATU		t-value
	I=1	I=0			
Log of farm income per ha	197,404	79,097	118,307	149 percent	10.46***
Log of total per adult equivalent consumption	3,779	2,690	1,089	40 percent	12.44***

****significant at 1 percent level*

Source: own calculation from survey data

As presented in Tables 5.25 access to irrigation significantly affects both outcome variables for both groups. For the current irrigation users, their farm income per ha and annual per adult equivalent food consumption expenditure would have decreased by 42 percent and 35 percent, respectively if they had not used irrigation. This suggests that current irrigation users would lose farm income per ha of birr 151,419 and per adult equivalent consumption expenditure level of birr 1,338 had they not used irrigation water, respectively. Similarly, the farm income per ha and annual per adult equivalent food consumption expenditure of non-users would respectively increase by 149 percent and 40 percent if they had access to irrigation. The better livelihood condition of the households who used irrigating was also confirmed through observations of the housing conditions (by the principal author), FGDs, and key informant interviews. In one of the FGDs, for instance, one of the participants put the situation as "… it is pity that the people who are using irrigation agriculture are making lots of money while we practice rain-fed agriculture and sell our produces in seasons when everything is cheap…”. Another participant added that “lack of water had reduced my production by more than half”. This finding is consistent with previous studies that reported a positive direct link between irrigation use and farm income, food security, and employment (AMEDE, 2015; BACHA *ET AL*., 2011; BELAY & BEWKET, 2013; BUES, 2011; SMITH, 2004; WICHELNS, 2014). According to the FAO (2003) report, irrigation has the potential to increase crop yields by 100-400 percent compared to rainfed crop production.

5.3. Results from the Household model

5.3.1. Model Validation and Baseline results of the household model

Model validation is crucial in any economic analysis to check whether the modeling procedure is valid and results are plausible compared to the real world situation considered. HAZELL & NORTON (1986) underlined that validation of a programming model begins with comparison of model results with actual values of variables considered. However, because of the subjective nature of model validation it is imperative to follow systematic approach to model validation so as to bring in some level of objectivity. In this regard, MCCARL & APLAND (1986) explicitly indicated two model parts of validation: Validation by construct and validation by result. Validation by construct refers to making sure the model construction is ‘motivated by real world observations’ while validation by result involves comparison of model results with real world observations (MCCARL & APLAND, 1986).

Regarding the model construction, as presented in the model structure section, it has been tried to ensure the validity of all the components as per their representation of the system under study against relevant theories, precedence, and past experience. Constraints were also used based on actual observation of important variables as per minimum and/or maximum limits. The parameters used in the model have been obtained from the survey data (See Table A.1 to Table A.4). The final step in the validation of our model construction was eliminating coding errors that resulted in infeasible solutions.

In this section, validation result of the baseline model is presented for the selected variables. The baseline model is set to maximize overall utility of the three groups identifying the optimal water and other input use by each group. Table 5.27 shows observed values and baseline solution for selected model variables for the upstream households. The result shows that the model value could replicate the actual observed values. In the upper stream parts of the river, one could see slight variations in the amount of water and compost between the actual and model calibrated values. Otherwise, the values of the model and the actual observed values are similar for other variables. This is a very good indicator that the model is good enough to mark realities in the upper stream part of the river.

Table 5.27: Actual and baseline values for selected variables in Upstream parts of the river

Variables	Observed	Baseline solution	PAD
Sugarcane			
Yield in kg per ha			
Labor hrs. per ha	4,112.448	4,112.448	-
Amount of compost in kg per ha	15,455.3	14,200	(8.84)
Amount of water in M^3 per ha	19,342	16,830	(14.93)
Khat			
Yield in kg per ha			
Labor hrs. per ha	2,824.104	2824.104	-
Amount of Fertilizer in kg per ha	562.368	562.368	-
Insecticide cost in ETB per ha	1,487.46	1487.46	-
Amount of compost in kg per ha	18,421.428	18,420	(0.01)
Amount of water in M^3 per ha	9,613	9,613	-
Maize			
Yield in kg per ha			
Labor hrs. per ha	3,648	3,648	-
Enset			
Yield in kg per ha			
Labor hrs. per ha	3740.448	3740.448	-
Amount of compost in kg per ha	25,398.26	25,400	0.01

PAD refers to percentage of average deviation
Source: Own computation

Table 5.28 depicts observed values and baseline solution for selected model variables for the Middle stream households. The maximum variation observed is on the amount of water used, which is 12 percent. But, the values of other variables are more or less similar. This suggests that the model is pretty much good to manifest the reality such that possible results from this simulation are realistic.

Table 5.28: Actual and baseline values for selected variables in middle stream parts of the river

Variables	**Observed**	**Baseline solution**	**PAD**
Sugarcane			
Yield in kg per ha			
Labor hrs. per ha	3936	4112	4.47
Amount of Fertilizer in kg per ha	481	496	3.15
Amount of water in M3 per ha	19342	16830	-12.98
Khat			
Yield in kg per ha			
Labor hrs. per ha	2916	2824	-0.03
Amount of Fertilizer in kg per ha	550	562	0.02
Amount of compost in kg per ha	17759	18420	0.04
Amount of water in M3 per ha	9613	9613	0
Maize			
Yield in kg per ha			
Labor hrs. per ha	318	3648	10.45
Amount of Fertilizer in kg per ha	318	204	-0.36
Enset			
Yield in kg per ha			
Labor hrs. per ha	3890	3740	-0.04
Amount of compost in kg per ha	26660	25400	-0.05

Source: Own computation

5.3.2. Results of the simulation from the household model

Controlling the expansion of khat cultivation through fiscal policies

The first scenario dwells on examining the possible impacts of enhancing the productivity of sugarcane through investing on technology, improving the efficiency of water use and taxing *Khat* production. Following such simulation, the production of sugarcane increases while the production of khat decreases. The simulation has caused resource and input reallocation. The results are featured at Table 5.29.

Table 5.29: Percentage change of Production and input use from the baseline for Simulation 1.1 of Sugarcane and Khat

	Upper		Middle		Lower	
Variables	**Baseline**	**Sim1.1**	**Base**	**Sim1.1**	**Base**	**sim1.1**
Sugarcane						
Yield in kg per ha	132720	117	13,171	117.38	11,768	421.5
Labor hrs. per ha	4112	0.00	3,936	0.00	3,251	0.0
Fertilizer in kg per ha	496	0.01	481	0.00	395	0.0
Insecticide cost in ETB per ha	2423	44.13	2,665	35.08	1,914	0.0
compost in kg per ha	14200	0.02	19,820	3.50	13,929	0.0
water in M^3 per ha	16,830	14.93	19,342	0.00	19,342	-4.0
Khat						
Yield in kg per ha	79,435	-0.50	122,534	-0.50	47,661	-96.7
Labor hrs. per ha	2824	0.00	2916	0.00	1827	0.0
Amount of Fertilizer in kg per ha	562	0.01	550	0.00	200	0.0
Insecticide cost in ETB per ha	1487	0.00	1241	0.00	648	0.0
Amount of compost in kg per ha	18420	0.01	17759	0.00	16463	0.0
Amount of water in M^3 per ha	9613	0.00	9613	0.00	9613	-36.9

Source: Own computation

The results of the simulation indicated in the table shows that the production of sugarcane increase by more than 100 percent in all parts of the stream of the river. In relative terms, the increase in production of sugarcane is the highest in the lowest parts of the river compared to upper parts. For instance, the production of sugarcane increases by nearly by 117 percent in both the upper and middle parts of the river while the figure goes as high as 421 percent in the lowest part of the river. On the contrary, the production of *Khat* has been decreased both in the upper and lower parts of the river. But, the highest rate of change has occurred in in the lower parts of the river where sugarcane production has increased by a larger proportion. Hence, the intervention is so successful in the lowest part of the river compared to its upper parts.

The rationale of promoting the production of sugarcane emanates from the fact that it relatively uses less water compared to *Khat*, intensively uses labour such that it ensures sustainable use of resources and generates more employment in the rural area as well as sustained the flow of income to households. This is empirically supported by the experiences of East Harerghe area where households have been suffering from shortage of water because of high water consumption by Khat in the area since so long. So, if the production of sugarcane is promoted, the stock of water, which could be river or groundwater, can serve for longer period of time. In this regard, the results reveal that the consumption of water has increased by sugarcane in the upper stream while the consumption of water has decreased in the lower parts of the stream. The reduction in the production of Khat has also resulted in a reduction in the consumption of water in the lower parts of the stream. The figure has shown that the reduction of water consumption goes as high as 37 percent.

The results of the simulation have again revealed that there is a change in the input consumption pattern of households. For instance, the amounts of insecticide used per ha and compost consumption per ha have increased, but the consumption of fertilizer per ha remained the same. This could be because sugarcane uses more insecticide and compost compared to Khat.

As it has been indicated in Table 5.29, the production of Khat has decreased while the production of sugarcane has increased. Since Khat is more profitable to households' income from crop sale decreased by nearly 15 percent in the upper and middle parts of the river. This shows that the increase in sales income from sugarcane could not offset the loss of income from the sales of khat. Nevertheless, in the lowest part of the river where the production of sugarcane is the highest, income from sugarcane has offset the loss in income from khat so that the income from crops increased by 33.8 percent.

On the other hand, sugarcane is labour-intensive such that the demand for labour increased following the increase in the production of sugarcane. Consequently, income from labour has increased. In addition to this, the amount of labour invested on crops on upper and middle streams remained the same. This entails that there is no additional demand for labour but the amount of labour invested on crops have increased in the lowest part of the stream where the increase in sugar induced additional demand for labour. This made income from labour to decrease in the lowest part of the river.

The net impact of the simulation on total income depends on the relative influence of income from labour and sales of crops. The results in Table 5.30 revealed that total income has decreased in the upper and middle part of the river but the income of the households in the lowest part of the river has increased. This shows that the reduction in sales revenue offset the gain in income from labour in the upper and middle parts of the river while in the lowest part of the river an increase income from sales of crops offset the loss of income from labour and hence income of households has been increased by 16 percent.

Table 5.30: Comparison of baseline and simulation 1.1 results (in percent)

	Upper		**Middle**		**Lower**	
Variables	Baseline	Sim1.1	Base	Sim1.1	Base	Sim1.1
Income from labor(birr)	2,026,996	8.25	1,527,057	16.98	2,190,414	-19.60
Income from crops sales	8,135,352	-15.17	12,538,844	-15.27	4,883,344	33.83
Total Income	10,390,949	-10.27	14,343,815	-11.54	7,396,399	16.53
Total labor invested on crops	73,044	0.00	117,596	0.00	46,090	76.85

Source: Own computation

Water pricing

The aim of water pricing is to ensure efficient allocation and productive use of water, as it is manifestly scarce in many countries (GLEICK 1996; POSTEL 1996; SECKLER *ET AL.*, 1998). The irrigation sector is the largest user of global water resources and should be a primary target for water pricing. Commonly, capital and other subsidiary investments are required to move water from the natural water bodies to the irrigation fields. This means that irrigation water pricing targets surface water and where infrastructures have been built to deliver water from the source to the fields. In the study area, there are infrastructures that move the water from the river to the irrigation field. Hence, water pricing is recommended to sustain irrigation schemes.

Water pricing has its own impacts on production pattern of small holders given the fact that small holders will be tempted to produce agricultural activities that are profitable in a bid to finance their water bills. In this case, farmers might be producing more of Khat than sugarcane. The same goes to our results, which have shown that the impact of water pricing reduces the production of sugarcane and the amount of water used by sugarcane along the stream of the river. However, water pricing does not have any impact on Khat production and its respective water consumption.

The reduction of the yield of sugarcane increases at an increasing rate along the course of the stream. Hence, the highest yield reduction occurred on the lowest parts of the river where the percentage of reduction reached as high as 45 percent and the corresponding consumption of water reduced by nearly 54 percent. In addition to water, the respective input consumption has decreased. For instance, the consumption of compost and pesticide decreases proportionally with the decrease in the production of sugarcane. Water pricing could not reduce the production of Khat and its input consumption pattern. This entails that Khat so profitable that it has the capacity to pay the required water tax. The input consumption patter of Khat remained the same. Thus, the policy only impacted sugarcane production.

Table 5.31: Production and input use per ha for baseline and simulation 2 (percent)

Variables	Upper		Middle		Lower	
Sugarcane	Base	Sim2.1	Base	Sim2.1	Base	Sim2.1
Yield in kg per ha	132,720	-21.0	13,171	-26.1	11,768	-45.0
Labor hrs. per ha	4,112	0.0	3,936	0.0	3,251	-4.6
Fertilizer in kg per ha	497	0.0	481	0.0	395	0.0
Insecticide cost in ETB per ha	2,423	-12.5	2,665	-26.1	1,914	-31.6
Compost in kg per ha	14,200	0.0	19,820	-26.1	13,929	-30.0
Water in m3 per ha	19,342	-27.2	19,342	-32.4	19,342	-53.7
Khat						
Yield in kg per ha	79,435	0	122,534	0	47,661	0
Labor hrs. per ha	2,824	0	2,916	0	1,827	0
Fertilizer in kg per ha	562	0	550	0	200	0
Insecticide cost in ETB per ha	1,487	0	1,241	0	648	0
Compost in kg per ha	18,420	0	17,759	0	16,463	0
Water in m3 per ha	9,613	0	9,613	0	9,613	0

Source: Own computation

Income from crop sales did not decrease so much following water pricing. This is basically because the lion's share of income from crop sales comes from *Khat* whose production was not impacted by water pricing. Income from labor in the upper stream has increased. This could be because as labor has been released from sugarcane, it will be engaged in off-farm activities. Because of this, the reduction in sales income from sugarcane has been offset by the increase in income from off-farm activities. This entails that water pricing promotes off-farm activities by squeezing sugarcane production.

Table 5.32: Change in income of households for baseline and simulation 2 (percent)

	Upper		Middle		Lower	
Variables	Base	Sim2	Base	Sim2.1	Base	Sim2.1
Income from labor	2,026,996	8.30	1,527,057	0.00	2,190,414	0.00
Income from crops sales	8,135,352	-0.03	12,538,844	-0.03	4,883,344	-0.10
Total Income	10,390,949	1.59	14,343,815	1.81	7,396,399	2.15
Total labor invested on crops	73,044	0.00	117,596	0.00	46,090	-0.03

Source: Own computation

Land allocation

Crop prioritization is one of the strategies used by policy makers. Small holders tend to engage in the production of crops that yield the highest benefit in the short run without considering the likely impact in the long-run. To combat such problem, land policy could be used to ensure sustainable growth and development. To examine the impact of different policy options, three different simulations have been considered. The first simulation assumes equal allocation of land between Khat and sugarcane production by households in the study area. The second simulation (Sim3.2) examines the likely impact of allocating more land to Khat production and the third simulation (Sim3.3) examines the impact of allocating more land to sugarcane production.

The results of the first simulation, allocating equal land between Khat and sugarcane, have been used as a point of reference to make comparison with the rest two simulations (Sim3.2 and Sim3.3). The results have shown that allocating more land to Khat decreases the production of sugarcane by nearly 59 percent in the upper and middle stream parts of the river and the figure goes as low as 32 percent in the lowest part of the river. On the other hand, more land allocation to Khat increased Khat production with equal magnitude along the stream of the river.

Table 5.33: Production and input use and simulation results

Variables	Base	Sim3.2	Sim3.3	Base	Sim3.2	Sim3.3	Base	Sim3.2	Sim3.3
Sugarcane									
Yield in kg/ha	1,583,697	-50	7.76	2,452,561	-50	7.61	1,008,613	-32	7.46
Labor hrs/ha	4,112	0.00	0.00	3,936	0.00	0.00	3,251	0.00	0.00
Fertilizer in kg/ha	496	0.00	0.00	481	0.00	0.00	395	0.00	0.00
Insecticide cost in ETB /ha	2,488	7.97	-1.22	2,467	8.02	-1.36	1,628	17	-1.49
Compost in kg/ha	14,203	0.00	0.00	18,349	8.02	-1.3	12,105	15	-1.49
Water in M3/ha	17,444	10	-1.65	17,501	10	-1.7	11,593	66	-1.93
Khat									
Yield in kg/ha	39,872	53	-9.1	61,419	53	-9.1	23,926	53	-9.1
Labor hrs/ha	2,824	0.00	0.00	2,916	0.00	0.00	1,827	0.00	0.00
Amount of Fertilizer in kg/ha	562	0.00	0.00	550	0.00	0.00	200	0.00	0.00
Insecticide cost in ETB/ha	1,487	0.00	0.00	1,241	0.00	0.00	648	0.00	0.00
Compost in kg/ha	18,421	0.00	0.00	17,759	0.00	0.00	16,463	0.00	0.00
Water in M3/ha	9,613	0.00	0.00	9,613	0.00	0.00	9,613	0.00	0.00

Source: own computation

The impact of land allocation among crops on income has revealed that allocating more land to *Khat* increases total income and income from crops sales more than allocating more land to sugarcane. Since *Khat* is less labour-intensive total labour invested on crop decreases so does the income that comes from income from labour. It is a vivid fact that *Khat* is more profitable to farmers than sugarcane production such that when more land is allocated to it, farmers could earn more income. On the contrary, allocating more land to sugarcane increase total labour invested on crops and hence the income from labour increase but total income decreases. This is because the income from sales of crops decreases.

Table 5.34: Land allocation and income

Variables	Upper			Middle			Lower		
	Base	Sim 3.2	Sim3.3	Base	Sim3.2	Sim3.3	Base	Sim3.2	Sim3.3
Income from labor	2276338	-6.3	1.1	1944593	-12.2	2.2	2290332	-3.5	4.1
Income from crops sales	5541918	26.4	-4.6	8547658	26.3	-4.7	3377948	30.0	-26.6
Total Income	8046856	16.4	-2.9	10770165	18.6	-3.3	5990920	15.6	-15.5
Total labor invested on crops	89509	-10.0	1.7	138001	-8.0	1.4	63800	-15.1	20.7

Source: Own computation

5.4. Discussion

It is widely accepted that irrigation increases productivity thereby reducing poverty and food insecurity. Even though Ethiopia is considered as water abundant country, the agriculture sector is affected by water scarcity owing to the spatial and temporal variability in the availability of the resource. On the other hand, Ethiopian agricultural policy has been aggressively pursuing a number of small-scale irrigation schemes aimed at improving rural livelihoods. But, there are puzzling inquires including assessing the impact of irrigation on poverty and food security. Apart from this, the study area has its own peculiar features that require further policy intervention. The study used both econometric and household models to address the research questions.

The study has signified that those farmers who have access to irrigation were found to be lower on the incidence, depth, and severity of poverty than those farmers who do not have access to irrigation. Other studies have also shown similar results. For instance, HUSSAIN *ET AL*. (2002) have revealed that the incidence of chronic poverty is 10 percent (5 percent) lower for irrigated areas than adjoining rained areas in Sri Lanka (Pakistan). HUANG *ET AL*. (2006) also found a strong positive correlation between access to irrigation and household income, leading to poverty reduction and equitable income distribution in China. The situation is also the same in Mali where DILLON (2011) showed that households with access to irrigation have higher household expenditures than those of households without access to irrigation.

The study has also indicated that irrigation has its own impact on food security and asset building of farmers. It is supposed that irrigation brings commercialization of agriculture, which tends to increase household income of food consumption and nutritional adequacy. The research implicated that irrigation had a positive and significant impact on per adult equivalent food consumption, the household's farm income, non-farm income, and household asset. The results of the study is supported by ALESSANDRA & TISORN (2018) who have showed that beneficiaries from participatory irrigation raise revenues and enable a switch from relying mainly on consuming their own produce to purchasing more food from the market in Ethiopia. Moreover, irrigation beneficiaries accumulate more assets in the form of livestock and are more likely to share food with non-beneficiaries.

The study identified the most salient factors that affect farmers' decision to irrigate. Variables relating to institutional issues and governance of the irrigation scheme, access to information and social network, and water scarcity level have a significant impact on farmer's decision to irrigate. The result falls in conformity with MUSARA *ET AL.* (2010) who showed that sex, age and training of the household heads significantly influenced micro-irrigation adoption. Hence, knowledge gain through extension services or having adequate information determines households' participation in micro irrigation.

The study pointed out that the water demand for Khat is by far greater than sugarcane as it requires frequent irrigation per year per ha. The research has also shown that *Khat* yields higher economic benefits in the short run compared to sugarcane. Because of this, farmers in all parts of the stream are tempted to allocate more land to the production of Khat. This goes in line which GESSESSE & PETER (2008) findings. They have shown that over the ten-year period 1991 to 2000, Khat production in Wondo Genet increased by 180 percent in volume. For instance, in 1991 Khat was cultivated in Wosha PA by only 10 farmers on barely 2 ha of land but by the year 2000 the number of farmers who cultivated Khat increased to 84 farmers and the coverage of Khat has mounted to 27 ha of land.

Apart from this, the study carried out spatial analysis on irrigation, water use and pattern of land allocation to Khat and sugarcane production. The result has revealed that land allocation to Khat and sugarcane vary along different courses of the stream of the river. For instance, from the total land, nearly half of it goes to the production of Khat in the upper basin while the figure goes as low as 30 and 24 percent in the middle and downstream courses of the river, respectively. This implies the share of land allocated to Khat decreases from the upper to the lower courses of the river. As we know, more water is available at the upper parts of the stream where households have the right to access more water as compared to households at the lower parts of the stream. In addition, the research has identified that the amount of water used per ha per crops decreases from the upper to the lower parts of the rivers. Since Khat intensively uses water and require frequent irrigation, its land coverage decreases from the upper stream to the lower stream for the availability of water for irrigation proportionally decreases from the upper to the lower parts of the stream. This entails that water availability triggers more Khat production. During the FGD, it has been learnt that the upper-stream households have advantages of accessing more water that make farmers produce more Khat production. Apart from this, lower-stream households have revealed that lack of adequate water is the primary cause for farmers not to engage in Khat production.

The study further paves the way to conceptualize on the mechanism as to how the long run sustainability of economic benefits of irrigation using household modelling could be ensured. This is possible by opting the crop type that uses less water per ha per annum but relatively yields long run benefits to households. Thus, introducing policies that promote the production of the most socially desired crops namely sugarcane is also equally important. It has been long noted that *Khat* is a socially undesired crops as it causes addiction, health problem and reduces the productivity of labor in the long run. So, designing policies that promote the production of sugarcane and that hamper the production of *Khat* should be a prime concern in a bid to enhancing the socioeconomic benefits of the community in the long run. Towards this end, different policies including water pricing, enhancing the productivity of sugarcane through investing on technology, improving the efficiency of water use and taxing *Khat* production and system that promote the allocation of land to sugarcane have been proposed and examined.

The study revealed that Khat production would yield higher benefits in the short run and has come up with that allocating more land to Khat increases total income. It has also caused more increment of income from crops sales compared to allocating more land to sugarcane. This is because Khat is so less labor intensive that excess labor will be released which could be hired in other sectors. This enables labor to participate elsewhere to generate more income from nonagricultural activities. On the contrary, allocating more land to sugarcane increases total labor invested on crops. This tends to create more rural employment if it is well managed and accompanied by sound policies and if sugarcane has the capacity to pay higher wage rates to the extra labor force. The finding more or else goes in line with the findings of BINSWANGER & QUIZON (1986) who applied a general equilibrium model of India's agricultural sector post-Green Revolution to examine the impact of expanding the irrigated area by 10 percent on the rural poor. The result has shown that aggregate output has increased by 2.7 percent, but residual farm profits was declined by 4.8 percent.

The other proposed policy comprises both fiscal measures and technology improvement. In this policy package, taxing *Khat* cultivation, adopting better technology to enhance efficiency and water saving for sugarcane production have been considered. The result has shown that households gain more income. This policy enables households to switch to the production of sugarcane in the long term. Because these policies ensure higher income gains from sugarcane and able to offset subsequent income loss from Khat production. Indeed, similar results have shown that adopting better technologies would boost productivity and ensures higher income gains for farmers. For instance, several studies have shown similar results that reveal the significant positive impact of improved agricultural practices on the welfare of smallholders (ABEBE AND SEWNET 2014, KASSIE *ET AL*., 2018). JANVRY AND SADOULET (2002) have also indicated that the adoption of agricultural technologies improves agricultural productivity, which lead to an increase in home-consumed food and marketable surplus, which in turn reduces poverty and vulnerability of adopters.

Water pricing has been suggested so long to ensure efficient water allocation in the study area. The rationality of the policy is to hamper households not to use more water for irrigation to ensure long run sustainability of production. The results of the simulation indicate that water pricing promotes the production of Khat. This is because Khat production could afford to pay for the additional water tax, but the production of sugarcane could not. So, water taxing exacerbates the problem as allocating more land to Khat would be considered as a way out for farmers to pay the addition fees of water. The result more or else is supported by JULIO & JOSE (2000) who has pointed that pricing of water results in a serious reduction in farm income, as a result of two factors that operate in the same direction. The farmer responds to price increases by reducing his water consumption through changes in crop plans, introducing less profitable crops as substitutes for more valuable water-demanding crops.

Different studies have shown that the shift towards a *Khat*-based farm economy was unavoidable in the absence of other feasible alternatives (MULATU & KASSA, 2001). The results call for blend of policies namely taxing *Khat* cultivation, enhancing the efficiency of sugarcane and the efficiency of water usage by sugarcane production to ensure high welfare of households and long run sustainability of production of sugarcane. The water pricing promotes the production of *Khat*. The combined policies that have been considered to induce productivity shows that it is possible to promote the production of sugarcane using systemic interventions for better water allocation.

Institutional factors play key role of for the successful functioning of the irrigation scheme in the study area. There is, however, growing concern that the performance of the irrigation schemes is below expectations. Several reasons are mentioned for the underperformance of irrigation schemes including design failure, poor water management practices, and weak institutions (AMEDE, 2015; BELAY & BEWKET, 2013; DENEKE *ET AL*., 2011). It is clear fact that effective water management along the stream ensures efficient water use. But, assessment of the physical irrigation infrastructure indicated performance problems of the canals and a significant amount of water lose during transportation. Irrigation is undertaken on a turn taking basis based on a schedule set by WUA committee. Diversion of the river is the sole source of irrigation and use of alternative sources is almost non-existent.

The lack of efficient institutions in the village is signified by the type of irrigation technology which is being used by the village. The assessment from the field attested that the irrigation technology is only furrow and there is no storage facility which enables to distribute water adequately to different parts of the stream. The inadequacy and weaknesses of the institutional set-up involved in the management of the scheme were also made clear in the analysis. As it has been shown above, households who are living in the upper parts of the stream uses more water (which is three time more) than the lower parts of the stream. This signifies that the water is not fairly distributed along different parts of the stream. The results of the focus group discussion and the key informant interview also show the existence of an unfair distribution of water, corruption, bribery, and weak legal status in the committee governing the scheme.

The existence of this weak and ill managed committee exacerbates the problem of water inefficiency. It has also been noted that households are willing to pay to adopt better technology of irrigation if the water governing system is improved. Participants have also believed that the water is adequate enough to all households along the stream if better technology and efficient water sharing scheme is installed. Furthermore, the participants of the FGD revealed that the WUA committee generally was described by the community as not trustworthy.

The participants of the FGD further noted that households are willing to switch to sugarcane production and other crops by replacing Khat if there are high productive crops which yield as high profit as Khat. For such end, they described that the provision of irrigation should be accompanied by the availability of improved seed variety and credit access with low interest rate. From the field assessment and observation, it has been learnt that there is high involvement of middlemen and brokers in the product market that reduces the benefit of farmers. The participants of the FGD explained that the marketing system should be improved to benefit them more from their products. Apart from this, the supply of modern inputs and improved varieties is fully controlled by the government such that more options and improved systems of provision of improved variety seeds should be availed. Similarly, there is very limited access to credit market for various reasons.

6. SUMMARY AND CONCLUSIONS

This chapter briefly highlights major findings of the whole study and pinpoints suggestions for policy uptake. In three subsections, the chapter indicates summary of major findings, conclusions and policy implications and outlook.

6.1. Summary of Major Findings

Descriptive summary of the context and the relevant variables indicated significant difference on the livelihood outcomes between farmers who have access to irrigation and their counterparts. Poverty analysis using the FGT indices based on own constructed consumption poverty line also reveal that the incidence, depth, and severity of poverty were found to be higher among farmers who do not have access to irrigation. Assessment of the physical irrigation infrastructure indicated performance problems of the canals and a significant amount of water loss during transportation. Irrigation is undertaken in turns based on a schedule set by WUA committee. Diversion of the river is the sole source of irrigation and use of alternative sources is almost non-existent.

The irrigation technology is only furrow with no storage facility. The analysis also clearly showed the inadequacy and weaknesses of the institutional set-up involved in the management of the scheme that cause the existence of an unfair distribution of water, corruption, bribery, and weak legal status. Findings from FGDs and key informant interviews also revealed that the WUA committee to be generally not trustworthy and one which exacerbates the existing water scarcity. It was possible to learn from the analysis that high involvement of middlemen and brokers affect the functioning of markets in the study area. The supply of modern inputs and improved varieties is fully controlled by the government. Similarly, there is very limited access to credit market for various reasons.

The analysis on the determinants of farmers' decision to irrigate and impact of irrigation on the welfare of households showed the existence of a selection bias among users and non-users (as can be seen from the significant correlation coefficient between the error terms of the selection equation and outcome equation). Amount of chemical fertilizer applied, pesticide used, and landholding size had positive and significant impact on the farm income of the respondent households. Landholding per plot and distance to nearest market, on the other hand, had negative and significant impact on farm income of the households. Regarding per adult equivalent food consumption the households' farm income, non-farm income, and household asset had a positive and significant impact. Household size and dependency ratio, on the other hand, had a negative impact on the per adult equivalent food consumption of the surveyed households. The treatment effects (ATT and ATU) are positive and significant for both users and non-users indicating that access to irrigation has resulted in a significant positive impact on farm income and consumption expenditures.

The results of the simulation from the bioeconomic household model have revealed different and distinct outputs. The results call for blend of policies namely taxing *khat* cultivation, enhancing the efficiency of sugarcane and the efficiency of water usage by sugarcane production to ensure high welfare of households and long run sustainability of production of sugarcane. The water pricing promotes the production of *khat* while the land allocation, which seems a forced policy by its very nature, promotes the production of sugarcane. The combined policies that have been considered to induce productivity shows that it is possible to promote the production of sugarcane using systemic interventions for better water allocation.

6.2. Conclusions and Policy Implications

The Ethiopian Economy is dominated by smallholder rain-fed agriculture, which suffers from highly variable rainfall and unpredictable weather conditions, which adversely affect its growth. Despite the fact that the sector contributes almost half of the country's GDP and employs 80 percent of the population, spatial and temporal variability of water, soil degradation, land fragmentation and low level of improved technology adoption and input use have impaired its performance. This kept about a third of the country's population below poverty line. On top of this, high population growth is creating more demand on food, which obviously cannot be satisfied by agricultural land expansion.

This calls for solutions related to agricultural intensification. In fact, agricultural intensification requires technology adoption and input use, which further need availability of water to augment dry season production. This is possible through irrigation development. Cognizant of this, the Ethiopian government has been investing in soil and water conservation and irrigation development with due emphasis on small-scale irrigation as a way out of poverty and food insecurity.

Considering the findings of this study, several policy implications could be drawn. The general direction would be ensuring a reliable and sustainable access to irrigation water as the results indicated its significant positive impact on livelihood in general and food security and poverty reduction in particular. This, however, requires intervention in several aspects of the scheme and local institutions to tap into the potentials available. As a starting-off point, renovating and improving the conditions of the canals of the irrigation scheme could be used to reduce wastage and ensure access of more people to irrigation water. Alongside making sure that water is available, the government should work on promoting the adoption and provision of better technologies. Moreover, water storage facilities could significantly enhance crop production in the study area through opening up alternative water availability mechanisms for an extended period of the dry season. Such facilities also make possible multiple uses of water like fisheries, which can be considered to enhance the livelihood of households especially of women and vulnerable groups with small/no landholdings.

Households involved in this study who have access to irrigation water but are still below the poverty line witness the existence of transaction costs involved in securing access to water, purchasing other inputs, and selling outputs, which claim a huge share of their income. This calls for interventions in relevant institutional settings and markets to fully realize the potential of irrigation. Responsible bodies including the local government should strengthen WUA through sound legal framework with proper monitoring and evaluation systems to ensure good governance and fair allocation of water. The focus group discussions and key informant interviews revealed that the rules and bylaws should not be imposed from the people in the government structure rather the water users should be allowed to autonomously develop them for better effectiveness. Participation of the farmers should be enhanced to create a sense of belongingness and trust. Further targeted technical support and advice from the extension officers would play a significant role in making effective use of the water.

The huge involvement of brokers and middlemen in the market especially for *khat* and sugarcane is also another problem. In this regard, it would be beneficial for the farmers if they could be organized in producer cooperatives for collective marketing. Especially, with the highly developing sugar industry in the country, there is huge market demand for sugarcane and the farmers could seize this opportunity. Facilitating access to small and medium credit facility can also improve the farmers' capacity to invest in alternative irrigation water sources like shallow well and rainwater harvesting facilities and modern agricultural inputs. The success stories of a scheme in a study (BELAY & BEWKET, 2013) where the WUA established a saving and credit unit where users save and borrow money could be replicated in this scheme to alleviate the problem of credit access.

The scenario analysis through the bioeconomic model revealed that different policy intervention resulted in different reaction and decision by the farm households. It calls for combined policy intervention to see the desired and sustainable response from the farmers while ensuring high level of welfare. Last but not least, it is vital to make sure the interventions are inclusive of the poor by developing better targeting mechanisms. The study area is one of the densely populated areas in the country with very small and fragmented landholdings. The young generation is running out of land to stay in the agriculture sector. The importance of non-farm sector is critical in such situations as shown by the positive significant impact on income and consumption.

6.3. Outlook

Evidently, this study has dwelt on primary cross-sectional data. As a result, it has not analyzed poverty dynamics and decisions across time. This is one of the areas for future research. The modeling is also done in a static manner where dynamic water allocation decisions are not taken care of. Given yearly oscillations in water availability due to the erratic nature of rainfall, water use decisions do vary accordingly. That this research does not touch upon such dynamism is one of its limitations, which could be an area attracting future research in the study area or anywhere else in the country. Further, there is a caveat to the reader to be cautious in the interpretation and generalization of the findings.

Zusammenfassung

Die äthiopische Wirtschaft ist stark vom Agrarsektor abhängig. Dies wird durch die Tatsache belegt, dass der Agrarsektor mit fast 36 Prozent zum Bruttoinlandsprodukt (BIP) beiträgt und 80 Prozent der Bevölkerung beschäftigt. Allerdings wurde das Wachstum des Sektors durch eine Vielzahl institutioneller, ökologischer und anderer Faktoren gebremst. Dazu gehören die räumliche und zeitliche Variabilität der Wasserverfügbarkeit, die Degradierung der Bodenqualität, die Fragmentierung des Bodens und ein geringer Grad an Übernahme neuer Technologien, sowei ein geringer Einsatz von Betriebsmitteln. Abgesehen davon wird der Sektor von Kleinbauern dominiert, die anfällig für externe Schocks sind und nur begrenzt in der Lage sind, auf ihrem Land Investitionen zu tätigen. Diese Situation hat insgesamt eine geringe landwirtschaftliche Produktivität im Land zur Folge, als Folge davon lebt etwa ein Drittel der Bevölkerung des Landes unter der Armutsgrenze.

In jüngster Zeit gibt es eine neue Initiative von Seiten der Regierung, diese bemüht sich darum die Ausweitung von kleinen Bewässerungsanlagen im ländlichen Raum zu fördern und so Armut und Ernährungsunsicherheit zu verringern. Der Grund dafür ist, dass Äthiopien in allen Landesteilen von vielen wasserführenden Flüssen und Bächen durchzogen ist. Viele der Oberflächengewässer bestehen aus kleinen und großen Flüssen, die verschiedene Orte durchqueren. Daher gibt es Rivalität und einen ständigen Konflikt zwischen den Gemeinschaften bezüglich der Wassermenge, die sie in ihre jeweiligen Orte umleiten. Das Untersuchungsgebiet dieser Arbeit ist ein typisches Beispiel für einen solchen Ressourcenkonflikt um Wasser. Im Untersuchungsgebiet gibt es einen kleinen Fluss, der drei Ortschaften durchquert und somit verschiedene Wassernutzer am oberen, den mittleren und den unteren Teil des Flusses, mit Wasser versorgt. Daher ist die Frage der optimalen Nutzung des fließenden Wassers in einer Weise, die den maximalen Nutzen bringt, von entscheidender Bedeutung. Es gibt einige Untersuchungen, die bisher im Untersuchungsgebiet zu den Faktoren die die Nutzung der Bewässerung beeinflussen durchgeführt wurden. Allerdings gibt es bisher keine Untersuchungen über die optimale Wasserverteilung mit Hilfe von ökonomischen Modellen und die Auswirkungen der Bewässerung auf die Armut. Diese Forschungsarbeit schließt die beschriebene Forschungslücke mit Hilfe eines bioökonomischen Modells und betrachtete verschiedene mögliche Handlungsalternativen, um nach möglichen Wegen zu suchen, die eine gerechte Verteilung des Nutzens auf die im Verlauf des Baches lebenden Haushalte zu gewährleisten.

Wie bereits erwähnt, ist die Umleitung des Flusses die einzige Quelle der Bewässerung, und die Nutzung alternativer Quellen ist fast nicht vorhanden. Die Bewässerungstechnik besteht nur aus dem graben von Furchen in denen das Wasser fließt und es gibt keine Speichermöglichkeiten für das Wasser. Die Unzulänglichkeit und die Schwächen des institutionellen Aufbaus, der mit der Verwaltung des Systems verbunden ist, wurden in der Analyse ebenfalls deutlich gemacht. Die Existenz einer ungerechten Verteilung des Wassers, Korruption, Bestechung und ein schwacher Rechtsstatus wurden als Merkmale des Ausschusses, der das System verwaltet, identifiziert. Der Ausschuss der Wassernutzer wurde im Allgemeinen von der Gemeinde als nicht vertrauenswürdig und als derjenige beschrieben, der die bestehende Wasserknappheit verschlimmert. Das wurde während der Einzelgespräche sowie den Fokusgruppengesprächen von den Teilnehmern wiederholt. Was die Märkte betrifft, so wurde eine hohe Beteiligung von Zwischenhändlern und Maklern festgestellt. Die Versorgung mit modernen Betriebsmitteln und verbesserten Sorten wird vollständig von der Regierung kontrolliert. Auch der Zugang zum Kreditmarkt ist aus verschiedenen Gründen sehr begrenzt.

Die deskriptiven Ergebnisse haben gezeigt, dass es einen signifikanten Unterschied in den sozioökonomischen Merkmalen zwischen Bauern, die Zugang zu Bewässerung haben, und solchen, die keinen Zugang haben, gibt. Die Armutsanalyse wurde mit Hilfe der FGT-Indizes (Foster-Greer-Thorbecke-Indizes) auf der Grundlage der selbst konstruierten Armutsgrenze des Verbrauchs durchgeführt. Es wurde festgestellt, dass die Häufigkeit, Tiefe und Schwere der Armut bei Bauern, die keinen Zugang zu Bewässerung haben, höher ist. Die Bewertung der physischen Bewässerungsinfrastruktur zeigte Leistungsprobleme der Kanäle und einen erheblichen Wasserverlust während des Transports. Die Bewässerung wird nach einem vom Ausschuss der Wassernutzer festgelegten Zeitplan abwechselnd durchgeführt.

Weitere Analysen haben auch gezeigt, dass es deutliche Unterschiede in den Produktionsmustern zwischen den Haushalten gibt, die in den flussaufwärts gelegenen, mittleren und unteren Teilen des Flusses leben. Dies wird durch die Tatsache belegt, dass die Haushalte, die in den Gebieten des oberen Flusses leben, mehr Khat produzieren als die Haushalte, die entweder im mittleren oder im unteren Teil des Flusses wohnen. Relativ gesehen produzieren die Haushalte, die im mittleren Teil des Flusses leben, mehr Khat als die Haushalte, die im unteren Teil des Flusses leben. Im gleichen Muster ist die Wassermenge pro Hektar verteilt, die von den Haushalten in den oberen Teilen des Flusses verbraucht wird. Sowohl für die Khat- als auch für die Zuckerrohrproduktion werden weitaus größere Wassermengen pro Hektar entnommen, als die Menge die von den Haushalten in den unteren Teilen des Flusses verbraucht wird. Dies könnte mit dem Standortvorteil zusammenhängen, dass die Haushalte im oberen Teil des Flusses Zugang zu mehr Wasser haben.

Die Identifizierung von Faktoren, die die Landwirte zur Nutzung von Bewässerung veranlassen, ist sehr hilfreich für angemessene politische Interventionen. Daher wurden zusätzliche Analysen durchgeführt, um die Bestimmungsfaktoren für die Entscheidung der Landwirte für die Bewässerung und die Auswirkungen der Bewässerung auf das Wohlergehen der Haushalte zu untersuchen. Die Ergebnisse zeigten, dass Variablen, die sich auf institutionelle Fragen und die Steuerung des Bewässerungssystems, den Zugang zu Informationen und sozialen Netzwerken sowie den Grad der Wasserknappheit beziehen, erhebliche Auswirkungen auf die Entscheidung der Landwirte für die Bewässerung haben. Unter den Faktoren, die die Ergebnisvariablen beeinflussten, hatten die Menge des ausgebrachten chemischen Düngers, das verwendete Pestizid und die Größe des Landbesitzes einen positiven und signifikanten Einfluss auf das Betriebseinkommen der befragten Haushalte. Der Landbesitz pro Parzelle und die Entfernung zum nächstgelegenen Markt hatten hingegen einen negativen und signifikanten Einfluss auf das landwirtschaftliche Einkommen der Haushalte. Was den Lebensmittelkonsum pro Erwachsenenäquivalent anbelangt, so hatten das landwirtschaftliche Einkommen, das Einkommen außerhalb des landwirtschaftlichen Betriebes und dass Haushaltsvermögen einen positiven und signifikanten Einfluss auf das landwirtschaftliche Einkommen der Haushalte. Die Haushaltsgröße und der Abhängigkeitsquotient hingegen hatten einen negativen Einfluss auf den Lebensmittelkonsum pro Erwachsenenäquivalent der befragten Haushalte.

Weitere Analysen wurden mit Hilfe von bioökonomischen Modellen durchgeführt, um alternative Politiken zu identifizieren, die eine optimale Wasserverteilung entlang des Flusses gewährleisten. Es gibt im Wesentlichen zwei Cash Crops (Zuckerrohr und Khat), die im Untersuchungsgebiet produziert werden. Khat verbraucht mehr Wasser als Zuckerrohr und hat unerwünschte sozioökonomische Auswirkungen. Daher sollte es Interventionen geben, die in Betracht gezogen werden sollten, um die Produktion von Khat zu reduzieren und die Produktion von Zuckerrohr zu erhöhen, damit das Wasser optimal über den Flusslauf verteilt werden kann. Zu diesem Zweck wurden drei Simulationen in Betracht gezogen, nämlich die Verbesserung der Effizienz der Wassernutzung und die Besteuerung der Khat-Produktion, die Besteuerung des Wassers und die Zuweisung von mehr Land an Zuckerrohr. Die erste Simulation, bei der die Effizienz verbessert wird und Khat besteuert wird, verbessert die Produktion von Zuckerrohr. Die Wasserpreisgestaltung fördert die Khat-Produktion, während die Landzuweisung die Produktion von Zuckerrohr fördert.

Auf der Grundlage der Ergebnisse dieser Studie wurden mehrere politische Implikationen herausgearbeitet. Die Hauptrichtung wäre die Gewährleistung eines zuverlässigen Zugangs zu Bewässerungswasser mit positiven Auswirkungen auf die Lebensgrundlage und der damit verbundenen Verbesserung der Ernährungssicherheit und der Verringerung der Armut in der Region. Dies erfordert jedoch einen Eingriff in verschiedene Aspekte des Programms und der lokalen Institutionen, um die vorhandenen Potentiale zu erschließen. Die Szenarioanalyse durch die bioökonomische Modellierung ergab, dass unterschiedliche politische Interventionen die Haushalte zu unterschiedlichen Maßnahmen veranlassen. Es wird eine kombinierte politische Intervention gefordert, um die gewünschte und nachhaltige Reaktion der Bauern zu sehen und gleichzeitig ein hohes Wohlstandsniveau zu gewährleisten. Nicht zuletzt muss sichergestellt werden, dass die Interventionen die Armen mit einbeziehen, indem bessere zielgerichtete Mechanismen entwickelt werden. Das Untersuchungsgebiet ist eines der dicht besiedeltsten Gebiete des Landes mit sehr kleinem und zersplittertem Landbesitz. Der jungen Generation geht das Land aus, um in der Landwirtschaft zu bleiben. Die Bedeutung des nichtlandwirtschaftlichen Sektors ist in solchen Situationen von entscheidender Bedeutung, wie die positiven, signifikanten Auswirkungen auf Einkommen und Konsum zeigen. Die Ergebnisse der Simulation aus dem bioökonomischen Modell zeigen, dass die Unterstützung zur Erhöhung der Produktivität der Zuckerrohrproduktion es ermöglicht, die Gesamtproduktion von Zuckerrohr zu erhöhen. Daher sollte die Regierung oder der zuständige Betreiber ein System zur Steigerung der Produktivität von Zuckerrohr einführen, so dass die Gemeinde mehr Land für Zuckerrohr zur Verfügung hat, das eine nachhaltige Wassernutzung über den gesamten Flusslauf gewährleistet.

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APPENDEX

Table A.1: Technical coefficients obtained from economic estimation of crops used in the production function in each household

		Labor	Fertilizer	Insecticide	Compost	Water
Upper, middle and lower streams	Sugarcane	0.3660431	0.1160097	0.0219023	0.0358285	0.7264282
	Khat	0.1590262	0.3555288	0.0530066	0.03756	0.4143951
	Maize	0.8586418	0.141119	0.000	0.000	0.000
	Enset	0.4844995	0.000	0.000	0.4824402	0.000

Table A.2: The maximum limits of the agricultural inputs per ha by each household under current condition

		Labor	Fertilizer	Insecticide	Compost	Water
Upper	Sugarcane	4112.448	496.968	3492.4812	14203.284	19342
	Khat	2824.104	562.368	1487.46	18421.428	9613
	Maize	3648	322.284	0	0	0
	Enset	3740.448		0	25398.264	
Middle	Sugarcane	3936.192	481.752	3600.76	20513.352	19342
	Khat	2916.6	550.2	1241.268	17759.80	9613
	Maize	3099.072	318.42	0	0	0
	Enset	3890.136	0	0	26660.808	
Lower	Sugarcane	3251.232	395.904	1914.9084	13929.732	19342
	Khat	1827.276	200.724	648.288	16463.352	9613
	Maize	1997.568	241.296	0	0	0
	Enset	3214.848	0.0000	0.0000	19300.908	0.0000

Table A.3: Water requirement by crops by households

	Sugarcane	Khat	Maize	Enset
Irrigation water requirement per ha calculated using CROPWAT	10382	3550	0	0
Crop water requirement for each crop	19342	9613	0	0
Current level of water use by households for each crop in cubic meter total	0	0	0	0
Upper	261811.50	102272.2	0	0
Middle	82626.85	28999.67	0	0
Lower	0	0	0	0

Table A.4: Other income and wage related indicators in the study area

	Upper	Middle	Lower
Fixed income generated from off-farm employment per household	228,600	277,914	32,2640
Initial cash endowment	1,043,100	998,100	46,8450
Fixed labor hours invested in non-farm activities per day	50	51	47
Maximum time available that HH's (household group) members can invest in other farm labour work in hours per day	0	0	107
Maximum hired labor in man day per ha per households per crop			
Sugar	209.07	197.06	181.74
Khat	82.43	80.15	26.90
Maize	161.81	80.16	64.51
Enset	198.88	156.94	237.90
The initial land allocation in ha to each crop by household			
Sugar	14.07	22.4425	9.6725
Khat	17.32	17.1875	14.845
Maize	7.075	11.515	11.9775
Enset	7.495	9.28	8.78
The initial land allocation in ha to each crop by household			
Sugar	0.924	924	924
Khat	102.23	102.23	102.23
Maize	5.45	5.45	5.45
Enset	6.35	6.35	6.35

A.5: The GAMS code

```
****set ***
set  t  "Time periods of the planning horizon (individual simulation periods)"     /   2016*2016    /   ;
set household "Farm household type U representing Upstream, D1, downstream and D0 far downstream"  /U, D1, D0/ ;
set optim_household(household) "Households to be considered during current solve run" ;
set crop "type of crops"  /sugarcane, khat, maize, enset/;
set irr_crop (crop)  "Type of Irrigated crops" / sugarcane, khat/;
set rainfed_crop (crop) "Type of Rainfed crops" /maize, enset/;
set input "Agricultural inputs"   /labor, fertilizer, insecticide, compost, water/;
set utility_source "Sources of utility for the households" /consumption_food, consumption_nonfood, leisure/
set FoodItem "Food items in the consumption basket of the households" /meat, milk, maize, enset, teff, vegetables, fruits/
set cropfood(crop, FoodItem) crops that are also food /maize.maize, enset.enset/;
set NonFoodItem "Non-food consumption items" /clothing, medication, education/;
***parameter*********
parameter  UtilityWeights(utility_source)  Weight of household consumption of items in Utility-function  by household
        /consumption_food=0.83, consumption_nonfood=0.04, leisure=0.13/;
scalar DiscountRate /0.18/;
parameter Effrain (crop)   Effective rainfall per ha used by each crop over the growing period in m³ per ha?
                    /sugarcane=8960, khat=6063, maize=0, enset=0/;
scalar CEBL The average Conveyance efficiency of the canals in the irrigation scheme   /0.65/;
Table CDcoefficients (household, crop, input)  Cobb-Douglas stochastic production frontier coefficients for inputs
                    labor     fertilizer    insecticide      compost     water
U.sugarcane       0.3660431        0.1160097      0.0219023       0.0358285      0.7264282
U.Khat          0.1590262        0.3555288       0.0530066      0.03756        0.4143951
U.maize          0.8586418        0.141119       0.0000         0.0000         0.0000
U.enset         0.4844995        0.0000         0.0000        0.4824402       0.0000
D1.sugarcane      0.3660431        0.1160097      0.0219023       0.0358285      0.7264282
D1.khat         0.1590262        0.3555288       0.0530066      0.03756        0.4143951
D1.maize         0.8586418        0.141119       0.0000         0.0000         0.0000
D1.enset        0.4844995        0.0000         0.0000        0.4824402       0.0000
D0.sugarcane      0.3660431        0.1160097      0.0219023       0.0358285      0.7264282
D0.khat         0.1590262        0.3555288       0.0530066      0.03756        0.4143951
D0.maize         0.8586418        0.141119       0.0000         0.0000         0.0000
D0.enset        0.4844995        0.0000         0.0000        0.4824402       0.0000 ;
table constant (household, crop) intercepts from production function estimation plus coefficients for location dumies(indicating
technicl efficiency)
         sugarcane         khat          maize         enset
U        0.344525         -0.03357       0.330935      -0.23735
D1       0.344525         -0.03357       0.330935      -0.23735
D0       0.344525         -0.03357       0.330935      -0.23735;
Table Capacity(household, crop, input)  The maximum limits of the agricultural inputs per ha by each household under current
condition(Actual per ha values scaled up by 20 percent)
               labor         fertilizer    insecticide      compost       water
U.sugarcane       4112.448       496.968        3492.4812       14203.284      19342
U.Khat          2824.104        562.368        1487.46        18421.428      9613
U.maize          3648          322.284       0.0000         0.0000        0.0000
U.enset         3740.448       0.0000        0.0000        25398.264      0.0000
D1.sugarcane      3936.192       481.752        3600.76        20513.352      19342
D1.khat         2916.6         550.2         1241.268       17759.80       9613
D1.maize         3099.072        318.42        0.0000         0.0000        0.0000
D1.enset        3890.136        0.0000        0.0000         26660.808      0.0000
D0.sugarcane      3251.232       395.904        1914.9084      13929.732      19342
D0.khat         1827.276        200.724        648.288        16463.352      9613
D0.maize         1997.568        241.296        0.0000         0.0000        0.0000
D0.enset        3214.848        0.0000        0.0000         19300.908      0.0000 ;
Parameters IrrWatReq (crop) Irrigation water requirement per ha calculated using CROPWAT software in cubic m per ha?
/sugarcane=10382, Khat=3550, maize=0, enset=0/;
Parameter  CropWatReq(crop)  Crop  water  requirement  for  each  crop  (  sum  of  Effective  rainfall  and  Irrigtion  water
requirement(the formula symbol is CWR)
/sugarcane=19342, khat=9613, maize=0, enset=0/;
Table current_water_use(household, crop)  Current level of water use by households for each crop in cubic meter total
         sugarcane         khat          maize         enset
U        261811.50         102272.2       0.00          0.00
D1       82626.85          28999.67       0.00          0.00
D0       0.00              0.00           0.00          0.00 ;
```

```
scalar TotalAnnualDays    total days in a year to be used in minimum food requirement /365/;
scalar WorkingDaysPerYear average working days in a year (261 minus 14 public holydays in Ethiopia) /247 /;
 scalar DailyLabourHours  maximum working hours per day  / 8 /;
scalar WagePerDayFarmLabour average wage rate of daily farm laborer per day /56.5/;
Parameter WagePerHourFarmLabour;
WagePerHourFarmLabour = WagePerDayFarmLabour / DailyLabourHours;
parameter TotalTimeEndowment_md(household)  labor time endowment in man day of household in adult equivalent annual
/U=72840.30, D1=80028, D0=64491.70/;
Parameter TotalTimeEndowment(household) laber endowment in hours;
TotalTimeEndowment(household) = TotalTimeEndowment_md(household) * DailyLabourHours;
**Hiring out non agricultural
parameter Off_farm_income (household)        fixed income generated from off-farm employement per household
/ U=228600, D1=277914, D0=322640/;
parameter DailyLabourInvestedNonFarmEmployement(household) Fixed labor hours invested in non-farm activities per day
/U=50,D1=51, D0=47/;
parameter AnnualLabourInvestedNonFarmEmployement(household) Fixed labor (hours) invested in non-farm activities per
year;
AnnualLabourInvestedNonFarmEmployement(household) = DailyLabourInvestedNonFarmEmployement(household) *
WorkingDaysPerYear;
**Hiring out agricultural
parameter DailyLabourInvestedOtherfarmLabour(household) "Maximum time available that HH's (household group)members
can invest in other farm labour work in hours per day"
/U=0, D1=0, D0=107/;
parameter MaxLabourInvestedOtherfarmLabour(household)      "Maximum labor (hours) that can be invested per year per
household group";
MaxLabourInvestedOtherfarmLabour(household)=              DailyLabourInvestedOtherfarmLabour(household)              *
WorkingDaysPerYear;
table HiredInLabourDays_o (household, crop) Maximum hired labor in man day per ha per households per crop
sugarcane      khat       maize       enset
U          209.07         82.43     161.81      198.88
D1          197.06         80.15     80.16       156.94
D0          181.74         26.90     64.51       237.90 ;
Parameter MaxHiredInLabourHours(household, crop)  Maximum available hirable labor in hours hired by households refined;
MaxHiredInLabourHours(household, crop) =  HiredInLabourDays_o (household, crop)* DailyLabourHours;
parameter InputPrice(input)               price per unit of agricultural inputs used
/labor=0 , fertilizer=12.71, insecticide=1, compost=0.22, water=0/;
Parameter InitialCashEndowment(household) Net cash income available at the begginig of the planning horizon
 /U= 1043100,D1=998100,D0=468450/;
parameter price(crop)   Average selling price of crops produced by the households
/sugarcane=.924, khat=102.23, maize=5.45, enset=6.35/;
parameter PriceFood(FoodItem)  Average price of the food items purchased by the households
/meat=99.30, milk=10.62, fruits=8.98, vegetables=5.09,enset=6.35, maize=5.45, teff=12.98/;
table CostsPurchasingNonFoodFx(household,NonFoodItem) fixed annual non food consumption expenditures of the
households
            clothing      medication      education
U            9700         3845            9600
D1            17685         5424            17885
D0            9120          6390            10075;
scalar MinKcal    minimum dayly food requirement (adult equivalent)
/2100/;
Parameter MinKcal_Mix (FoodItem) Minimum calory contributions of different food items based on the currently observed
consumption pattern of the households
 /meat=14.49, milk=193.20, fruits=14.07, vegetables=36.54, enset=1155, maize=581.7, teff=105/;
Parameter AdultEqHHSize (Household) family size of the households in adult equivalent units for consumption
/ U=425.77, D1=472.65, D0=407.91/;

Table MinFoodNeedsKcal_Mix(household,FoodItem) Minimum Annual food requirement in adult eqivalent unit in a
currently observed mix
                 meat              milk          fruits        vegetables          enset                 maize       teff
        U        2251833.66   30024448.86   2186563.12    5678537.06     179493987.75   90399699.28      16317635.25
        D1        2499774.95   33330332.7    2427317.70    6303780.31     199257423.75   100353284.32     18114311.25
        D0        2157374.80   28764997.38   2094842.20    5440336.46     171964658.25   86607655.15    15633150.75 ;

Parameter FoodKcal(FoodItem)   energy content of the food items in the households consumption basket in Kcal # per what?
kg?
/meat=1100, milk=1470, fruits=1210, vegetables=160, enset=2030, maize=2333, teff=1660/;
table CropArea(household, crop)  the initial land allocation in ha to each crop by household in t=2015
```

```
            sugarcane   khat    maize   enset
U            9.07       12.32   2.075   2.495
D1          17.4425     12.1875  6.515    4.28
D0           4.6725      9.845   6.9775   3.78 ;
table CropArea(household, crop)  the initial land allocation in ha to each crop by household in t=2015
            sugarcane   khat    maize   enset
U           14.07       17.32   7.075   7.495
D1          22.4425     17.1875  11.515  9.28
D0           9.6725     14.845   11.9775 8.78
scalar EulersNumber /2.71828/;
Positive Variables
InputLevel(household,crop,input,t)        variable describing the level of input use by households per ha
LNYield(household,crop,t)                 Variable describing the logarithmic yield of each crop in each household in t
Production(household, crop,t)             Variable describing the amount of output produced in Kg for each crop per HH
LandSize(household,crop,t)                Variable describing the size of land allocated to each crop in each household in ha(?) ;
Equation
QInputLevel(household, crop, input,t)     Function constraing the amount of differnt inputs use (but not water) not to exceed the available capacity by households in t
QLNYield(household,crop,t)                Function calculating the logarithmic  yield per ha of each crop in t
QProduction(household,crop,t)             Function translating the log-yield of the respective crop into kg-yield in t ;
QInputLevel(household, crop, input,t) ..  Capacity(household, crop,input)=g= InputLevel(household, crop, input ,t);
QLNYield(optim_household,crop,t)..        LNYield(optim_household,crop,t)   =e=   sum(input, CDcoefficients(optim_household,crop, input) * log(InputLevel(optim_household,crop, input,t) +1E-6) )+ constant (optim_household, crop);
QProduction(household,crop,t)..   Production(household,crop,t)   =E=   (exp(   LNYield(household,crop,t)))   * LandSize(household, crop, t);
Parameter
MaxWater_BL Available Water (constant)
Gross_Scheme_discharge Water available for irrigation;
MaxWater_BL = sum((household,crop), current_water_use(household, crop));
Gross_Scheme_discharge = MaxWater_BL;
Positive Variable
GrossIrrWaterUse(household, crop,t)       "Variable describing the total irrigation water requirement of each crops per household considering the conveyance efficiency of the system"
Total_Water_HH(household, t)              "Variable for the overall water use per hh" ;
Equations
QCrop_wat_req(household, crop,t)          "limit the water use to the need of the plants per ha for each household per crop in t"
QIrr_wat_use_hh(household,crop,t)         "aggregate from per ha to overall per hh and crop"
QTotal_Water_HH(household, t)             "new equation to sum up water use over the crops"
QTotal_Water_Balance(t)                   "Overall Water balance for all" ;
Qcrop_wat_req(household,crop,t)..         InputLevel(household, crop,"water", t) =L=  CropWatReq(crop);
QIrr_wat_use_hh(household,crop,t)..       GrossIrrWaterUse (household, crop,t) =E= (InputLevel(household, crop, "water", t)- Effrain(crop))* LandSize(household, crop, t);
QTotal_Water_HH(household, t)  ..         Total_Water_HH(household, t)  =E=  SUM(crop, GrossIrrWaterUse(household, crop,t));
QTotal_Water_Balance(t)  ..               SUM(household, Total_Water_HH(household, t)) =L=  Gross_Scheme_discharge ;
Parameter CostsTotalNonFoodEx(household)  Total cost of all non food Items;
CostsTotalNonFoodEx(household) = SUM(NonFoodItem, CostsPurchasingNonFoodFx(household, NonFoodItem));
Positive Variables
LabourInvestedOtherFarm(household,t)      "labour on other farms in hours per year"
HiredLabourInvested(household,t)          actual labour hired per household and year in hours
LabourInvestedNonFarmEmployement(household, t)   actual labour invested in non-farm employment (hours per year)
TotalCashIncome(household,t)              "total cash income per household in t"
IncomeFarmLabour(household,t)             "cash income from farm labor employment on another farm per household in t"
IncomeCropSales(household,t)              "cash income from crop sales per household in t"
IncomeOffFarmEmployement(household,t)     "cash income from non-farm employement per household (non farm income: a fixed amount"
AmountCropSold(household,crop,t)          "amount crops sold, per hh and crop and year, by AJ"
AmountFoodPurchased(household, FoodItem,t)   amount food to be purchased per hh per year and item in kg, by AJ
TotalCashNeeds(household,t)               "cash needs per household in t"
CostsHiringInLabour(household,t)          "cash needs for hiring in farm labour per household in t"
CostsPurchasingFood(household,t)          "cash needs for purchasing consumption food items per household in t"
CostsPurchasingInputs(household,t)        "cash needs for purchasing agricultural inputs per household"
CashSurplus(household, t)   ;
IncomeOffFarmEmployement.fx(household,t) = Off_farm_income (household) ;
```

Equations
QIncomeBalance(household,t) "Ensuring that cash income is equal to expenses per Household in t"
QTotalCashIncome_t(household,t) "Calculating total cash income per household in t"
QIncomeFarmLabour(household,t) "Calculating income from farm labour work per household in t"
QIncomeCropSales(household, t) "Calculating income from crop sales per household in t"
QTotalCashNeeds(household,t) "Calculating total cash needs per household in t"
QCostsHiringLabour(household,t) "Calculating cash needs for hiring in labour per household in t"
QCostsPurchasingFood(household,t) "Calculating cash needs for purchasing food per household in t"
QTotalInputCosts(household,t) "Calculating cash needs for purchasing agricultural inputs per household in t" ;

QIncomeBalance(household,t).. TotalCashIncome(household,t)=E= TotalCashNeeds(household,t)+ CashSurplus(household,t);
QTotalCashIncome_t(household,t)..
TotalCashIncome(household,t)=E=IncomeCropSales(household,t)+IncomeOffFarmEmployement(household,t)+ IncomeFarmLabour(household,t) ;
QIncomeFarmLabour(household,t).. IncomeFarmLabour(household,t)=E=LabourInvestedOtherFarm(household,t)* WagePerHourFarmLabour;
QIncomeCropSales(household, t).. IncomeCropSales(household,t)=E=Sum(crop,AmountCropSold(household,crop,t)* price(crop));
QTotalCashNeeds(optim_household,t).. TotalCashNeeds(optim_household,t) =E= CostsHiringInLabour(optim_household,t)
+CostsPurchasingFood(optim_household,t)+CostsTotalNonFoodEx(optim_household)+
CostsPurchasingInputs(optim_household,t);
QCostsHiringLabour(household,t).. CostsHiringInLabour(household,t) =E= HiredLabourInvested(household,t) * WagePerHourFarmLabour;
QCostsPurchasingFood(household,t).. CostsPurchasingFood(household,t) =e= sum (FoodItem, AmountFoodPurchased(household, FoodItem,t)* PriceFood(FoodItem));
QTotalInputCosts(household,t).. CostsPurchasingInputs(household, t)=e= sum ((crop,input), InputLevel(household,crop,input,t) * LandSize(household, crop, t) * InputPrice(input));

Positive variables
Leisure(household,t) Level of leisure per household
OwnLabourProductive(household,t) Amount of family labour invested in productive (non-leisure) activities per household
TotalLabourInvestedCrops(household,t) Total of own and hired labour used for the production of crops during the year per household in t
OwnLabourInvestedCrops(household,t) Total own labor invested in crop production during the year per household in t ;
Equations
QTotalTimeEndowment(household,t) Function making sure that family productive time and leisure should not exceed the total labor time pool of the household
QTotalOwnLabourInvested(household,t) Function calculating the total own labor invested in different activites that the household engaged in
QTotalOwnLabourCrops(household,t) Function culculating the total own labor invested in crop production as a difference between total labor invested in crop production and hired labor invested for crop production
QHiredLabourInvested(household,t) Function constraining that the total hired labor per household should not exceed the maximum hirable labor days
QTotalLabourInvestedCrops(household,t) calculating the total labor invested in crop production per household in t;
QTotalTimeEndowment(household,t)..TotalTimeEndowment(household)=g=OwnLabourProductive(household,t)+ Leisure(household,t) ;
QTotalOwnLabourInvested(optim_household,t)..OwnLabourProductive(optim_household,t)=e=
OwnLabourInvestedCrops(optim_household,t)+LabourInvestedOtherFarm(optim_household,t)+
LabourInvestedNonFarmEmployement(optim_household,t);
QTotalOwnLabourCrops(household,t).. OwnLabourInvestedCrops(household,t) =e= TotalLabourInvestedCrops(household,t)- HiredLabourInvested(household,t) ;

QHiredLabourInvested(household, t).. HiredLabourInvested(household,t)=L=
sum (crop, MaxHiredInLabourHours(household,crop) * LandSize(household, crop, t)) ;
QTotalLabourInvestedCrops(household,t)..
TotalLabourInvestedCrops(household,t) =e= sum (crop, InputLevel(household,crop,"labor",t) * LandSize(household, crop, t));

Parameter MinFoodNeedsKcal(household) Minimum kcal per household;
MinFoodNeedsKcal(household) = AdultEqHHSize(Household) * MinKcal*365 ;
Positive Variables
FoodConsumption(household, FoodItem, t) Annual consumption in Kg per HH per food-item

```
FoodConsumptionKcal_PerFoodItem(household,FoodItem,t)          Annual food consumption in Kcal per each food item
AmountCropOwnConsumption(household, crop, t)                   Annual consumption of own produced crop in kg per HH per crop
AmountFoodItemOwnConsumption(household, FoodItem, t)  ;
AmountCropOwnConsumption.fx(household, crop, t) =0;
AmountFoodItemOwnConsumption.fx(household, FoodItem, t) =0;
loop (crop,
AmountFoodItemOwnConsumption.up(household,FoodItem,t)$(cropfood(crop, FoodItem)) = INF;
);
loop (FoodItem,
AmountCropOwnConsumption.up(household,crop,t)$(cropfood(crop, FoodItem)) = INF;
);
Display AmountFoodItemOwnConsumption.up;
display AmountCropOwnConsumption.up;

Equations

QProdBalance(household, crop, t)             Equation balancing Total Production with all possible uses of own production of crops
IdentityOwnFood(household, t, crop, FoodItem)                Establish identity between some crops and some food items
QFoodAvailability(household, FoodItem, t)                  Equation making sure food consumption can be achieved from the two sources: purchases & own production
QAnnual_ConsumptionKal_PerFoodItem(household,FoodItem,t)      Equation converting annual food consumption from KG of each household to Kcal  per food item
QNutritionMix(household,FoodItem,t)                              Equation setting maximum limit for annual  consumption mix for different food items based on the current consumption pattern of the HHs
;
QProdBalance(household, crop, t)..
        Production(household,crop,t)=g=AmountCropOwnConsumption(household,crop,t)+
AmountCropSold(household,crop,t);
IdentityOwnFood(household, t, crop, FoodItem)$cropfood(crop, FoodItem)..
 AmountCropOwnConsumption(household, crop, t) =E=  AmountFoodItemOwnConsumption(household, FoodItem, t);
QFoodAvailability(household, FoodItem, t) ..

FoodConsumption(household,FoodItem,t)=e=AmountFoodPurchased(household,FoodItem,t)+AmountFoodItemOwnConsumption(household,FoodItem,t);
QAnnual_ConsumptionKal_PerFoodItem(household,FoodItem,t)..
FoodConsumptionKcal_PerFoodItem(household,FoodItem,t)=e=FoodConsumption(household,FoodItem,t)*
foodKcal(FoodItem);
QNutritionMix(optim_household,FoodItem,t)..
FoodConsumptionKcal_PerFoodItem(optim_household,FoodItem,t)=g=
inFoodNeedsKcal_Mix(optim_household,FoodItem);
Parameter MaxLandSize(household, t)   available area          alpha;
MaxLandSize(household, t) = SUM (crop, CropArea(household, crop));
alpha=1;


Equations
QAllocatedLandSizec(household,t)             "Making sure sum of individual land sizes allocated to each crop do not exceed total available land"
QAllocatedLandSize(household,t)           "Making sure sum of individual land sizes allocated to each crop do not exceed total available land" ;
QAllocatedLandSizec(household,t)..         LandSize(household, "sugarcane", t) =e=  alpha*LandSize(household, "Khat", t);
QAllocatedLandSize(household,t)..          MaxLandSize(household,t)=g= Sum(crop, LandSize(household, crop, t)) ;

Variable
AnnualUtility(household, t)   utility per year and hh
Utility(household)           utility per household
TOTAL_UTILITY ;
Equations
Qutilityhh_t(household, t)    calculation of utility per household and year
Qutilityhh(household)        calculation of utility per household
QUtility                     calculation of total utility  ;
Qutilityhh_t(household,t) ..
 AnnualUtility(household,t)=E=sum(FoodItem,FoodConsumption(household,FoodItem,t)*PriceFood(FoodItem))**
UtilityWeights("consumption_food")*CostsTotalNonFoodEx(household)**UtilityWeights("consumption_nonfood")*
(Leisure(household,t)*WagePerHourFarmLabour)** UtilityWeights("leisure");
```

```
Qutilityhh(household)     ..   Utility(household) =E= SUM(t, AnnualUtility(household,t)* (1/((1+DiscountRate)**ord(t))  ) );
QUTILITY. .    TOTAL_UTILITY  =E=  sum (optim_household, Utility(optim_household) );
Model Wondogenet /all/;
OPTION minlp   = BARON      ;
OPTION nlp     = CONOPT     ;
Wondogenet.optfile = 1      ;
Solve Wondogenet using NLP maximizing TOTAL_UTILITY;
```

A.6: Questionnaire

Introductory Statement:

The information from this survey will be used only for academic purposes to be carried out by A PhD candidate from JLU-Giessen-Germany, department of Agricultural Economics in collaboration with Hawassa University-Ethiopia. It is carried out with the aim of examining the impact of optimum water use on household welfare.

Your response to these questions is anonymous. However, if you agree we will write down your contact information in case some issues in the questionnaire are unclear.

Thank you for your kind co-operation!

The questionnaire is intended for households that practice small scale private irrigation by diverting surface water from a river. Please note if there are any deviations from this in the location in which the interview takes place.

Start of interview: Date (mm/dd/yr):____________________ Time: _____________________

Name of Interviewer: ____

Household Characteristics

Key for 1.4.– Marital status	Key for 1.5.1 – Gender:
1. Married, 2. Single	1. Male 2. Female

Section 1: Household Roster--Members of Households, Education, and Employment

1.1. Name of respondent ____

1.2. How long has the household been involved in farming? __________ (In number of years)

1.3. Household size (of owner of the farm): ________________________________

1.4. Marital status of the owner of the farm (Key)__________________________

1.5. HOUSEHOLD ROSTER

HH Id. No.	1.5.1 Gender **(key)**	1.5.2 Age (**years**)	1.5.3 Education (**No. of years)**
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

Key for 1.7.1, 1.7.4, and 1.7.7:

Activities

1. Crop production	**4.**Irrigation related activities (Abstracting river, irrigating field etc)	**7.** Small business
2. Livestock production	**5.** Farm labor worker for another farm	**8.** Student
3. Off farm employment (Teacher, health worker, driver etc)	**6.** Participation in social capital (Idir, Equb, Fnural, weedings, debo, etc)	**9.**Other (Please specify) ………………………

1.6: Time Spent on different activities

HH ID	1.6: **Time spent on Activities**									
	Crop production	Shared labor	Livestock production	Off farm employment	Irrigation related activities	Farm labor worker for another farm	Participation in social capital	Small business	Student	Other (Please specify) …
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										

1.7: Time spent and income generated from activities

HH ID	1.7.1 Activity 1 (key)	1.7.2 Time spent (PD/week)	1.7.3 Income from activity 1 (ETB/day)	1.7.4 Activity 2 ***(key)***	1.7.5 Time spent *(PD/ week)*	1.7.6 Income fromactivity2 *(ETB/ day)*	1.7.7 Activity 3*(key)*	1.7.8 Time spent *(PD/ week)*	1.7.9 Income from activity3 *(ETB/ day)*
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									

Section 2: Household Assets

2.1.0: Type of Asset	2.1.1 1:Yes; 2: No	2.1.2 How many?	**Replacement cost, Year purchased and OP**		
			2.1.3 Estimated current value (ETB)	2.1.4 Year purchased (**Ethiopian Calendar**)	2.1.5 Original price (**ETB**)
1. Gold/jewelry					
2. Iron cooking pan(s)					
3. Modern bed					
4. Radio					
5. Toilet					
6. Cell phone					
7. Primary residence made of stone/concrete or brick					
8. Refrigerator					
9. Car(s)					
10. Primary residence with metal roof material					
11. Other, specify ___________					

Key for 3.1.2- Soil type: 1.Clay 2.Sandy; 3.Dark soil; 4. Red soil; 5. Other [pls. specify]_______	**Key for 3.1.3 - Soil fertility**: 1. Highly fertile 2. Moderately fertile 3. Infertile	**Key for 3.1.4 - Slope:** 1. Flat, 2. Slight incline 3. Steep	**Key for 3.1.5 – Soil Depth** 1. Deep 2. Medium 3. Shallow
KEY for 3.1.6 – Conservation type 1: Soil bund 2. Stone bund 3. Fanya Juu 4. Grass strip 5: Water way 6: Planting tree	7:Ploughing along the contour 8: Do not practice 8: Others Specify **Key for 3.1.7 - Source of water**: 1. Public well + private pumping /transport; 2. Public river storage + private pumping;	3. Private well + private pumping; 4. Rain fed 5.Water harvesting 6. Other (Please specify)……………….. **Key for 3.1.8 – Source of own landholding:** 1. Inherited, 2. purchased, 3. from the government	**Key for 3.1.9 - Land certified:** 1. Certified 2. Not certified 3. Leased in from government
Key for 3.1.110 - Type of land use: 1: Own use, 2. Renting out (cash rent), 3. Renting in, 4. "Pure" Sharecropping in,	5."Pure" Sharecropping out, 6. "Cost-sharing" Sharecropping in 7. "Cost-sharing" Sharecropping out	8: Communal land (traditional ownership), 9: Borrowed land in (Do not pay for usage),	10. Borrowed land out (does not receive money for usage) 11: Other (pls. specify___________)

Section 3: Land Tenure/Characteristics

3. Land ownership and land holding

3.1. Current total own landholding in haha

Parcel No	Name of location of parcel	Plot No	3.1.1 Area of plot (ha)	3.1.2 Soil type **(key)**	3.1.3. Fertility of soil **(key)**	3.1.4 Slope **(key)**	3.1.5 Soil Depth **(key)**	3.1.6 Land Management			3.1.7. Source of water **(key)**	3.1.8Source of own landholding **(key)**	3.1.9 Land certified **(key)**	3.1.10 Type of land use **(key)**	3.1.11 If rented, what is the annual rent *(ETB)*	3.1.12 If share-cropped, what is your share? *(percent)*	3.1.13 Distance of from homestead (km)
								Type of conservation (**key**)	Initial cost	Annual maintenance cost							

3.2. (a) Have you sold land? ____ (1: yes, 2: no), (b). If yes, state reason:_______________________________, (c) current value:_______________ (d) for ___________(size - ha) [**or** (e) original selling price _______________/(f) year______]

3.3. If you would rent all your land out for one year, what would you obtain for it? ______________________(ETB)

3.4. If this farm (including land, buildings, equipment and livestock) were for sale, what is its approximate value? ______________________ [if too difficult, go to 3.5]

3.5. If you were to purchase a farm identical to yours (including land, buildings, equipment and livestock), what would you have to pay for it? __________________

KEY for 4.1.2 – Type of ownership

1. Household has ownership;

2. Jointly owned with other households/farm entities,

3. Hired for household or joint use

Section 4: Farm Machinery, Farm Buildings, Wells & Pumps, and Wage Rate

4.1: Information on Farm Tools and Machinery that you used:

Tool/Machinery/ Implements	4.1.1: Number	4.1.2: Who owns the equipment? **(key)**	4.1.3: If you own it, year purchased	4.1.4 If you own the tool/machinery, please state current value [CV]/unit *(ETB) or original price [OP]/unit with year*		4.1.5 Repair cost during (Dec. 2013-Nov. 2014	4.1.6 Average lifespan of item (No. of years)
				(a) CV/unit	(b) OP/unit		
Farming tools:							
1. "Gejera"							
2. Hoe							
3. Spade/shovel							
4. Pick axe							
5. "Deger"							
6. Winnower							
7. Plough and yoke for animals							
8. “Maresha”							
9. Reaper/Sickle							
10. Manual sprayer							
11. "Wagel" tip							
12. "Erfe" (handle)							
13. Rake							

Tool/Machinery/ Implements	4.1.1: Number	4.1.2: Who owns the equipment? **(key)**	4.1.3: If you own it, year purchased	4.1.4 If you own the tool/machinery, please state current value [CV]/unit *(ETB) or original price [OP]/unit with year*		4.1.5 Repair cost during (Dec. 2013-Nov. 2014	4.1.6 Average lifespan of item (No. of years)
				(a) CV/unit	(b) OP/unit		
14. Wheelbarrow							
15. Carts (hauling)							
16. Other Light Machinery (please specify __________							
Machinery							
20. Generator/Diesel Pumps							
Farm Animal Power							
21. Bulls/oxen							
22. Horses							
23. Mules							
24. Donkeys							
25. Other Animal Power (please specify___________)							

Key for 4.2.1 type:

1: hand-dug borehole/well,
2: drilled borehole/well,
3: pond/lake,
4: micro reservoir/dam,
5: barrel/ cistern
6: Water way/canal
7: Other Please specify ………….

Key for 4.2.5 and 4.3.7 - ownership*:*

1: household has ownership;
2: jointly owned with other households/farm entities
3.Farmer association
4.Water user association,
5. other_______

Key for 4.3.2 - type:

1: diesel,

2: electricity,

3: manual [treadle pump],

4: wind,

5: other [please specify______]

Key for 4.3.9: - purpose

1: irrigation of crops,

2: irrigation of garden,

3: drainage,

4: domestic uses;

6: other (please specify)_________

4.2 What irrigation and water storage facilities do you use for crop production?

4.2.1 Type (***key)***	4.2.2 Year established	4.2.3 Value (ETB)		4.2.4 If borehole/well, depth in m, if reservoir capacity in m3		4.2.5 Who owns? ***(key)***	4.2.6 If you need to pay for usage, how much per m3? *[including government charges]*	
				(a) m	(b) m3		(a) unit	(b) amount
		CV	OP					

4.3 Do you use or own a pump? 1. Yes, 2. No ______If yes, please provide information on the pump(s)

4.3.1 Pump	4.3.2 Type ***(key)***	4.3.3 Year purchased if you own it	4.3.4 Original Price [OP] or current value [CV] *(ETB)*		4.3.5 Repair cost 12/2013-11/2014 *(ETB)*	4.3.6 Flow rate *(l/sec)*	4.3.7 Who owns? ***(key)***	4.3.8 Lifespan *(No. of years)*	4.3.9 Purpose ***(key)***	4.3.10 If associated with 4.3.1, include No.	4.3.11 Payment for usage	
			(a) OP	(b) CV							(a) unit	(b) amount
Pump 1												
Pump 2												
Pump 3												

4.4 Wage rate for farming

<table>
<tr><td rowspan="3">4.4</td><td rowspan="3">Farm Wage Rates</td><td colspan="4">Hired Labor</td><td colspan="4">If someone from the household works on someone else's farm, wage received</td></tr>
<tr><td colspan="2">Adult</td><td colspan="2">Child (≤15)</td><td colspan="2">Adult</td><td colspan="2">Child (≤15)</td></tr>
<tr><td colspan="2">4.4.1a</td><td colspan="2">4.4.1b</td><td colspan="2">4.4.1c</td><td colspan="2">4.4.1e</td></tr>
<tr><td>4.4.1</td><td>Average wage/day (across various activities) for each type of worker</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>4.4.2</td><td>Total In kind payments* or benefits per day (across various activities) [quantity] [incl. housing, food, land, crops, education, health]</td><td>Item</td><td>Amt (kg)</td><td>Item</td><td>Amt (kg)</td><td>Item</td><td>Amt (kg)</td><td>Item</td><td>Amt (kg)</td></tr>
<tr><td>4.4.3</td><td>Total number of laborers working during December 2013-November 2014</td><td colspan="2"></td><td colspan="2"></td><td colspan="4" rowspan="2"></td></tr>
<tr><td>4.4.4</td><td>Maximum number of labor working during December 2013-November 2014</td><td colspan="2"></td><td colspan="2"></td></tr>
</table>

Key for 5.1.1 - Crop type:

1.Sugarcane
2.Potato
3.Chat
4.Avocado
5.Lettuce
6.Tomato
7.Banana
8.Beetroot
9.Maize
10.Cabbage
11.Enset
12.Papaya
13.Mango
14.Carrot
15.Pepper
16.Eucalyptus tree
Others please specify……………

5. Crop Production - Annual and Perennial crops (for annual crops December 2013-November 2014)

5.1. Information on the primary crops grown on your farm: 5.1.1 Please state the average yield of your **principal** crops in a ***normal*** year.

(Translate all units into KG per HA and make notes on translations)

<table>
<tr><td rowspan="3">5.1.1 Crop Type (use crop type code)</td><td colspan="2">Annual</td><td colspan="8">Perennial</td></tr>
<tr><td colspan="2">Normal year Average yield per ha</td><td rowspan="3">Year established</td><td rowspan="3">Useful life</td><td colspan="6">Yield</td></tr>
<tr><td>Meher</td><td>Belg</td><td colspan="2">Maximum</td><td colspan="2">Moderate</td><td colspan="2">Minimum</td></tr>
<tr><td>Crop 1</td><td></td><td></td><td>Meher</td><td>Belg</td><td>Meher</td><td>Belg</td><td>Meher</td><td>Belg</td></tr>
<tr><td>Crop 2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Crop 3										
Crop 4										
Crop 5										
Crop 6										
Crop 7										
Crop 8										
Crop 9										
Crop 10										

Key for 5.2.1. f: Source of water

Public well +Private pumping/transport

Public river storage + Private pumping

Private well + Private pumping

4. Rain fed

5.Water harvesting

6. Others, Please specify

Key for 5.2.1.g – Type of Irrigation technology:

1. Flood;

2. Furrow;

3. Border;

4. Micro sprayer;

5. Surface Drip

6. Center Pivot

7: Trickle;

8: Sprinkle:

9. Individual (Hose, Bucket, etc)

10. Flowing river;

11. Other [specify] ____________________

Key for 5.2.2 a-b, 5.2.3.c-g; 5.2.3.a-e, 5.2.9a-e

1. "Gejera"

2. Hoe

3. Spade/shovel

4. Pick axe

5. "Deger"

6. Winnower

7. Plough and yoke for animals

8. “Maresha”

9. Reaper/Sickle

10. Manual sprayer

11. "Wagel" tip

12. "Erfe" (handle)

13. Rake

14. Wheelbarrow

15. Carts (hauling)

16. Other Light Machinery (please specify __________

Machinery

22. Generator/Diesel Pumps

Farm Animal Power

26 Bulls/oxen

27. Horses

28. Mules

29. Donkeys

30. Other Animal Power (specify___________)

Production data on annual and perennial crops (for Annual use Dec 2013-November 2014)

5.2 Production Cost and Income for Seasonal Crops

Parcel	**Plot**	**5.2 COST OF PRODUCTION** **5.2.1 Production activities**							**5.2.2. Land Preparation**									
		5.2.1a. Area	5.2.1b. Planted crop type	5.2.1c Share of plot planted with crop	5.2.1.d Planting date [y/m/d)	5.2.1.e Harvesting date [y/m/d]	5.2.1f. Source of water (**key**)	5.2.1.g Type of irrigation technology (**key)**	5.2.2a. Tools used in land preparation **(key)**		5.2.2b. Tools used in land preparation (**key)**		5.2.2c. Pair of animal-draft used in land preparation **[4.1]**		5.2.2d. OL use in land preparation (PD)		5.2.2e. HL use in land preparation (PD)	
									No	Days	No	Days	No	Days	A	C	A	C

Production data on seasonal crops for last year

Parcel	Plot	Planted crop type	**Cost of production: 5.2.3. Planting**														**Cost of production: 5.2.4 Seed**				
			5.2.3a OL planting: (PD)		5.2.3b HL planting: (PD)		5.2.3c Tools used (key)		5.2.3d Tools used (key)		5.2.3e Tools used (key)		5.2.3f Tools used (key)		5.2.3g Tools used (key)		5.2.4.1 Own Seed		5.2.4.2 Purchased Seed		5.2.4.3 Improved variety? [1=yes 2=no]
			A	C	A	C	No	Amount (kg)	Value (ETB/kg	Amount (kg)	Value (ETB/kg	Days	No	Days	No	Days	Amount (kg)	Value (ETB/kg	Amount (kg)	Value (ETB/kg	

Production data on seasonal crops for Dec 2013-Nov 2014

Parcel	**Plot**	Planted crop type	**Cost of production 5.2.5 Fertilizing**															
			5.2.5a. OL fertilizing (PD)		5.2.5b. HL fertilizing (PD)		5.2.5.1 Urea		5.2.5.2 DAP		5.2.5.3 Manure		5.2.5.4 Compost		5.2.5.5 Other, specify		5.2.5c. Tools used in Fertilizing/Pesticides: **(**key)	
			A	C	A	C	Amount (kg)	Value ETB/kg	Amount (kg)	Value ETB/kg	Amount (kg)	Value ETB/kg	Amount (kg)	Value ETB/kg	Amount (kg)	Value ETB/kg	No	Days

Key for 5.2.7a - type: 1: diesel 2: electricity, 3: manual [treadle pump], 4: wind, 5. Others---------

Production data on seasonal crops for December 2013-November 2014

Parcel	**Plot**	Planted crop type	**Cost of production** **5.2.6 plant protection**																			
			5.2.6a. OL pesticide app		5.2.6b.HL pesticide app		5.2.6.1 Insecticide (name):				5.2.6.2 Herbicides (name):				5.2.6.3 Fungicides (name):				5.2.6.4 Others, specify			
			A	C	A	C	Type	Units	Qty	Value/Q	Type	Units	Qty	Value/Q	Type	Units	Qty	Value/Q	Type	Units	Qty	Value/Q

Production data on seasonal crops December 2013-November 2014

Parcel	**Plot**	Planted crop type	**Costs of Production** **5.2.7 Irrigation petrol/electricity/labor**									
			5.2.7a Pump (**key)**		5.2.7b1 Diesel [liters/hour and ETB/liter]		5.2.7b2 Electricity [cost in ETB/hour]	5.2.7c Irrigation fee/Period	5.2.7d OL irrigation (PD)		5.2.7e HL irrigation (PD)	
			Code	Hours	Liters/hr	ETB/liter	Cost per hour	ETB	A	C	A	C

Production data on crops December 2013-November 2014

Parcel	**plot**	Planted crop type	**Cost of production**					**Cost of production**																	
			5.2.8. Other Labor / Machinery fuel					**5.2.9. Harvesting**																	
			5.2.8a OL weeding (PD)		5.2.8b HL weeding (PD)		5.2.8c Diesel fuel for machinery [total per season per crop] in ETB	5.2.9a Harvesting tools (**key**)		5.2.9b Harvesting tools (**key**)		5.2.9c Harvesting tools (**key**)		5.2.9d Harvesting tools (**key**)		5.2.9e Harvesting - animal-draft (**key**)		5.2.9f OL harvesting (PD)		5.2.9g HL harvesting (PD)		5.2.9h Other, specify
			A	C	A	C		No.	Days	No.	Days	No.	Days	No.	Days	No.	Days	A	C	A	C	

Production data on crops for December 2013-November 2014

Parcel	**Plot**	Planted crop type	**Cost of production 5.2.10. Post-Harvest (Threshing and transport)**				5.2.11. Total production after harvest
			5.2.10a OL post-harvest. Processing		5.2.10b HL post-harvest processing		
			A	C	A	C	

Key for 5.2.11h - Sold to
1: other local farmers
5: cooperative
6: other (pls. specify)___________
2: local market
3. Provincial market
4: middleman, trader

Production data on crops for December 2013-November 2014

Crop type	5.2.11 II. Production and Income									
	5.2.11a - amount consumed by household	5.2.11b - amount consumed by livestock	5.2.11c - amount left for seed next season	5.2.11d - amount lost after harvest (pest/storage)	5.2.11e - amount sold	5.2.11f Selling price (ETB/kg)	5.2.11g Sales tax	5.2.11h Sold to: **(key)**	5.2.11i Total revenue	5.2.11j Net income (*only if they know)*

Crop water use

Unit key: mm or m3 or liters (Fill for each plot and each season)

5.3 Crop water use

Parcel	Plot	Crop (key)	No. of days	No. of hrs per day	Flow rate/hour	Depth in mm	Water amount applied/ day	Total

***Key* for 6.2**:

1. Government Agency: ___________,
2. Agriculture research station,
3. NGO,
4. Other (specify) ________________

***Key* for 6.5**:

1. Government Agency [note down]: ___________________,
2. Agriculture research station,
3. NGO,
4. Other (specify)____________

***Key* for 6.7:**

1: Television;

2: Radio;

3: Neighboring farmer,

4: Shopkeepers in village;

5: None,

6: Others (please specify) _______

key for 6.9:

1. walk;
2. animal;
3. cart;
4. truck or other motorized vehicle;
5. Other (Specify)_______________

Section 6: Access to Extension, Markets and Credit

Extension and Training	**Yes**	**No**
6.1: Have you attended training for farmers in the last 2 years? (1: yes; 2: no)		
6.2: Which organization provided the training (Key)?		
6.3.1: Do you get information and advice from extension workers? (1: yes; 2: no)		
6.3.2 Do you get information/advice through farmer-to-farmer extension (1: yes 2: no)		
6.4: How many times did they visit you in the last 6 months		
6.5: The Extension officials who visit/contact you are from which organization? (**key**)		
6.6 Have extension officers provided information on expected rainfall and temperature? (1: yes; 2: no)		

6.7: If you get any technical assistance and advice from other sources apart from official extension workers, from where do you receive the necessary information? (Key)

Markets

6.8: How far is it to the nearest market where you ***sell*** your harvest? (a) In distance:_________(kms); **or** (b)__________in time (hrs)

6.9: What means of transport do you use to get to market? (Key) _____________________________

6.10: How far is it to the nearest market where you ***obtain*** your inputs? In distance: (a)_________(kms); **or** (b)_____________ in time (hrs)

6.11: Can you please tell us the total cost of the following activities?

	Type	Annual and perennial crops	
		unit	Cost [ETB]
6.11.1	Transport costs		
6.11.2	Packing/marketing		
6.11.3	Other (*please specify*) _____________		

key for 6.12.5

1: to buy farm machinery;

2: to buy farm inputs (seeds, fertilizers, pesticides);

3: to buy livestock;

4: to pay hired labor;

5: to pay rent or taxes

6: to start off-farm business;

7: to buy food/household goods;

8: to pay for education,

9: to pay for health expense;

10: to buy building materials;

11: to pay for travel costs;

12: for wedding;

13: for funeral;

14: repay other debts;

15: Other [specify]

6: 12 Credit Access

	6.12.1 Source yes = 1; no = 2	6.12.2 How often?	6.12.3 Total amt received	6.12.4 Interest rate *(Interest Rate/year)*	6.12.5 Use of credit for***(key)***
6.12.1 Relatives					
6.12.2 Neighbors (not relatives)					
6.12.3 Farmer associations/ co-operatives					
6.12.4 Commercial banks					
6.12.5 Traders					
6.12.6 Other private money lenders					
6.12.7 Credit and saving associations					
6.12.8 Microfinance institution					
6.12.9 NGO					
6.12.10 Women/Youth/ other associations					
6.12.11 Religious institution					
6.12.12 Government office					
6.12.13 Others (specify)					

Section 7: Expenditures on food and income

7.1 **Food expenditures: How often did your household in the last MONTH** *[outside of question period]* **spend money on the following food items?**

7.1.1	7.1.2	7.1.3	7.1.4
Food item	1: yes, 2: no	If yes, number of times (1, 2, 3…)	How much
1. Meat			
2. Milk			
3. Fruit			
4. Vegetables			
5. Total food expenditures of household last week			

7.2. Other Income (last 12 months, December 2013 to November 2014) of the household

7.2.1	7.2.2	7.2.4
Type of Income	Income obtained? (1 yes, 2: no)	Total income (ETB)
1. Gifts		
2. Remittances from city [relatives]		
3. From pension:		
4. Sale of assets for farming [agricultural tool, machinery, building, etc.]		
5. Sale of assets non-farming [TV, fridge...]		
6. Other [specify]:		
9. TOTAL		

7.3 What is the total net household income from farm activities in a normal average year?____________________

This part of the questionnaire we would like to know how much the farmers are willing to pay for more water

8. Water availability, Perception, and Willingness to Pay:

<table>
<tr><td colspan="2">8.1 Is the water available currently enough for your irrigation activities</td><td colspan="3">8.2How do you describe the current level of scarcity of water</td><td colspan="6">8.3. Perception on the overall availability of water</td></tr>
<tr><td rowspan="3">Yes</td><td rowspan="3">No</td><td rowspan="2">High</td><td rowspan="2">moderate</td><td rowspan="2">Not scarce</td><td colspan="3">River water</td><td colspan="3">Rain water</td></tr>
<tr><td>Has been the same</td><td>Has been deteriorating since 2002</td><td>Has been improving since 2002</td><td>Has been the same</td><td>Has been deteriorating since 2002</td><td>Has been improving since 2002</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

8.4 Willingness to pay open bid

8.4.1 Do you need more water for irrigation		8.4.2 For how many more hours do you need the water	8.4.3 Are you willing to pay for better and guaranteed irrigation water		8.4.4 How much are you willing to pay for			
Yes	No		Yes	No	1^{st} 15 min	2^{nd} 15 min	3^{rd}15min	4^{th} 15 min

8.5. If the answer for no. 8.4.1 is ‘yes’ and 8.4.3 is ‘No’ why?

I cannot afford it

I do not care much about improved water availability

It is the government’s responsibility to pay

I already pay enough taxes

I am satisfied with the existing situation

I Do not trust the existing water distribution scheme……………………………………

Other (please specify): ……………………………………………………………….

8.6. Willingness to pay closed bid for each

Bid	Response		Amount
20-40	Yes	NO	
40-60			
60-80			
>=80			

What crop would you grow if you would get more water...

How much portion of your land? ....

How much would you expect to harvest……………………………………………………………….

For how much would you expect to sale your produce……………………………………………………..

Where would you store if you would get more supply of water……………………………………………

How are you adapting to the problem of water scarcity…………………………………………………….

What do you think would be the best solution to permanently solve the problem of water scarcity?

Who do you think should solve it? ....

This section **must** be completed after the interview is completed. Given the importance of the following data for mapping and tracking purposes, Please ensure it is filled out accurately.

Instructions: This section to be filled out by interviewer.

Time Interview Ended (date and time): __________________

Name of interviewer: ________________________________ (this information is important to validate survey responses and will be used to cross check in the event that there are unusual observations during the analysis of the data)

Date of interview (mm/dd/yr) [ ]

Respondent Households' identification Number (Unique Household ID- should be assigned prior to interview) [ ]

Optional: Contact Information of Respondent: ____

<u>Location of Farm</u>

River [ ]

Kebele [ ]

Peasant Association [ ]

Farmers group [ ]

Water user group [ ]