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The Economics of Irrigation Systems in Ethiopia

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Abstract

The Government of Ethiopia has made a strong commitment to developing and expanding various types of irrigation systems, technologies, and institutions among smallholder farmers. As a result, the irrigated area in the country has substantially increased over the last three decades. Today, a variety of irrigation technologies and institutional arrangements can be found in the country. However, it remains unclear which institutions and irrigation technologies and combinations are most effective for rural growth, poverty alleviation, and environmental sustainability.

This thesis seeks to address these issues through assessing the economics of irrigation in Ethiopia. Starting from exploring the institutional arrangements for irrigation water management at federal, regional and local levels, the study investigates the role of multiple types of irrigation management systems and irrigation technologies in influencing three factors central to irrigation's future in the country: profit generation, farmers' empowerment and environmental sustainability. The research implemented using a mixed methods approach, including a unique and comprehensive household and plot level survey conducted in ten districts of the country in 2016/17, as well as qualitative data collected through focus group discussions in the same area. The data are further enriched with Landsat images and climate variables (for period 1981-2016) that are linked to geo-referenced household and plot level latitude and longitude coordinates.

A nested approach is used as an analytical framework to examine the existing institutional arrangements related to irrigation water development and management. The findings show that even if the policies, strategies, and the legal instruments are well specified, and the relevant institutions and organisations have been established, there has been weak enforcement capacity, overlaps in mandates, duplication of efforts and absence of an integrated system of information and resources management among organizations at each administrative level.

The economic analysis, using Inverse Probability Weighted Regression Adjustment (IPWRA) estimators, indicates that plots that use pumps and are in privately farmer managed, farmer group-managed, and jointly farmer-government managed systems score the highest net returns, at USD 1770/ha, USD 1700/ha, and USD 1350/ha, respectively. The lowest average net farm returns are recorded by farm households in joint farmer-government operated canal irrigation systems, at around USD 570/ha.

Using various indicators of farmers' empowerment through irrigation, econometric findings suggest that, compared to open access pump irrigators, all other irrigating farmers are more likely to be empowered; pump users have greater decision-making autonomy regarding using and managing the resource. Considering collective empowerment, farmer-led systems have a higher degree of beneficiaries' participation, decision-making capacity and a better-established irrigation governance system than irrigators who participate in systems jointly managed with the government.

Regarding environmental sustainability, the results of the NDVI, FGD and econometric analyses demonstrate that the overall trend observed in all types of irrigation sites included in the study is that vegetation has been increasing since irrigation development started. The most significant improvement in vegetation cover is noted in plots and surrounding areas that are directly managed by individual farmer irrigators pumping groundwater. Moreover, farmers participating in pump irrigation systems that are jointly operated with the government have adopted a larger number of sustainable land management (SLM) practices than farmers in other systems.

The overall results of the research indicate a need for immediate intervention in gravity irrigation schemes due to their low-income generation and for action on irrigation activities that are not supported by institutions due to problems related to equitable access to and management of the scarce resource. Strong emphasis should be given to active engagement, participation, and capacity building of all stakeholders at each level in the management and use of all irrigation systems.

This study comprehensively assessed the economics of irrigation systems in Ethiopia analysing the influence of various combinations of institutional and technological approaches on a series of key outcome indicators, such as net profits, empowerment, and environmental conditions, which are important for long-term poverty alleviation and environmental sustainability in Ethiopia. It is hoped that this information can be a valuable input for improved irrigation development to help achieve Ethiopia's vision of a climate-resilient green economy.

Zusammenfassung

Die äthiopische Regierung hat sich nachdrücklich dazu verpflichtet, verschiedene Bewässerungssysteme, technologien und -institutionen für Kleinbauern zu entwickeln und auszubauen. Infolgedessen hat die bewässerte Fläche des Landes in den letzten drei Jahrzehnten erheblich zugenommen. Heute gibt es im Land eine Vielzahl von verschiedenen Bewässerungstechnologien und Institutionen. Es bleibt jedoch unklar, welche Institutionen und Bewässerungstechnologien und Kombinationen für das ländliche Wachstum, die Armutsbekämpfung und die ökologische Nachhaltigkeit am effektivsten sind.

Diese Arbeit versucht, diese Fragen durch eine Bewertung der Wirtschaftlichkeit von Bewässerung in Äthiopien anzugehen. Ausgehend von einer Untersuchung der Bewässerungswassermanagementinstitutionen auf nationaler, regionaler und lokaler Ebene untersucht die Studie die Rolle verschiedener Arten von Bewässerungsmanagementsystemen und Bewässerungstechnologien für drei Faktoren, die für die Zukunft der Bewässerung im Land von zentraler Bedeutung sind: Gewinnerzielung, Förderung der Bauern und ökologische Nachhaltigkeit. Die Forschung verwendet einen "mixed methods" Ansatz, die eine umfassende Umfrage auf Haushalts- und Grundstücksebene, die 2016/17 in zehn Bezirken des Landes durchgeführt wurde, sowie qualitative Daten, die durch Fokusgruppendiskussionen in demselben Bereich gesammelt wurden, miteinschließt. Diese Daten wurden zudem mit Landsat-Bildern und Klimavariablen (für den Zeitraum 1981-2016) angereichert, die mit georeferenzierten Breiten- und Längenkoordinaten der Haushalts und Parzellendaten verknüpft wurden.

Ein komplexer Ansatz wird als analytischer Rahmen verwendet, um die bestehenden Institutionen im Zusammenhang mit der Entwicklung und dem Management von Bewässerungswasser zu untersuchen. Die Ergebnisse zeigen, dass, selbst wenn Politik, Strategien und Rechtsinstrumente sehr gut definiert sind und die entsprechenden Institutionen und Organisationen eingerichtet wurden, die Durchsetzungsfähigkeit gering ist, es Überschneidungen gibt und integrierte Systeme der Informations- und Ressourcenverwaltung zwischen den Organisationen auf jeder Verwaltungsebene fehlen.

Die wirtschaftliche Analyse unter unter Verwendung von der IPWRA (Inverse Probability Weighted Regression Adjustment) Methode zeigt, dass landwirtschafliche Flächen, auf denen Motorpumen für die Bewässerung verwendet werden, und die direkt von Bauern, Gruppen von Bauern, oder von Bauern mit der Regierung zusammen bewirtschaftet werden, hohe Nettoerträge erzielen, respektive 1770 US-Dollar pro Hektar, 1700 US-Dollar pro Hektar und 1350 US-Dollar pro Hektar fuer die drei Optionen. Den geringsten durchschnittlichen Nettoertrag erzielen landwirtschaftliche Haushalte, die von der Regierung verwaltete Kanalbewässerung betreiben, mit rund 570 US-Dollar pro Hektar.

Basierend auf verschiedenen Indikatoren der bäuerlichen Förderung („empowerment") durch die Bewässerung legen ökonometrische Ergebnisse nahe, dass im Vergleich zu Pumpbewässerungsanlagen, die offen zugängliche Wasserressourcen verwenden, alle anderen Bauern, die Pumpbewässerung betreiben mehr gefördert oder „empowered" sind. Sie verfügen über eine größere Entscheidungsautonomie hinsichtlich der Nutzung und Verwaltung von Wasseressourcen. Eine Untersuchung von Ermächtigung durch kollektive Massnahmen zeigt darüber hinaus, dass Systeme, die von Bauern direkt verwaltet werden eine höhere Beteiligung von Bauern haben, eine bessere Entscheidungsfähigkeit sowie ein besser etabliertes Bewässerungs-Governance-System als Systeme, die von Bauern gemeinsam mit der Regierung verwaltet werden.

In Bezug auf die ökologische Nachhaltigkeit, zeigen die Ergebnisse von NDVI Analysen, Gruppendiskussionen und ökonometrischen Analysen, dass bei allen Bewässerungstypen eine

Zunahme der Vegetation seit Beginn der Bewässerungsinvestitionen stattgefunden hat. Die stärkste Zunahme an Vegetation ist in bewässerten und umliegenden Flächen zu finden, die von Bauern direkt mit Grundwasser bewässert werden. Zudem, finden sich eine größere Anzahl von Praktiken für die nachhaltige Landbewirtschaftung auf Bodenflächen, die gemeinsam von Regierung und Bauern verwaltet werden.

Die Gesamtergebnisse der Forschung zeigen, dass wegen geringem Einkommen sofortige Eingriffe in die Überflutungsbewässerungssysteme notwendig sind, sowie Maßnahmen bei Bewässerungsaktivitäten erforderlich sind, die ohne geeigneten institutionellen Rahmen ausgeführt werden, da dies zu Problemen im Zusammenhang mit einem gerechten Zugang zu und einer Bewirtschaftung der knappen Ressourcen führen kann. Ein starkes Augenmerk sollte auf die aktive Einbeziehung, Beteiligung und den Kapazitätsaufbau aller Beteiligten auf jeder Ebene bei der Verwaltung und Nutzung aller Bewässerungssysteme gelegt werden.

In dieser Studie wurde die Wirtschaftlichkeitder Bewässerung in Äthiopien umfassend analysiert und der Einfluss verschiedener Kombinationen von institutionellen und technologischen Ansätzen auf eine Reihe wichtiger Ergebnisindikatoren wie Nettogewinn, Empowerment und Umweltbedingungen analysiert, die für die langfristige Armutsbekämpfung und die Umwelt in Äthiopien wichtig sind. Es ist zu hoffen, dass diese Informationen einen wertvollen Beitrag zur Verbesserung der Bewässerungsentwicklung leisten können, um Äthiopiens Vision einer klimaresistenten grünen Wirtschaft zu verwirklichen.

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List of Abbreviations

AGP	Agricultural Growth Program
AMIT	Affordable Micro Irrigation Technology
ATA	Agricultural Transformation Agency
ATE	Average Treatment Effects
ATT	Average Treatment Effect on the Treated
BVP	Bivariate Probit
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station
CRGE	Climate Resilient Green Economy
CSA	Central Statistical Agency
CV	Coefficient of Variation
DAP	Diammonium Phosphate
EDRI	Ethiopian Development Research Institute
EEPA	Ethiopian Environmental Protection Authority
ETB	Ethiopian Birr
FAO	Food and Agricultural Organization
FDRI	Federal Democratic Republic of Ethiopia
FGD	Focus Group Discussion
FTC	Farmer Training Centres
GDP	Gross Domestic Product
GIS	Geographic Information System
GoE	Government of Ethiopia
GPS	Global Positioning System
GTP	Growth and Transformation Plan
IFPRI	International Food Policy Research Institute
IDA	Institutional Decomposition and Analysis
IMT	Irrigation Management Transfer
IPCC	Intergovernmental Panel on Climate Change
IPWRA	Inverse Probability Weighted Regression Adjustment
IWMI	International Water Management Institute
IWUA	Irrigation Water Users' Association
IWUC	Irrigation Water Users' Committee
KII	Key Informant Interview
masl	Meters above sea level
MoA	Ministry of Agriculture
MoARD	Ministry of Agriculture and Rural Development
MoF	Ministry of Finance
MoFED	Ministry of Finance and Economic Development
MOM	Management, Operation and Maintenance
MoWIE	Ministry of Water, Irrigation and Energy
MoWR	Ministry of Water Resources
NASA	National Aeronautics and Space Administration
NBE	National Bank of Ethiopia
NDVI	Normalized Difference Vegetation Index

NIR	Near-Infrared
NPS	Nitrogen-Phosphate with Sulphur
O&M	Operation and Maintenance
OWWCE	Oromia Water Works Construction Enterprises
PIM	Participatory Irrigation Management
POM	Potential-Outcome Mean
RBA	River Basin Authorities
RBHC	River Basin High Council
R&D	Research and Development
S&W	Soil and Water
SNNPR	Southern Nations, Nationalities, and Peoples' Region
SSI	Small-Scale Irrigation
TISMU	Tibila Irrigation Scheme Management Unit
TLU	Tropical Livestock Units
TM	Thematic Mapper
USD	United States Dollar
WB	World Bank
WRDF	Water Resources Development Fund
WRI	World Resources Institute
WRMP	Water Resources Management policy
WWCE	Water Works Construction Enterprise
WWDSE	Water Works Design and Supervision Enterprise
WUA	Water Users' Association

1. GENERAL INTRODUCTION

1.1 Background

Natural resources such as water play a fundamental role in the sustainability of rural livelihoods. Improvement in access to water for irrigation has both direct and indirect benefits for poverty alleviation and sustainable development. Direct benefits operate through localized and household-level effects, while indirect benefits operate through aggregate (regional and national) level impacts (Hussian & Hanjra, 2004).

Access to irrigation helps to diversify livelihoods and reduce vulnerabilities for rural farm households, since it creates options for extended production across the year, increases agricultural yield and creates employment opportunities (Ahmed & Sampath, 1992; Lipton et al., 2003; Gebremedhin & Peden, 2003; Hussain and Hanjra, 2004; Awlachew et al., 2008). Resulting increases in household incomes may grow rural expenditures and thus help stimulate the rural economy. The transition to a market economy integrates farm households into land, labour, commodity, and information markets which contribute to empowering the farm community in general and irrigation beneficiary households in particular (Hussain & Hanjra, 2004). In addition, participation of farmers in associations such as water users' associations can widen social networks and provides opportunities for empowerment, enabling farmers to create or build-up social capital (Gebremedhin & Peden, 2003). Smallholder irrigators mostly grow high value marketable crops such as fruits and vegetables during the dry season. Consequently, consumption of those crops among irrigation users and their communities usually increases (von Braun et al., 1989; Molden, 2007; Rosegrant et al., 2009; Burney et al., 2010; Domenech & Ringler, 2013). The same studies also indicate that since the crops produced are often rich in micronutrients, they can provide important nutrition benefits to farm households. Irrigation can also lead to increased consumption of animal source foods, through higher income and improved livestock productivity (Domenech & Ringler, 2013). The indirect irrigation-poverty linkage functions via sub-national, national, and economy-wide effects. Irrigation investment may act as a production and supply shifter with strong and positive effect on growth benefiting the poor in the long run (Hussain & Hanjra, 2004; Rosegrant et al., 2009).

On the other hand, poor irrigation practices accompanied by inadequate drainage may have adverse environmental impacts that include decreases in downstream river flow, increased evaporation in irrigated areas, lowering of groundwater tables, and pollution of water systems. In addition, irrigation may have long-lasting indirect effects on the environment such as water logging, soil salinity and ecological damage which have the potential to cause loss of soil fertility and productivity in irrigated agriculture (Holy, 1993; Hussain & Hanjra, 2004; Rosegrant et al., 2009; Molabo Montpellier Panel, 2018).

Furthermore, irrigation may have unexpected effects on the health, social, cultural, aesthetic, and political lives of the surrounding environment (Holy, 1993; Malabo Montpellier Panel, 2018).

On top of all that, the demand for water in general and water for agriculture in particular has risen exponentially, while supply has become more erratic and uncertain overtime (Seckler et al., 1998; Keller et al., 2000; Rosegrant et al., 2009; World Bank, 2016). Agriculture accounts for more than 80% of water withdrawals in the developing world (Cai et al., 2001). Over the next decades, the demand for agricultural water will continue to increase, due to growing population and increased wealth. Consequently, it is essential that irrigation water is used not only profitably but also sustainably (Rosegrant & Ringler, 1998; Rosegrant et al., 2009; Malabo Montpellier Panel, 2018). In sub–Saharan Africa, inadequate food production levels coupled with increasing water scarcity create serious challenges to agricultural as well as economic growth. Water demand for domestic, and industrial uses is also expected to grow faster than agricultural water demand in sub-Saharan Africa, which puts high pressure on supplies of irrigation (Rosegrant et al., 1999). Studies also show that rising temperature and unpredictable and erratic rainfall due to climate change will likely intensify water scarcity and lead to greater competition for agricultural water use (Bates et al., 2008; IPCC, 2014; World Bank, IFC, and MIGA, 2016). Generally, the challenges emanating from increasing water scarcity can be addressed via two strategies: (i) supply management by designing appropriate policies and actions to locate, develop and exploit new sources of water for irrigation, household and industrial uses and (ii) demand management which includes incentives and mechanisms that promote efficient use and conversation of water (Gebremedhin & Peden, 2003, Rosegrant et al., 2009; World Bank et. al., 2016).

1.2. Irrigation and its components

Irrigation systems are not stand-alone physical units. They are complex in their nature and include various interconnected components that vary in many dimensions. Vincent (1997) argues irrigation water as natural resource which flow to farm fields to support plant growth and transform biomass production. Ostrom (1990) and Bromley & Cernea (1989) conceive natural resources as a form of capital to which people have access, and irrigation as an investment that enhances potential utility of the natural resource, i. e., water. In order to capture, convey and distribute water to farm plots, irrigation technology must be available. Irrigated agriculture involves a range of technological interventions that modify the flow and cycles of natural ecosystem, to create a new agroecosystem. Therefore, we can perceive irrigation as a technology which indicates irrigation as a physical process (Vincent, 1997; Ostrom & Gardner, 1993; Mollinga, 2003; Meinzen-Dick, 2014). According to Plott & Meyer (1975) and Tang (1992), this process can be divided into four stages:

production, distribution, appropriation, and use. At the production stage, irrigation water is made available at locations and times when it does not naturally occur in the form of precipitation and immediate runoff. For instance, irrigation water can be produced by damming the flow of a river and delivering water during irrigation seasons. The irrigation water produced, will be distributed through a canal or a pump to the irrigated area at the distribution stage. At the appropriation stage, farmers withdraw water from rivers, tanks or groundwater and spread water using furrow, flooding, or pressurized systems on the farmland. These structures are the appropriation resources. The water appropriated by farmers is then used to irrigate crops in fields; the fields and crops together constitute the use of resources.

However, management activities by the associated human processes are required to make the physical structures perform as planned. The technologies in place should be accompanied by appropriate institutional set-ups for sustainable irrigation performance (Meinzen-Dick, 2014). Maintaining an irrigation system over the long term also needs contributions in labour, cash, and in-kind form, while benefits are difficult to be measured and dispersed over time and space (Ostrom and Gardener 1993). This makes an irrigation system a sociotechnical process with human and material elements to achieve higher performance of the irrigation system (Uphoff 1986, Vincent 1997; Mollinga, 2014). Additionally, factors such as engineering, agronomy, and economics influence the success of irrigated agriculture.

The benefit from irrigation may be limited unless the water users employ their labour and capital in ways that make good use of available land and water resources. Irrigated agriculture also demands various levels of cooperation among water users and with people at the management level. Hence, relations among farmers and between farmers and people at the management level make irrigation a social process. Ostrom (1990) and Bromley and Cernea (1989) consider irrigation special in the way it requires collective action in development and operation. Coordination functions can be provided by any of the following entities: (i) a national or regional government agency, (ii) an irrigators' association, or farmers’ group (common) (iii) a private household or enterprise, (iv) open access (no coordination). An irrigation system can be classified depending on the kinds of collective-choice entities involved in governance and the kinds of resources governed (Tang, 1992; Ostrom & Gardner, 1993; Meinzen-Dick, 2014).

Empirical evidence from field and experimental settings illustrates that, without effective institutions, natural resources such as irrigation water will be underprovided or overused. Much of the focus in the development literature as well as in irrigation departments operating across the world has been on the importance of physical technology to improve irrigation and agriculture performance, rather than on institutions and the social dimensions of irrigation management (Ostrom, 1992; Ostrom et al., 1993; Huppert 2002, 2013; Vincent & Roth 2013; Meinzen-Dick, 2014). The situation in Ethiopia is no different. Irrigation development in Ethiopia has emphasized on the agronomic, engineering, and technical aspects of irrigation developments, with limited consideration to policy, institutional and social factors.

1.3. The local setting

Ethiopian economy has achieved 10% average annual growth during 2006/07-2017/18. However, agriculture remains the main contributor of the economy which accounts for 35% of GDP, 84% of export earnings and 80%, of the labour force (NBE 2018). The country's agriculture is largely rainfall-based and dominated by smallholder farmers. Rainfall in Ethiopia is characterised by high spatial and temporal variability, with major implications for the performance of the agricultural sector and the whole economy. Studies indicate that high rainfall variability is likely to increase as a consequence of climate change and this will most likely worsen Ethiopian agriculture, as a result of higher frequency of drought and floods (IPCC, 2007; Deressa et al., 2007; Tessema et al., 2013; Gebreegziabhe et. al., 2013). Improvement in agricultural water management offers one of the most effective mechanisms to protect against the ongoing and predicted negative impacts of climate change and variability, to improve the quantity and quality of crop and livestock production and productivity and to restore degraded land (Awulachew, 2007; IWMI, 2007; Namara et al., 2007; 2010; Hagos et al., 2009; 2012).

Ethiopia is endowed with vast water resources. It is home to 12 river basins with an annual runoff volume of 122 billion m^3 of water and an estimated 2.6 billion m^3 of ground water potential. This corresponds to an average of 1,575 m^3 of physically available water per person per year, which is a relatively large volume (Awulachew et al., 2008). Despite the high potential of the country for irrigation and the immense attention given for irrigation, less than 10% of the estimated potential of irrigable land is currently under irrigation. Traditional irrigation schemes date back several centuries, though are difficult to trace back exactly (Rahmato, 2008). Modern irrigation development schemes are a recent phenomenon in Ethiopia. The imperial government in the 1950s took the first initiative to develop large scale and high technology water projects for the purpose of providing industrial crops to the growing agro-industries and increase export earnings. Most schemes were constructed as either private farms or joint ventures. All these large-scale schemes were nationalized by the military government in 1975 and handed over to the Ministry of State Farms. Most small-scale irrigation schemes owned by landlords were also confiscated and transferred to producers' cooperatives. It was only after the devastating famine of 1984/85 that the government began to show some interest in small scale irrigation development. The focus was turned to small scale communal irrigation schemes, when the Ethiopian Peoples' Revolutionary Democratic Front (EPRDF) took power in 1991 (Gebremedhin & Pedon, 2002).

Realizing the country's water resources potential for irrigation development and its contribution towards sustainable economic growth and rural development, the government has embarked on wide range of water development efforts throughout the country. The government has made significant commitment on institutional building and policy design for the irrigation sector. One of the rural development strategies is decentralizing and developing of natural resource management-including water for irrigation-to the lower level. In the country's Second Growth and Transformation (GTP II 2016-20), irrigation has been identified as an important tool to poverty alleviation and sustainable rural development. Investment in irrigation also comprises over 1/3rd-the largest share- of the total budget of US$582 million of the Ministry of the Agriculture's Agricultural Growth Program (World Bank 2015). Moreover, irrigation has been identified as one of the most appropriate adaptation options for the adverse options of the country (IPCC-TGICA, 2007).

The government of Ethiopia aspires to significantly increase the irrigated land through rainwater harvesting, small, medium, and large-scale irrigation schemes. Specifically, the government has provided strong emphasis to the development of small-scale irrigation schemes. Improvement and rehabilitation of farmer-managed traditional schemes have been at the forefront of its water development policy. According to FAO AQUASTAT country profile 2016, between 2004 and 2015, the area under agricultural water management in Ethiopia increased from 510 thousand ha to 1.96 million ha, of which around 1.1 million ha was estimated to be cultivated by farm households using traditional structures. There has been expansion of diversified types of small irrigation water control structures including dams and reservoirs, hand-dug wells, ponds, modern as well as traditional spring and river diversions. Thousands of deep and shallow wells have been developed in Ethiopia since 2002/03 (Deneke et al., 2011). Various kinds of water lifting technologies such as gravity (canal), motor pump (electric, diesel or gasoline), treadle pump and rope and washer are often used to withdraw water from rivers, lakes, ponds or wells. Households are adopting pumps across the country. Data from the Ethiopian Revenue and Custom Authority show that around 800,000 motor pumps had been imported between 2004-10 (Gebreegziabher et al 2014). As of April 2019, the government has allowed irrigation equipment including pumps and its accessories to be imported free of duty and tax and to be sold through cooperative associations. Pressurized water lifting systems such as sprinkler and drip irrigation systems have been introduced in various regions of Ethiopia (Evans et al., 2012).

1.4. Statement of the problem

The government of Ethiopia has focused on the irrigation sector of the country with the aim of ensuring poverty alleviation in the face of extreme weather conditions and population growth. Since 1991, institutional arrangements governing the water sector of the country have been undergoing frequent changes. The government has engaged in decentralizing and devolving responsibilities of governmental agencies managing the sector to lower levels.

Ethiopia has a three-tiered federal system with national, regional, and local administration and the role of local communities in resource management has been increasing. At local level, various scales of devolved irrigation water management systems have been implemented. These water management systems represent varying scales of collective organisations that range from jointly managed irrigation schemes by an agency and farmers, to communal systems (managed by water users' association or 'water fathers[1]') and privately developed and managed irrigation systems. The implementation of these management systems is expected to enhance local participation in decision making and empowering the community and farm households which contributes fundamentally to the needs of the poor (Crook & Sverrisson, 2001). Devolving natural resource management may have economic, social, and environmental benefits such as improved efficiency, more equitable control over use rights and distribution of benefits, and improved environmental management that lead to more sustainable use and management of natural resources overtime (Ribot, 2002; WRI, 2003).

At the same time, the government, development partners and farm households have made immense investments to adopt and expand various types of irrigation technologies. Canal (gravity) and pump technologies are applied to lift water from sources such as rivers, streams, reservoirs, wells, and lakes. Farm households also use diversified water application mechanisms (flooding, furrow, sprinkler, drip) on their farm. Careful design and implementation of appropriate water management systems and complementary irrigation technologies are critical to enhance the performance and impact of irrigation schemes and to the sustainable management and use of the natural resource base.

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[1] In some small traditional farmer-managed irrigation systems, the person in charge of the day-to-day O&M and distribution of irrigation water is called "water father" or water master".

Despite a vast literature on irrigation and poverty alleviation in Asia and a growing body of literature in sub-Saharan Africa[2], there is limited information on how participation in irrigation institutions and adoption of irrigation technologies by smallholder farmers respond to the various outcomes of using, managing and conserving irrigation water. Therefore, this study makes a full and comprehensive analyses of existing irrigation institutions from national to farm level and identify the existing gaps within and among different levels. After exploring the nature and diversity of irrigation technologies and multiple scales of devolved water management systems, their potential effect to raise smallholders out of poverty and sustainable development is analysed. The study considers the potential for devolved irrigation water management and complementary technologies to influence three factors central for poverty alleviation: farm net return, individual and collective empowerment, and environmental sustainability. Understanding the nature and magnitude of the outcomes and identifying the gaps within and among institutional arrangements at different levels is important for policy makers and practitioners involved in designing and implementing decentralization and devolution reforms in the use and management of several natural resources. In addition, such empirical knowledge is critical for designing relevant policies and institutions for effective scaling out/up of best practices of various combinations of water management and irrigation technologies in the country. Overall, it can be a valuable input for a policy design of a country such as Ethiopia that has a vision to build a climate resilient green economy.

1.5. Typology of irrigation systems and technologies in Ethiopia

Irrigation water management system for smallholder farmers in Ethiopia is diversified in its nature. It ranges from private access and use rights of an irrigation water source such as a shallow well, to full participation of group of farm households in the inception, design, establishment, and operation of an irrigation scheme, and to partial participation of farmers only at the low reaches of management level. For instance, in Amhara region, in Mecha *woreda*, one can find traditional irrigation water users who have full control of a scheme, while in the adjacent *kebele* at Koga dam[3], a government agency, the Abay River Basin Authority controls the water distribution system at the primary and secondary canal level and the rest by the beneficiary farmers. On the other hand, some water sources have

[2] Silliman & Lenton 1985, von Braun et al 1989; Rosegrant 1992; Gebremedhin & Pender, 2002; Hussain et al., 2001, 2006; Hussain, 2007; Huang et al., 2006; Van der Berg & Ruben, 2006; Namara et al., 2007; Hagos et al 2008; Hanjra and Gichuki, 2008; Hanjra et al., 2009; ; Bacha et al., 2009; Saleth et al., 2009; Gebregziabher et al 2009, Namara et al., 2010; Burney et al. 2010; Aseyehegn et al 2012; Hagos et al 2012; Domenech and Ringler, 2013; Hagos et al., 2013; de Fraiture & Giordano, 2014; Namara et al ., 2014; Domenech, 2015; Hagos et al., 2017; Garbero & Songsermsawas., 2018.

[3] Koga irrigation project is the first new large scale irrigation scheme in the Blue Nile river basin since the 1970s.

an open access character, where irrigation water users extract water openly with limited government intervention from a water source such as rivers and spring water.

(i) Privately managed irrigation system is a "micro-scale private irrigation" which refers to individualized micro-scale technologies for storing, lifting, conveying, and applying irrigation. The main character of farmers in privately accessed irrigation system is their reliance on drilled/hand dug wells or water harvesting ponds to store water for irrigation; treadle, robe and washer or motor pumps to lift water; and a variety of irrigation application technologies such as flooding, furrow, small bucket, or drip systems to apply water on a farm plot.

(ii) Users managed irrigation system refers to irrigation schemes where farmers and water users' associations (WUA) have full control and responsibility from inception to the construction and implementation of the scheme, including the utilization and management of the irrigation water. Usually, this kind of system is characterized as small scale and found in traditional irrigation schemes constructed using diversion weirs made from local materials and need annual maintenance. They may apply gravity or pump to lift irrigation water.

(iii) Jointly (users-agency) managed irrigation system refers to a system where farmers and a government agency manage irrigation schemes jointly. Since the schemes are usually medium or large-scale irrigation systems, a government agency has control of the water to the delivery point and are responsible for Operation and Maintenance (O&M) at higher level; the use of water and O &M thereafter is under the control of the farmers and their association. As farmer-managed irrigation systems, they may use gravity or pump irrigation technology to withdraw water from a source.

(iv) Open-access irrigation system refers to irrigation management without developed irrigation structures; irrigation is practiced without any schedule or turn, and this usually involves farmlands adjacent to a river or spring water. There is no water users' association (water users committee, 'water fathers') or any governmental agency involved in the management of the resource. Irrigators in this kind of irrigation system use technologies like motor pumps to lift water from a source. In this case, irrigation is an individualized undertaking in which there is no established institutional arrangement to manage the resource.

1.6. Conceptual framework of the study

The conceptual framework for this study is based on the unitary household model (Becker's, 1981); theory of collective action (Olson,1965; Balland & Platteau, 1996; Wade, 1988; Ostrom, 1990; Rasmussen and Meinzen-Dick, 1995); institutional analysis (North, 1990; Bromley, 1989; Hodgson, 2000) and transaction cost economics (Williamson, 1986); induced institutional innovation (Hayami & Ruttan, 1985); sociotechnical theory (Veldwisch et al., 2009; Mollinga, 2010, 2014; and Vincent, 1997, 2013); principal-agent theory (Huppert and Wolff, 2002 and Huppert, 2013); theoretical and empirical works by; Vermillion and Sagardoy, 1999; Jagger, et al., 2005 and Domenech & Ringler, 2013.

Intervention in irrigation water development can have poverty alleviation benefits through several pathways. Among the benefits, equitable control over procedural rights, high degree of participation, provision of decision-making autonomy and strong governance system(empowerment), better income generation opportunity (farm return) and improved environmental management lead to more sustainable use of natural resources overtime. Intervention in agricultural water management is hypothesized to be a potential development pathway out of poverty in a country like Ethiopia where the main economy relies on rainfed agriculture. The benefits can be achieved if (i) the economic and financial costs of irrigation agriculture should be a small proportion of the return from irrigation; (ii) beneficiary rural households need to be empowered and capacitated with acquiring information, making decisions, participating in local organisational structures; (iii) The resource also should be used and managed sustainability by taking into account adoption of land management practices to combat the possible negative effects of using and managing irrigation water.

The three factors central to poverty alleviation could be met successfully, if the right combination of irrigation water management systems and irrigation technologies are applied. In this study, irrigation is considered as a socio-technical system: the water management systems, organizations, and institutions are as important as the technical dimensions of a system in determining the performance of an irrigation scheme. An irrigation system may be taken as a network of heterogenous elements existed together by a diverse set of relationships that both its institutional and technical components operate at the same time. The network is administered by people, who mobilize resources to connect the components and consolidate their diversified control mechanism over them.

In this case, institutions are any water management practices that include water rights, conflict resolution mechanisms, stakeholders' participation, cost recovery and fee collection. Irrigation water is allocated via a variety of mechanisms that range from an absolute control by the government to a mixture of government and market allocation to predominantly market allocation. There are various irrigation water control technologies such as river, pond, lake, dam, shallow and hand dug wells and deep boreholes. To withdraw water from the sources, water lifting technologies such as bucket, gravity, treadle pump or motor (electric, diesel or gasoline) pump can be utilized. Technologies such as sprinkler and drip irrigation conveyance systems are used to apply water on farm fields. It may guide the development of technologies that fit for the existing institution and water management system. Apart from institutional and technological factors, environmental factors (precipitation and temperature), village level (access to market, information, services) and socio-economic (age, gender, and level of education) variables affect the benefits gained from using and managing irrigation.

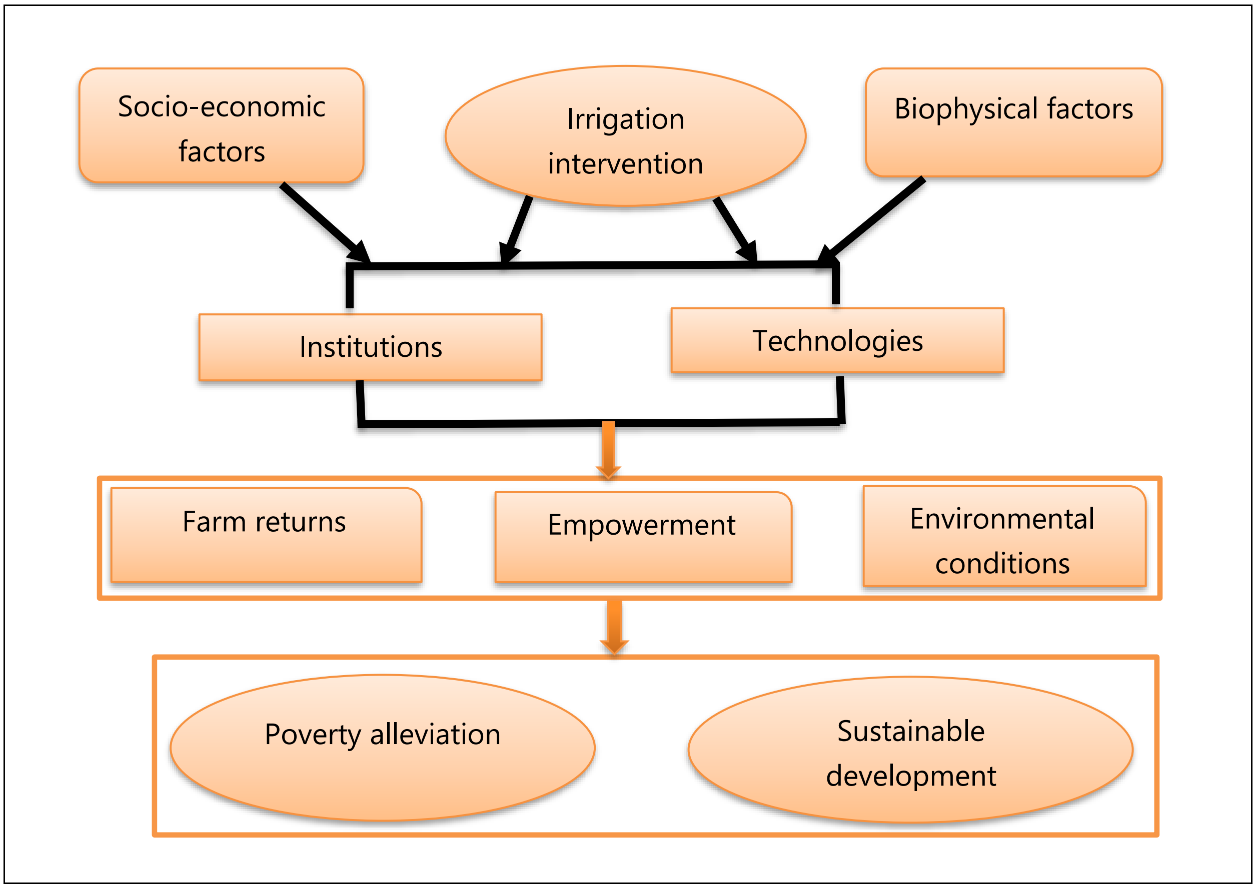

Figure 1.1. Conceptual framework of the study
Source: Own conceptualization based on the reviewed literature

1.7. Objectives and research questions

This thesis explores the economics of irrigation systems in Ethiopia by taking into account the potential for multiple scales of irrigation management systems and various irrigation technologies to influence three factors central to poverty alleviation: improvement in net returns, empowerment of irrigation water users at household and group level, and environmentally sustainable irrigation water use. Specifically, this study pursues the following objectives.

First, the study explores the institutional arrangements for irrigation water management at national, regional, and local levels in Ethiopia and identifies the horizontal and vertical gaps that exist at each level. A full and comprehensive analyses of existing irrigation institutions from national to farm household level is made.

Second, the study evaluates the impact of using irrigation water and identify which combination of water management and lifting technology leads to relatively higher net farm returns. Starting from analysing the difference among rainfed and irrigation systems in crop pattern, input use, output, net return, income and market access, the study uses econometric approaches to examine the impact of the joint effect of the various water management systems and adopted irrigation water lifting technologies on the impact of net farm returns. This analysis uses a multi-valued treatment effect that allows to estimate the treatment effects when there are more than two treatment levels (alternatives). Moreover, the method enables us to compare the outcomes between each paired combination of irrigation water management systems and technologies.

Third, the effect of multiple scales of devolved irrigation water management systems and various irrigation technologies on empowerment of farmers and users' groups in using and managing irrigation water is analysed. In the first part of the analysis, all irrigation beneficiary farmers are included, and empowerment is analysed as an individual's achievement. In the second analysis, only users-managed and users-and-agency managed irrigation systems are incorporated to explore factors that influence collective empowerment.

Fourth, major changes in environmental conditions since farmers started to use irrigation water were identified. Particularly, Landsat images were extracted for each plot after and before the start of using irrigation to compute normalized difference vegetation index (NDVI). Moreover, the role of various irrigation water management systems and irrigation technologies in adoption of sustainable agricultural land management is investigated. The analysis includes three kinds of land management systems: sustainable cropping systems; fertilizer use and physical investment in S&W conservation methods.

In order to achieve these four objectives, the proposed study pursues the following research questions:

1. What are the institutions in irrigation sector of Ethiopia?
   1.1. What are the institutional arrangements for irrigation water management at national, regional, and local levels in Ethiopia?
   1.2. What are the existing horizontal and vertical gaps?

2. Does access for irrigation (to various alternatives) have input use and farm return effect?
   2.1. Is there a difference among rainfed and irrigated agriculture systems in crop pattern, input use, output, net farm return, income, and market participation in the study areas?
   2.2. Is there a difference among various combinations of water management systems and adopted irrigation technologies in crop pattern, input use, output, net farm return, income, and marketing participation in the study areas?
   2.3. Does the joint effect of water management systems and adopted irrigation technologies have an impact on net farm return?
3. What are the factors that influence individual and collective empowerment of using and managing irrigation water?
4. Does access for irrigation have effects on sustainable land and water use and management?
   4.1. What are the potential impacts of using irrigation on environmental conditions?
   4.2. Does the joint effect of water management systems and adopted irrigation technologies have an impact on adoption of SLM practices?

1.8. Study areas and data

The main dataset utilized for this study comes from a cross-sectional survey on irrigation beneficiaries farm households and their plots in four regions of Ethiopia: Tigray, Amhara, Oromia and Southern Nations, Nationalities and Peoples' Region (SNNPR), which was undertaken from December 2016 to March of 2017. The survey focuses on 2015/16 production year with the objective of analysing the economics of irrigation mainly focusing on technologies in use and irrigation water management systems.

In order to enhance the validity and reliability of the data, information was gathered from multiple sources for purposes of triangulation. The instruments used are the following: (i)Household survey- A total of 464 irrigation beneficiary farmers were interviewed using structured household level questionnaires. The interviews were carried out using pen-and paper (PAPI) as well as computer-assisted personal interviewing (CAPI) methods. The study relied mainly on this dataset. Table 1.1 presents salient features of irrigation systems included in the study sites and number of questionnaires collected in each region.

(ii) Focus group discussion: In-depth focus group discussions with 6 to 12 irrigation water beneficiaries in various management systems and technologies were conducted in each village included in the study. This discussion gave much more specific and detailed information.

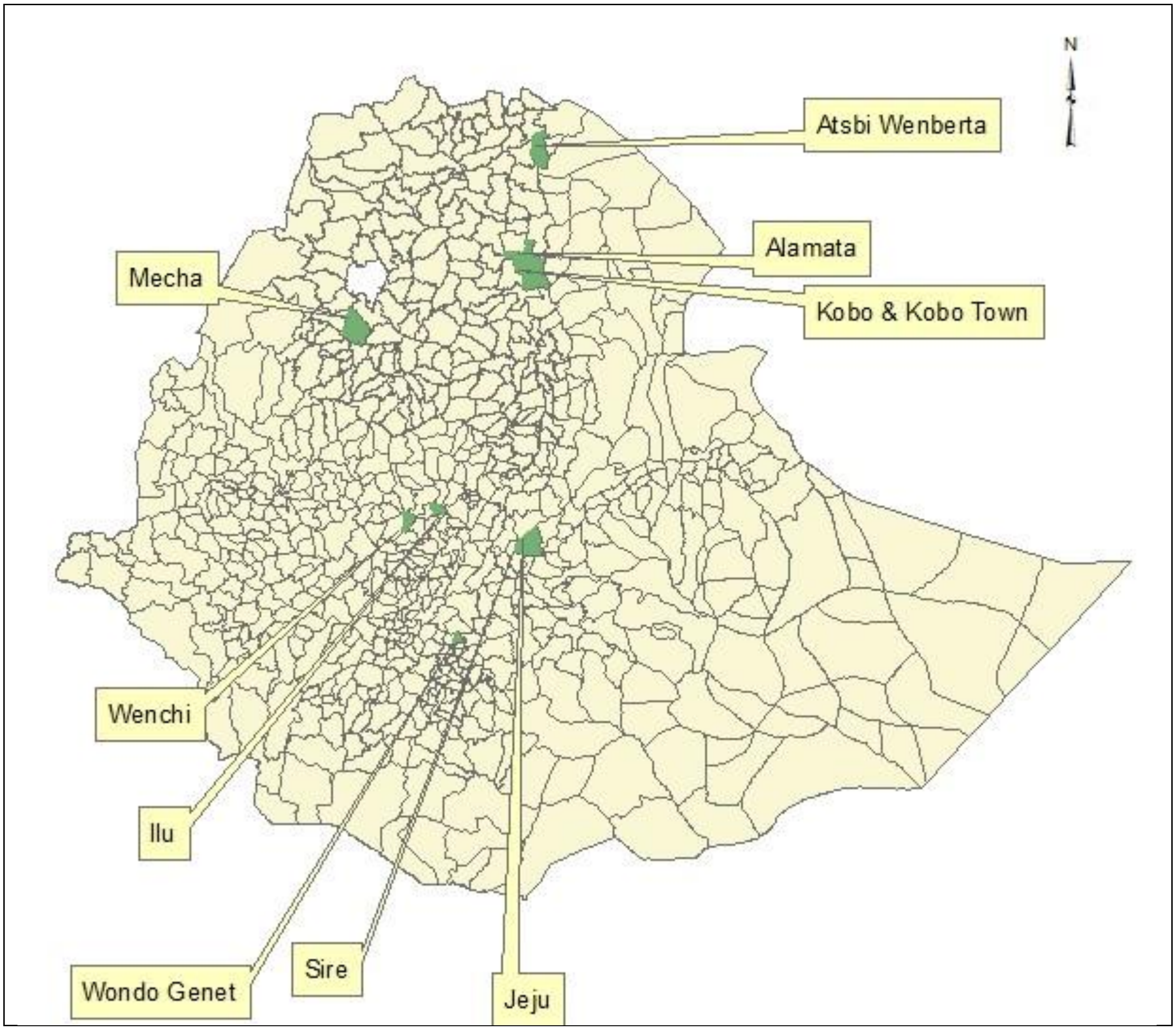

Figure 1.2. Locations of the study sites

Table 1.1. Salient features of irrigation schemes included in the study

Region	Zones included	Woredas[4] included	Agro-ecological zone [5]	No. of *Kebeles*[6]	Scale of irrigation	No. of household included	No. of plots included (rain-fed, irrigated, both)	No. of irrigated plots included
Tigray	Eastern Tigray	Atsebi Wemberta	Drought prone highland	2	Small, Micro[7]	51	188	67
	Southern Tigray	Raya Alamata	Drought prone highland, drought prone lowland	4	Small[8], Micro	49	148	73
Amhara	North Wello	Raya Kobo	Drought prone highland, Drought prone lowland	2	Large, Small, Micro	38	166	80
		Raya town	Drought prone highland, drought prone lowland	2	Large, Small, Micro	27	98	46
	East Gojjam	Mecha	Moisture reliable, highland-Cereal	2	Large, Small, Micro	66	337	176
Oromia	South West Shoa	Illu	Moisture reliable, highland-Cereal	8	Small, Micro	60	364	146
		Wonchi	Moisture reliable, highland-Cereal	2	Medium[9], Small, Micro	50	275	88
	Arsi	Sire	Humid moisture reliable, lowland	1	Large[10]	12	48	36
		Jeju	Humid moisture reliable, lowland	1	Large	8	30	19
SNNPR	Sidama	Wondo Genet	Moisture reliable, highland-*Enset*[11]	2	Small, Micro	103	512	306
4	7	10		26		464	2166	1037

Source: Author's compilation using survey data

[4] *Woredas* means districts, the third-level administrative divisions of Ethiopia.

[5] The characterization of agro-ecological zone has been expanded to "5 Ethiopia's" (drought prone, humid lowland moisture reliable, moisture reliable-cereals, moisture reliable-*enset* and pastoralist)for the Ethiopian Social Accounting Matrix developed by the Ethiopian Development Research Institute (EDRI). Previously, it was only "Three Ethiopias": moisture reliable highlands, drought prone highlands, and pastoral lowlands areas.

[6] *Kebele*, Peasant Association or Tabia are the smallest administrative units in Ethiopia.

[7] Micro- irrigation users–individualized household level irrigation schemes of less than one hectare.

[8] Small-scale irrigation systems-command area less than 200ha

[9] Medium-scale irrigation systems-command area 200-3000 ha a

[10] Large-scale irrigation systems -command area greater than 3000 ha.

[11] *Enset* is a root crop.

(iii) Community level questionnaire: Community interviews involved interviews with up to ten respondents were administered. The respondents have different positions in the community: a water master, a member of water user committee, an irrigation guard, a member of women's forum, an elder, a religious leader, a development agent, and an ordinary farmer. This questionnaire helped us to collect village level general information such as access to services, irrigation water management, distribution and use, irrigation services, agriculture input and output (quantity and price) and perception towards use of irrigation on livelihood, decision-making power, participation and perception on environmental change, weather and climate change and variability.

(iv) Key Informant Interviews (KII): Experts working on irrigation in different offices of governmental and non-governmental organizations were included in the KII. Mainly experts and researchers from federal to *kebele* level governmental offices and research institutes were involved. A checklist was used as a guide to ask key informants who have a good knowledge of the current situation of irrigation practices and management systems in Ethiopia, on specific irrigation schemes and the community. The questions were adjusted according to the position of the interviewee, the irrigation type under consideration, the management system, and other factors. Discussions were also conducted regarding content, relevance and implementation of water sector policies, strategies, and legal instruments.

(v) Reviews of published and unpublished sources that focus on irrigation sector institutions in Ethiopia were also undertaken. These include review and inventory of national and regional policies, formal laws and regulations, local informal rules and practices, and formal and informal organisations.

(vi) Satellite based bio-physical datasets:

(a) As stated in IPCC, 2007, the two most impotent variables in the study of climate change and variability are temperature and precipitation, especially in a country like Ethiopia that the economy heavily depends on rainfed agriculture. Hence, historical monthly temperature and precipitation data between January 1981 to December 2016 were derived based on geo-referenced household level latitude and longitude coordinates. The two climate variables are obtained from two different sources. The source dataset for temperature variable was 0.5 degree by 0.5-degree gridded time-series data downloaded from Climate Research Unit, University of East Anglia (Harris & Jones 2017). Since most parts of the Ethiopian highland experiences bi-modal rainfall pattern, the dataset for precipitation was categorized into two., i.e., the short rainy season which lasts from February to May (called *Belg*) and the main rainy season that contributes as substantial amount of rainfall in June, July, August and September called *Kiremt/Meher*. The datasets were downloaded from Climate Hazard Group InfraRed Precipitation with Station data (CHIRPS) that incorporate 0.05-degree resolution satellite imaginary with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring (Funk et al., 2015). After downloading the datasets from the respective sources, the monthly temperature and precipitation data values for the study sample households and farms were extracted and interpolated from the gridded time series data to household and farm-level GPS coordinates measured during the survey. The Thin Plate Spline method of spatial interpolation was used to impute household and plot-specific rainfall and temperature values using geo-referenced information, following studies by Di Falco et al., (2012); Teklewold et al., (2018).

(b) Landsat images were extracted for each plot before and after using irrigation water. The Landsat series of images were acquired from NASA/ U.S. Geological Survey Earth Observation satellites space-based images of the Earth's land surface (U.S. Geological Survey, 2016). After feeding this data to ArcGIS 10.5.1, normalized difference vegetation index (NDVI) analysis was computed to detect the spatial and temporal change of vegetation biomass before and after using irrigation in the study areas. The Landsat images produce 30cm pixel resolution imagery every 16 days, in which each scene represents a snapshot on a given acquisition data. The difference between two images is calculated by finding the difference between each pixel in each image and generating an image based on the result. Thus, for the purpose of this analysis, relevant images which were taken in February/March the year just before[12] they started using irrigation and in February/March 2015/16 (the time when the survey was conducted) are considered in the analysis. Images taken in the months of February/March were purposefully selected, since the two seasons are the driest months of a year in Ethiopia, and farmers particularly use irrigation water during those months to produce agricultural goods. After downloading the images, the Landsat data values for the study sample plots were extracted and interpolated from the gridded time series data and GPS coordinates. The thin plate spline interpolation technique was implemented to generate the Landsat data values at each farm level, following studies by Di Falco et al. (2012) that utilize the technique to interpolate climate variables.

Sampling

For descriptive and econometric analysis, data from cross sectional household and plot level survey are utilized. The sample was composed of a total of 2173 farming plots from 467 farm households. The data were collected using a multi-stage stratified random sampling method. In the first stage of the sample selection process, Oromia, Amhara,

[12] The starting time of using irrigation differs from plot to plot.

Tigray and Southern Nations, Nationalities and Peoples' Region (SNNPR) regions were purposively selected due to the relatively higher irrigation project developments in these regions. In the second stage, in consultation with irrigation experts at the federal and regional level, *woredas* (districts) which fulfil the objective of the study (diversified irrigation practices with water management systems) were identified. The survey covered 10 districts in different agro-ecological zones of the country. In the third stage, based on information from *woreda* office of agriculture and water resources, *kebeles* (peasant associations or *tabias*) which constitute different scales of irrigation (large, medium, and small) accessed by smallholders who produce various crops were selected. Finally, based on information provided by *kebele* level Bureau of Agriculture, Bureau of Water Resources, Water User Associations, and Cooperatives on the households who have irrigation water access, 467 irrigation water beneficiary farmers were randomly selected. Due to data inconsistency and incompleteness, three questionnaires were dropped which makes the total number of households 464 and farming plots 2166 in the survey. The data were collected from household heads and their spouses using trained and experienced enumerators with the knowledge of the local language. All FGDs and KIIs were done by the researcher with the help of language translators.

1.9. Method of analysis

For a deeper understanding of social, technical, and institutional dimensions of irrigation, their interactions, and the multiple ways in which they are embedded in a wider agro-ecological, socio-economic environment, a combination of methods of analysis are used. The research approach is characterized by an interdisciplinary approach. Though, econometric tools were mainly utilized, a combination of qualitative and quantitative methods of analysis are applied to enhance the validity and reliability of the findings.

1.10. Organization of the thesis

This thesis is organized into four self-contained, but related core chapters crafted to address the proposed research questions. Following this introductory part (chapter 1), chapter 2 makes a full and comprehensive analyses of existing irrigation institutions from national to farm household level and identifies the horizontal and vertical existing gaps at each level. Chapter 3 evaluates the impact of using irrigation water and identify which combination of water management and lifting technology leads to relatively higher net farm return. Chapter 4 addresses the effect of multiple scales of irrigation water management systems and complementary technologies on local level irrigation empowerment in using and managing irrigation water. Chapter 5 explores the potential positive as well as negative impacts of using irrigation and investigates the role of irrigation water management systems and complementary technologies on adoption of land management practices to combat the negative effects. Chapter 6 concludes the thesis by summarizing the main research findings and forwarding the implications of the study for policy and practice.

2. INSTITUTIONAL ANALYSIS OF IRRIGATION WATER MANAGEMENT IN ETHIOPIA

2.1. Introduction

The political and socio-economic transformations in Ethiopia for the past three decades have been largely centred on the need to shift from a centrally planned, command and control system to a more open market economy. The package of reforms that Ethiopia has been undertaking includes decentralization, de-monopolization, and promotion of private sector investment (Gebre-Egziabher, 1998; Adal, 2001). The water sector is not an exception in this regard. Institutional changes within the water sector, particularly to the irrigation sector, have been aimed at decentralizing and devolving of the governance structure for the past three decades. These reform initiatives are evident both at macro level and at sub-sectoral level (Assefa & Gebregziabher, 2007). Macro level institutional reforms of the water sector include development of water laws and water policies, preparation of national and regional water plans, and administrative reorganizations. At sub-sectoral level, the reforms include devolving responsibilities by means of water management transfer and participatory water management.

At federal level, the Ministry of Agriculture (MoA) and the Ministry of Water, Irrigation and Energy (MoWIE) and its subsidiary organizations[13] are the leading actors in charge of developing and handling of small, medium, and large-scale irrigation schemes in the country. The significance contribution of intervention in improved access of irrigation water is well recognized in the policy documents of the MoWIE and the MoA (MoWR, 1999) that envisages for sustainability, equity, and efficiency in use of water resources of the country.

At lower-level administration, the Ethiopian federation is divided into nine self-governing regional states and two administrative cities. The regions are further divided into zones, *woredas* (districts) and *kebeles* (sub-districts). The regional states have legislative, executive, and judicial powers in all matters within their geographical boundaries, expect those under the jurisdiction of the federal government such as defence and foreign affairs. In terms of organization of sectoral bureaus, there are more similarities than differences across regions. Likewise, the hierarchical structure of institutions for irrigation sector at regional, district and sub-district level has been arranged similarly.

[13] Subsidiary organizations include Water Works Design and Supervision Enterprise (WWDSE), Water Works Construction Enterprise (WWCE), and Water Resources Development Fund (WRDF).

The transfer of power from central to regional and local governments is believed to enhance development and promote the right to self-governance of nations and nationalities and peoples in the regions through increasing efficiency and equity (Ayele & Fessha, 2012). However, there has been a concern regarding the overall performance of the existing irrigation institutional set-up in the country. While decentralization has brought significant achievements in empowering governance in the regions, it has not brought genuine self-rule, particularly at lower administration level (Gebre-Egziabher & Berhanu, 2007). Saleth & Dinar (2006) shows that the water institution reforms undertaken in developing countries so far are not adequate for meeting the institutional requirements for sustainable water resources management. This is because the general nature of the reforms implemented in these countries are mostly at a policy level rather at an implementation level. In most cases, the nature of the reforms is ceremonial and cosmetic rather than changes that have substantive character.

Several global experiences show that a comprehensive institution for irrigation water use and management should take into account the technical requirements (infrastructure development, equipment and spare parts provision, day-to-day O&M activities), policy issues (guidelines, strategies, incentives, pricing and cost recovery), and institutional issues (governance and management of water resources, farmer organizations, extension and credit services, and marketing) (Easter et. al., 1998; Gebremedhin & Peden, 2002; Dinar, 2000; Saleth & Dinar, 2000; 2004 and 2006; Haileselassie et al; 2016). Sectoral institutions in irrigation development should be synchronized. Emphasis should be given to determine the appropriate mix and role of different stakeholders in the effort to develop, use, control and manage water resources. And institutional mechanisms need to be put in place to minimize transaction and resolve conflicts.

The government of Ethiopia has been striving to increase the current level of irrigation infrastructure. Between 2010/11 and 2014/15, the constructed large and medium scale irrigation schemes way exceeded the planned target by 15% (Ethiopian National Planning Commission 2016). The history of irrigation development in Ethiopia has been characterized by focusing on technical and engineering aspects, with inadequate emphasis provided to policy, institutional and socio-economic factors (Gebremedhin & Pender 2003; Brown 2011; Yami 2013; Yami and Snyder 2012; Haileselassie et al., 2016). However, the existing literature in Ethiopia on this subject provides little guidance as its focus is too narrow to consider irrigation sector institutions at country level. Past research by Haileselassie et al., (2012); Haileselassie et al., (2009); Hussein et al., (2009); Hagos et al., (2011) explored the set-up of land and water management policy and institutions in Nile Basin.

This study aims to improve our understanding of institutional arrangements for irrigation water management at federal, regional, and local (grassroot) levels in Ethiopia. This chapter undertakes a comprehensive analyses of existing irrigation institutions and specifically it pursues to answer the following two research questions: what are the institutional set-ups for irrigation water management at federal, regional, and local levels of the country? What are the existing horizontal and vertical gaps? Such analysis of institutions and their components provides useful insights for policy makers and practitioners at different level who are involved in designing and implementing decentralisation and devolution reforms, specifically in the irrigation sector.

The chapter is organized as follows: The next section presents a brief description of rational for decentralization and devolution of irrigation systems in the developing world, followed by discussion on conceptual and analytical framework guiding the study, while section 2.3 describes the data sources. Section 2.4 explains the methods used in our analysis. Section 2.5 discusses the results of the institutional analysis, while section 2.6. concludes with a summary and discussion of policy implications of the findings.

2.2. Rational for decentralization and devolution of irrigation systems in the developing world

In developing countries, beginning from 1950s to early 1980s, considering the possible benefits from irrigation development, the area of land under irrigation increased significantly (Cernea, 1985). Emphasis was given to technology and technological expertise in state managed large irrigation projects. Usually, foreign engineering experts were the managers of the projects (Vermillion & Sagarday, 1999; Molden et al., 2007). In most instances, the state was viewed as the natural institutions to drive the irrigation development. Large scale irrigation was argued as being a public good (Merrey et al., 2007). Ostrom and Gardner (1993) argue that the donor community reflected as the state is the 'owner' of irrigation projects by supporting costly public developments throughout the 1960s and 1970s. It was expected that enhanced financial gains from improvements in production and productivity levels of irrigated agriculture would enable the government or water users to meet the O&M costs of the systems. In the contrary, irrigation performance indicators were falling short of expectations for yield increases, area irrigated and technical efficiency in water use (FAO, 1990; 1995). The majority of irrigation schemes were suffering from maintenance problems, which led to high cost for maintenance and rehabilitation of the irrigation infrastructures (Huppert, 2002; Vermillion, 1997; Shah et al., 2002; FAO, 2007). Moreover, lack of efficient use of water caused waterlogging and salinity. As described in FAO (1995), as much as one-quarter of all irrigated land in developing countries suffers from varying degrees of land degradation such as salinization.

Partly pressured by the low performance of irrigation projects, 109 heads of states passed key outcomes on integration of environmental protection and socio-economic development at the 1992 Earth Summit in Rio de Janeiro. Among the key outcomes, two points were relevant to irrigation water: water should be treated as an economic good and water management should be decentralized (ICWE 1992, FAO 1995). Farmers and other stakeholders should play important roles in the management of natural resources such as irrigation water. Hence, irrigation management transfer or turnover has become a widespread strategy and implemented in more than 60 countries (FAO 2007). This trend has been observed also in sub-Saharan Africa where many central government authorities are involved in decentralising and devolving responsibility for managing and using irrigation systems to local administrations, communities, users' groups, and individuals farm households (Meinzen-Dick & Knox, 1999; Vermillion & Sagarday, 1999; Lind & Cappon, 2001).

Decentralization has been undertaken in a number of forms-ranging from total privatization where all functions of the management of the infrastructure are transferred to irrigation users (IMT)[14] to managing jointly or Participatory Irrigation Management (PIM)[15], where responsibilities are shared between governmental agencies and WUAs (Senanayake at al., 2014). As a result, the trend has been diverted to the promotion of small-scale irrigation (Turner 1994). It was hoped that the implementation of IMT and PIM would improve the efficiency, equity and sustainability of the resource base while also reducing the financial burden on the state. Moreover, devolution to user groups has coincided with greater emphasis on users' participation and decision-making, which leads to empowering local people as well as goals of improving program performance. Devolution policies are consistent with these trends because they transfer decision making from government to users who are directly affected (World Bank 1996; Meinzen-Dick & Knox, 1999; Vermillion & Sagarday, 1999; Saleth & Dinar 2006). The main aim is for communities and users to become the drivers of development (Saleth and Dinar 2006). Yet, the continual implementation of decentralization and devolution programs as a major solution for poor institutional performance in irrigation systems is still a subject of much debate (Vermilion 1997; Saleth & Dinar 2004; Saleth 2006; Senanayake at al., 2014).

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[14] Vermillion & Sagarday (1999) define the term irrigation management transfer (IMT) as "the relocation of responsibility and authority for irrigation management from government agencies to non-governmental organisations, such as water users' associations. It may include all or partial transfer of management functions. Other terms, such as turnover, devolution, privatization or disengagement are sometimes used synonymously with transfer."

[15] Similarly, Vermillion & Sagarday (1999) refer the term participatory irrigation management normally as "the involvement of water users in irrigation management, along with the government. It is not the same as IMT-which is about replacing government, not just working with it".

2.3. Conceptual and analytical framework

Based on the general definition of institutions by Commons (1934); North (1990); Ostrom (1990) and Saleth & Dinar (2003; 2009), in this study, irrigation institution is defined as a set of nested and linked rules that guide individual and collective decisions in the context of irrigation water development, allocation, use and management. This definition indicates that irrigation institutions are not monolithic but can be decomposed into different functionally related set of rules. These rules consist of formal and informal as well as macro and micro rules.

Generally, water institutions, as explained by Saleth & Dinar (2008), have the following features. First, water institutions are subjective in origin and operation, however, objective in manifestation and impact (Hodgson 1998). Secondly, they are path dependent in nature. Their current as well as future directions highly depend on their earlier course and history (North, 1990). Thirdly, their features of malleability and diversity do not diminish their properties of stability and durability (Adelman et al, 1992; Hodgson 1998). Their nature of relative durability and stability properties taken together with their path dependency feature makes institutional change essentially gradual, continuous, and incremental (North, 1990). Fourthly, since institutions comprise a number of functionally linked components, they are hierarchic and nested both structurally (North, 1990; Ostrom, 1990) and spatially (Boyer & Hollingsworth, 1997). This implies the existence of structural and functional linkages among institutional components. Thus, a change in one institutional component can facilitates both sequential and concurrent changes in other institutional components. This indicates the scope for scale economies and increasing returns in institutional change (North, 1990). Finally, institutions are complementary not only with each other but also with their environment that constitutes the cultural, social, economic, and political setting (North, 1990). Therefore, institutional change may arise from endogenous factors that include structural features within institutions as well as in exogenous factors such as spill over effects (Saleth, 2006).

Institutional decomposition and analysis (IDA) framework which was initially developed by Ostrom (1999; 2005) and modified by Saleth and Dinar (2004; 2006; 2008) is utilized in this study to assess the existing institutional arrangements and identify existing gaps at federal, regional, and local institutions responsible for irrigation system development, use, allocation, and management. It is a flexible tool to analyse various components of water institutions at different levels and contexts. In this case, institutions for irrigation water use and management are decomposed into three stages for analysis. Irrigation institutions can be decomposed into institutional environment (government framework) and institutional structure (governance structure) (North, 1990; Saleth & Dinar, 1999; 2003). The institutional environment is characterized by the social, economic, political, and resource-related factors that determine the irrigation sector and its institutions. The institutional structure, in turn, is decomposed into its three parts, i.e., irrigation law, irrigation policy and irrigation administration (irrigation-related organizations) [16]. And, finally, each of these three institutional components are broken further to highlight some of their policy relevant aspects.

This study only focuses on the institutional structure of irrigation, that includes the structurally linked and nested legal, policy and organisations governing various aspects of water resources. The institutional environment of irrigation, which characterizes the overall social, economic, political and resource related factors within which the institutional structure of irrigation evolves and interacts with the irrigation sector is not included in the analysis.

Figure 2.1 depicts a simplified visual representation of the institutional structure of irrigation and its components. It can be applicable to the institutional structure of irrigation for any given national, regional, and local context. The figure implies that the overall performance of irrigation institutions and their impact on the irrigation sector highly rely not only on the capabilities of their components but also on the strength of structural and functional linkages among each other. The arrows in the figure demonstrate a set of linkages possible both within and across the three components, i. e., legal instruments, policies, and organisations. For example, the legal instruments of how irrigation water sources and their relationship with land and environmental resources are treated within the law have linkages with policy aspects like priority setting for irrigation water uses a project-selection and design criteria. Hence, generally a water law that distinguishes the ecological linkages between irrigation water and other resources is more likely to encourage an irrigation policy that assigns a higher priority to environmental conservation and hydrological interconnectivity in project selection. Similarly, the legal aspect of water rights has multiple linkages with other components embedded within the irrigation legal instruments and across irrigation policies and organisations. The policy and strategy aspects relating to user participation and decentralisation have strong linkages in terms of ability to tap user support and contribution, while, at the same time, contributing to devolution. As can be noted, cost recovery in the policy and strategy component is highly connected with the capacity of finance staff in pricing and fee collection sector of the irrigation water organization (administration). Irrigation policies and strategies dealing with decentralization and devolution issues are directly linked with all elements of irrigation sector organizations.

[16]Irrigation water policies and legal instruments form the software components of irrigation sector and its organisation (administration) constitutes the hardware components.

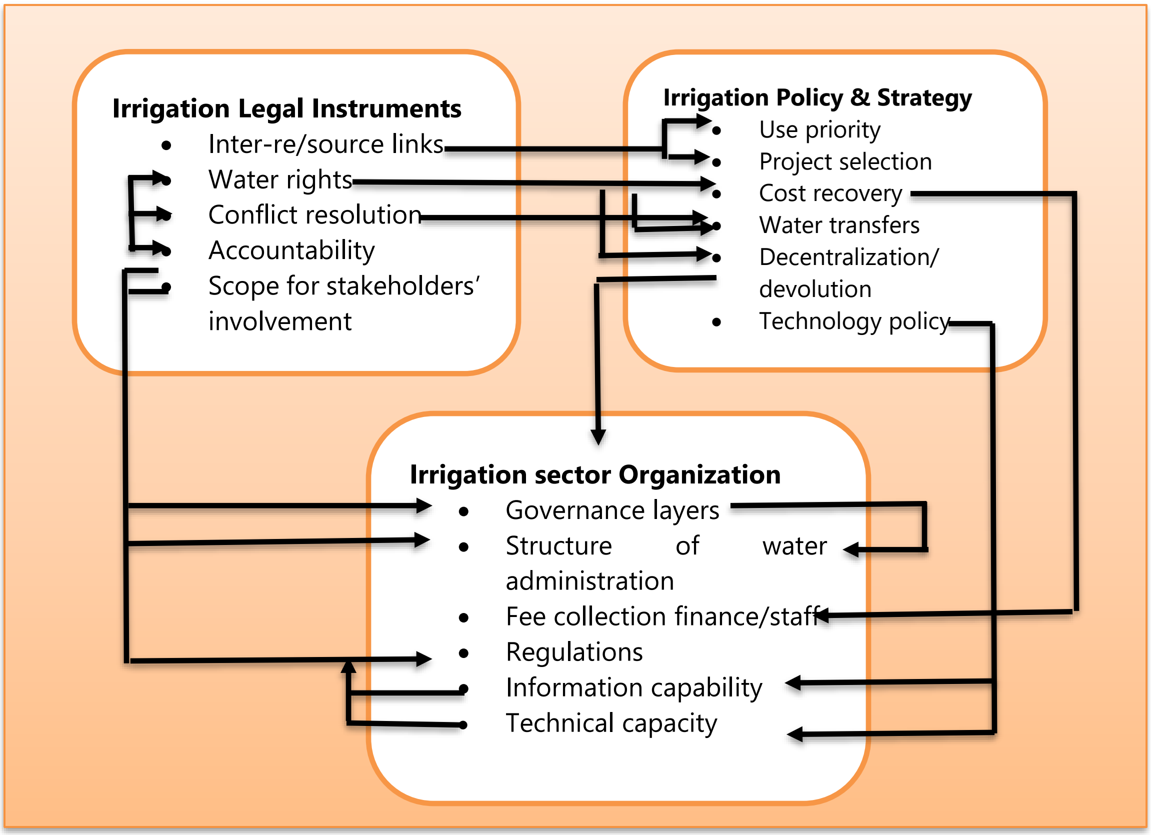

Figure 2.1. Irrigation Sector Institutional Structure

Source: modified from Saleth & Dinar (2004)

2.4. Data

The study employed data collected from multiple sources to analyse the institutional framework and existing gaps in the institutional setting in Ethiopia's irrigation sector. To understand the institutional arrangements for irrigation water at different scales, published and unpublished sources that focus on irrigation sector institutions in Ethiopia were reviewed. These include review and inventory of national and regional policies, strategies, legal instruments, local informal rules and practices, and formal and informal organisations. In addition, KII were conducted with experts and researchers working on irrigation at different levels of GOs and NGOs. The discussions were undertaken concerning content, relevance and implementation of water sector policies, strategies, and legal instruments.

Table 2. 1. Sources of Data

	Regions					
	Federal	Tigray	Amhara	Oromia	SNNPR	Total
Sources of qualitative data						
No. of KII conducted	12	6	4	4	3	29
No. of FGDs conducted		5	8	13	5	31
Sources of quantitative data						
No. of Woredas		2	3	4	1	10
No. of Kebeles		4	6	8	2	20
No of farm households		100	130	133	101	464
No of irrigated fields		140	298	293	306	1037

The national level institutional analysis is followed by an exploration of the nature and characteristics of local institutions for irrigation water management systems on the ground. This part of the study employs a cross-sectional survey of irrigation beneficiary farm households in four regions of Ethiopia: Amhara, Oromia, South Nations, Nationalities and Peoples' Region (SNNPR) and Tigray. The survey was conducted in 2016/17 with the objective of analysing the economics of irrigation mainly focusing on technologies in use and irrigation management. The sample is composed of a total of 1037 irrigated farming plots from 464 farm households. The data was collected using a multi-stage stratified random sampling method (refer section 1.8 for detail). The study only considers smallholder irrigators.

2.5. Method of Analysis

This study employs a qualitative approach to analyse the institutional arrangements in Ethiopia's irrigation sector. Institutional arrangements related to irrigation water development are assessed following a nested approach as an analytical framework. The study looks at a range of scales from the national down to the local perspectives. The existing institutional arrangement is classified into three different tiers: federal (national), regional (state), and local level organizations. At national and regional levels, the analysis is presented by dividing the institutional set-up into three broad categories: policies, laws, and administration. The existing institutional gaps are also identified at each level, accordingly. Where relevant, the interactions between the tiers are examined. The participation of different stakeholders in the establishment and development of the irrigation system and provision of technical support for beneficiary farmers is also discussed. The institutional analysis is followed by a descriptive analysis of the nature and characteristics of collective actions in local level institutional set-ups of the country.

2.6. Results and Discussions

2.6.1. Irrigation institutions in Ethiopia

Since institution for irrigation use and management is a complex entity, it is difficult to be exhaustive and comprehensive in a single study. As a result, this study opted to focus on certain key features of existing institutional arrangements and recent institutional changes in the three main components of the irrigation institutional structure, i.e., law, policy, and administration.

In Ethiopia, institutional arrangements related to irrigation water development can be broadly categorized into three different tiers: federal (national), regional (state), and local level organizations. The following section discusses the exiting institutional arrangements in Ethiopia and identify the gaps that exist at federal, regional, and local levels.

2.6.1.1. Irrigation policy and strategy

Water resources management in Ethiopia is guided by the National Water Resources Management Policy (WRMP). In 1999, the government of Ethiopia issued the first WRMP and irrigation policy is one part of the WRMP. As stated in the WRMP, the general objective of the irrigation policy is to develop the huge potential for irrigated agriculture to produce food crops and raw materials needed for agro-industries, efficiency and sustainably and without degrading the fertility of the production field and water resource base (MoWR, 1999). Following the WRMP, Ethiopia issued a water resources strategy in 2001 with the objective to translate the water resource management policy into action. The irrigation development strategy which sets a road map as to how to develop and manage the country's water resources to achieve national economic and social development objectives. As specified in the strategy document, the main aim of the irrigation development strategy is to expand irrigated agriculture, improve its use efficiency, enhance technical, financial, and environmental suitability of irrigation systems (MoWR, 2001).

The Five-Year Growth and Transformation Plan (GTP I: 2010/11-2014/15) emphasized the promotion of irrigation development while its second version (GTP II: 2015/16-2019/20) aims to improve the management of natural resources with a focus on improving sustainable water utilization and expansion of irrigation (FDRI 2016). The Ministry of Agriculture and Natural Resources, the Ministry of Water, Irrigation and Electricity, the Ethiopian Agricultural Transformation Agency, together with other development partners, initiated development of National Smallholder Irrigation & Draining Strategy in 2016. The objective of the strategy is to guide efforts and investments in smallholder focused irrigation and drainage during GTP II and after. In addition to supporting the previous efforts, the strategy mainly focuses on rapidly and effectively scaling up of smallholder irrigated agriculture across the country considering sustainability and stakeholder participation and engagement as priorities intervention areas in the sector (MOANR et al., 2016).

The Resilience Strategy for Agriculture of Ethiopia, under the Climate Resilient Green Economy (CRGE) [17], identified irrigation as one of 41 promising climate change adaptation options for both smallholders and industrial agriculture and the need to build resilience against the risks of current climate variability and future climate change (FDRE 2011). In addition, reduced deforestation through agricultural land in arid areas through irrigation has been identified as one mechanism to reduce emissions from the expansion of total cropland (FDRE, 2015).

Irrigation is also captured in the two Agricultural Growth Programs (AGP) – AGP-I (2011-2016) and AGP-II (2017-2021). AGP is a multidimensional investment program focuses on enhancing the production, productivity and commercialization of high agricultural potential areas that contribute to the overall economic growth and transformation. One of the components of AGP focuses on smallholder irrigation development. The main objective is to increase access to and efficient utilization of irrigation water by smallholders, particularly to increase the availability of irrigation through the rehabilitation and upgrading of existing irrigation scheme; establishment of new SSI systems integrated with access to roads where necessary, and household irrigation systems. The AGP also emphasizes the improvement of water management services through establishing and/or strengthening Irrigation Water Users' Associations (IWUAs) and introduction of improved water management.

2.6.1.2. Legal instruments governing management of irrigation in Ethiopia

The Ethiopian Water Resource Management Proclamation No. 197/2000, Council of Ministers Water Resource Regulation No. 115/2005, River Basin Councils and Authorities Proclamation No. 534/2007, Rural Land Administration and Land Use Proclamation No. 456/2005 and Irrigation Water Users' Associations Proclamation No. 841/2014 are the legal instruments that govern the operation and management of irrigation in Ethiopia.

Ethiopian Water Resource Management Proclamation

The Water Resource Management Proclamation No. 197/2000 states that all water resources of the country are the common property of the Ethiopian people and the state

[17] The Climate Resilient Green Economy (CRGE) strategy aims to build carbon neutral and climate resilient middle-income economy by 2025.

(Article 5). The fundamental principles of the Water Resource Management Proclamation are explained in detail under Article 6. Article 11 of the proclamation states that, "it is prohibited to construct waterworks, supply water for own use, transfer water abstracted from a water resources or received from another supplier, and release or discharge waste into water resources without having a permit from the supervising body". The Proclamation also describes water works that can be undertaken without permit. For example, use of water for traditional irrigation or from hand-dug wells do not require a permit from the supervising authority (Article 12/1/a-b).

Council of Ministers Water Resource Regulation

The Councils of Ministries Water Resource Regulation No. 115/2005 gives detailed provisions for the implementation of the Water Resource Management Proclamation No. 197/2000. The regulation provides explanation on the requirements for the issuance of permits for different uses of water; fees to be paid for permits; termination, suspension and transfer of water use, water quality control and dispute settlement.

River Basin Councils and Authorities Proclamation

The River Basin Councils and Authorities Proclamation No. 534/2007 provides for the establishment of River Basin High Councils (RBHCs) and River Basin Authorities (RBA). The RBHCs is the highest policy and strategic decision-making body. The River Basin High Councils and Authorities are expected to promote and supervise the integrated water resources management process in the river basins falling under their jurisdictions in the purpose of enhancing the socio-economic welfare of the people by emphasizing on participation, equitable benefit sharing, and sustainable management of the environment. The RBAs shall be accountable to the respective Basin High Council and the MoWIE (Article 10).

Rural Land Administration and Land Use Proclamation

Rural Land Administration and Land Use Proclamation No. 456/2005 covers all rural land in Ethiopia (Article 4). The implementation of this proclamation is exclusively vested in the regional states. According to this proclamation land distribution could be undertaken on irrigable land in order to use the resource properly and equitability (Article 9/2). For peasant farmers, semi farmers, semi pastoralists and pastoralists who are displaced from their holdings for purposes of constructing irrigation structures, land distributions shall be implemented in order to make equitable benefit sharing among the community (Article 9/4). If irrigation line crosses farmland during the construction of infrastructure, the land holder has the obligation to give up the farmland for construction (Article 10/2).

Irrigation Water Users' Associations Proclamation

Irrigation Water Users' Associations Proclamation No. 841/2014 creates legal basis for the establishment of Irrigation Water Users' Associations (IWUAs) as a particular type of legal entity for operation and management of irrigation systems. The previous legal framework-Cooperative Societies Proclamation No. 1547/1998 and Cooperative Societies (Amendments) Proclamation No. 402/2004-do not provide an appropriate legal basis for IWUA establishment. In the recent proclamation, IWUAs are recognized as a public law organization (Article 13). Membership is compulsory (Article 15); IWUAs operate on a non-profit /non-commercial basis and provides services to their members on a paid basis (Article 32).

2.6.1.3. Organizations responsible for irrigation sector development in Ethiopia

Organizations at the federal level

At federal level, the Ministry of Water, Irrigation and Electricity (MoWIE) and its affiliated organisations (such as Water Works Design and Supervision Enterprise (WWDSE), Water Works Construction Enterprise (WWCE) and the Water Resources Development Fund (WRDF)), the Ministry of Agriculture (MoA), the Environment, Forest and Climate Change Commission (EFCCC), and the Ministry of Finance (MoF) are responsible organizations for irrigation sector infrastructure development in Ethiopia.

MoWIE oversees the management of water resources, water supply and sanitation, large and medium scale irrigation, and electricity. It is established for planning, developing, and managing of water resources, preparing, and implementing of guidelines, strategies, policies, programs, and sectoral laws and regulations in the water sector. It undertakes research activities and provides technical support to regional water bureaus. The Ministry is responsible of regional and interregional water resource development and management, as well as functions that involve international procurement.

The WWDSE is a public consultant that conducts studies related to irrigation, basin development master plans and other water projects. The WWCE is responsible for the construction of dams for irrigation and other related development purposes. It is also in charge of collecting investment cost from beneficiaries of such dams and invest the money on other similar developments. The WRDF is a representative of MoWIE established for financing projects in the water and sanitation sector and for irrigation development through the provision of a long-term loan based on principles of cost recovery. The MoA is responsible for developing community-managed SSI schemes, i.e., up to 250 ha, from scheme formulation to development and extension services including marketing. The EFCCC is responsible to investigate the environmental impact of irrigation projects. The MoF is in charge of allocating capital budget for construction of irrigation projects. In addition, River Basin Authorities are responsible organizations for management and implementation of water related activities in their respective basin which have been developed most recently. To date the Awash, Abbay and Rift Valley Basin Authorities have been established.

Regional and local level organizations

In Ethiopia, the placement of the irrigation sector in terms of organizational structure differs across regions. Some regions such as Oromia have reorganized a separate irrigation authority, while in other regions like SNNPR and Beneshangul Gumuz, irrigation falls under the Bureau of Agriculture. In Amhara and Tigray regions the irrigation sector is split between the Bureau of Agriculture (for extension services) and the Bureau of Water Resources (for administration of irrigation infrastructure). In Dire Dawa city council, the irrigation sector is placed under the Bureau of Natural Resources. At lower administration levels, district and sub-district bureaus have been established with similar designations and responsibilities as the regional bureaus as described above.

Irrigation Water Users' Associations (IWUAs) are the most common local level institutions that are engaged in irrigation water management. The role of IWUA is mainly focused on the distribution of water among members, rehabilitation and maintenance of canals and addressing water related conflicts. In some places, government-supported irrigation cooperatives have been established in some irrigation schemes; these generally have broader operational scopes, including the provision of marketing, credit, and extension services.

The Ethiopian Agricultural Transformation Agency (ATA) is a further important organization in Ethiopia's irrigation scene. ATA supports the implementation of the Small-Scale Irrigation Capacity Building Strategy[18], focusing on water managment, and the promotion of micro-irrgation through affordable and availabe household irrigation technologies. The Household Irrigation Program is supported by other development partners through the Agricultural Growth Program (AGP). Many donors, local and international NGO's, research organizations, farmers' cooperatives, and private sector equipment suppliers are also involved in the irrigation sector.

Based on a study recommendation by ATA, as of April 2019, the Minstry of Finance (MoF) approved the imports of agricultural mechnization and irrigation equipment, including irrigation pumps, tools and spare parts, to be imported duty free into the country, with

[18] The Small-Scale Irrigation Capacity Building Strategy was developed by Ministry of Agriculture in collaboration with development partners from the Federal Republic of Germany and the State of Israel for enhancing irrigated agriculture capacity in Ethiopia.

the aim of providing incentives to invest in the importatiaon and local production of these technologies.

Overall, our findings reveal that there is a well-established institutional set-up in the irrigation sector of Ethiopia. The objectives are clearly defined. The exisiitng orgnizations have been established and the related policies and the legal instruments in place have also clear objectives, and some have developed strategies to meet the objectives. Despite all these efforts, there are significant problems observed in the organizational setting that affect activites, actors, and end results on the ground.

A careful examination of the profile of ministries depicts that there are overlaps in mandates between different ministries which oversee the sector. For example, MoWIE and MoA have responsibilities related to irrigation development; MoWIE is in charge of medium and large-scale irrigation works while MoA focuses on SSI and micro-water management. When civil works of large and medium scale irrigaiton schemes is completed, the provision of extension services and related inputs provisions are expected to be undertaken by MoA, though this may not be clear anywhere. Similary, overlap in mandates and duplication of efforst have been observed in the broad areas of integrated natural resource managemnt among MoWIE and EFCCC. For instance, both MoWIE and EFCCC are responsible for environemntal impact assessemnt and water pollution control. Our result is consisitent with previous studies studies by Haileselassie et al., (2009); Hussein et al., (2009); Hagos et al., (2011) which explore the institutional set-up of irrigation sector in the Blue Nile Basin and found there is no clear demarcation of mandates and responsibilities among ministries and organizations. The institutional challenges are even larger at region and local levels.

In this study, irrigation experts at regional, *woreda* and *kebele* level were asked whether the current structure of the irrigation sector is functioning well in their locality. The result shows that 45% of the experts think it is not functioning well; among these 88% believe that the root cause of the malfunctioning arises from the organizational structure and set up of the irrigation entity that leads to lack of coordination, duplication of efforts, and wastage of resources. Moreover, the existing information and resource sharing mechanisms do not ensure institutional harmony and efficient information and resource flows. Horizontal and vertical communication between ministries, bureaus and departments belonging to different sectors are rare. In most cases, these communications are informal. Especially, the communication of local organizations with the regional and federal-level institutions is very weak and integrated information management systems are lacking. Thus, ministries, bureaus, and departments attempt to fulfil their responsibilities without an interdisciplinary and integrated approach which is fundamental in the field of water resource management at each level. As Mollinga (2010) argued, there is a need of natural-social science interdisciplinary in water resources management which arises from its complexity and multidimensionality nature of water resources management problems.

Even if the policies, strategies, and the legal instruments are well specified, and the relevant organizations have been established, there has been weak enforcement capacity among organizations. According to discussions with key informants, the main reason for the weak enforcement capacity is inadequate staff and resources to do proper enforcement of rules and regulations. Similar results are observed in a study done by Haileselassie et al., (2012). They reported that regulations on water resources management, pollution control, land use rights, watershed development, and other related issues are not effective because of weak enforcement capacity in both upstream and downstream parts of the Blue Nile Basin of Ethiopia. The weak enforcement capacity of institutions can be connected to the lack of an integrated system of information and resource flow at the federal, regional and local levels. Other problems such as absence of monitoring and evaluation systems in the irrigation sector, significant reliance top-down approaches, continuous reorganizations of the sector, specifically at regional level (numerous reforms and destabilization of irrigation agency over the last 20 years in Amhara, Tigray, and Oromia) were mentioned as the major problems in the irrigation sector of Ethiopia.

2.6.2. Local level institutions for irrigation water management

Local level irrigation water management can be characterized in terms of the role played by users and government entities in the management of the resource. As such, four types of irrigation water management systems can be identified at the local level: (i) privately developed and accessed irrigation system, (ii) user-managed irrigation system, (iii) user-and-agency managed irrigation systems, and (iv) open access irrigation systems with limited government interventions. The next section continues to explore the nature and characteristics of local institutions for water management in Ethiopia. In addition, the existing gaps and problems encountered within those systems is examined.

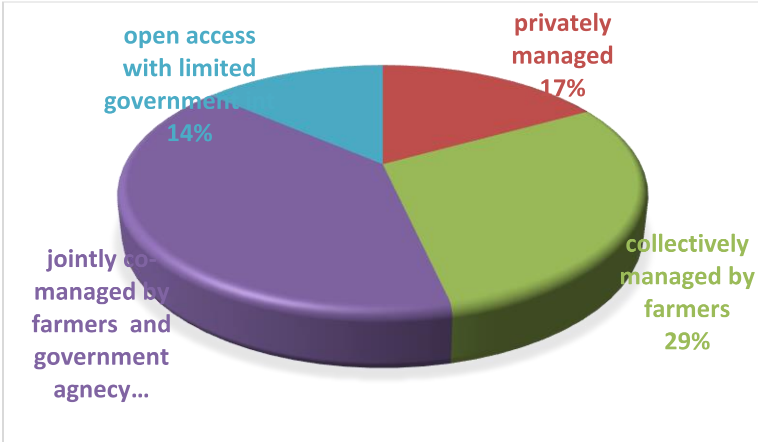

Figure 2. 2. Diversity of local water management practices
Source: Author's computation using own survey data

Table 2. 2. Irrigated plots by water management system and gender of household head

Irrigation water management system	Gender of HH	Freq no. of plots	%
Privately managed	Female	4	2.29
	Male	171	97.71
	Total	175	
Collectively managed by farmers	Female	37	12.09
	Male	269	87.91
	Total	306	
Jointly managed by farmers and government agency	Female	33	7.95
	Male	382	92.05
	Total	415	
Open access	Female	3	2.13
	Male	138	97.87
	Total	141	
Total	Female	77	7.43
	Male	960	92.57
	Total	1037	

Source: Author's computation using own survey data

2.6.2.1. Nature and characteristics of collective action in user-managed and user-and-agency managed irrigation systems

User-managed irrigation system refers to schemes in which farmers and the WUA have full control and responsibility in the inception and construction of the scheme as well as the distribution and utilization of irrigation water. User-and-agency managed system, on the other hand, refers to the management of schemes is done jointly by farmers and a government agency, where a governmental agency manages the main and secondary canals, and the farmers manage the tertiary units and beyond.

Since most user-managed and user-and-agency managed irrigation schemes have the character of a common pool resource, they face two types of resource management problems in collective action arrangements in irrigation water use: provision and appropriation. The problem of provision is mostly related with arranging the construction and maintenance of canals, while appropriation arises in water distribution and allocation arrangements. To overcome these problems, irrigation water users organize themselves at scheme level into Water Users' Associations (WUAs) for water control and use which include water distribution, construction, maintenance, and rehabilitation of infrastructure at scheme level, and block or group[19] leaders at each outlet level. Insight from FGDs with irrigators reveals they have their own Irrigation Water Users' Committee (IWUC), though their name may differ in different regions.

In both irrigation water management systems, the commonly practiced water distribution mechanism is rotational irrigation. The irrigation allocation is implemented based on the existing system layout and topographical conditions. As a result, irrigation water can be simultaneously delivered into each block (group). Water distribution turns are established depending on number of days before last turn, rather than water needs by plants. A block (group) gets water for a day per rotation while the number of rotations per week varies from season to season. During focus group discussions, farmers indicated that they follow crop-water requirement rates that is recommended by *kebele* extension workers when irrigating their plots. However, during our field work, it was noted that the application of water is without consideration of the soil type, crop type, and stage of growth. Interviews with local level irrigation extension workers indicated that irrigators tend to over-irrigate thinking that more water results more yields.

Around 1/3rd of the sampled irrigated plots in this study falls into users-managed systems (Figure 2.2), of which only 12.1% of them were cultivated by female headed households (Table 2.2). Usually, this kind of management system is found in traditional irrigation schemes. Most of them (64%) use gravity irrigation. The schemes are often constructed using diversion weirs made from local materials and need annual maintenance. Out of 306 plots under traditional schemes included in the sample, 163 (53%) divert river as a source of irrigation water. User-managed irrigation system further comprises a group of farmers who have developed a well to share the water collectively, by applying motor pumps to lift water. In 36% of the cases, farmers use pump in addition, to lift water from a source in areas where the landscape is not suitable to use gravity irrigation alone.

[19]A block or a group is the smallest social unit that has the capacity to use and manage the communal irrigation water.

Before establishing associations and getting formal recognition, the communities have already accumulated experience using rivers and spring water for irrigation purpose, ranging from 2 to 71 years. For example, farmers have been irrigating by diverting the Wesha River in Wondo Genet *woreda*, the Walga River in Wunchi *woreda*, and the Teji river in Teji *woreda* for decades without having formal and legal users' associations. It is a recent phenomenon that farmers in all the *woredas* have started to mobilize themselves into formal associations or groups to use the water due to the legal requirements set by the government.

The role of government agencies in the management of irrigation schemes is more common among large and medium-scale irrigation systems. The government agencies are responsible for operation and maintenance at higher levels of a system; users often carry out responsibilities at the lower reaches of management level. For instance, Koga irrigation project[20] in Amhara Region, Tibila Irrigation-based Integrated Development Project[21], Kobo-Girana pressurized irrigation project[22], Golgol Raya Development Project[23] are irrigation systems included in this study that fall in this category. As observed during our field work, all the operational management of the schemes are undertaken by government agencies (their respective basin authorities and regional irrigation bureaus). Farmers' contribution to the operation and maintenance of the irrigation system is insignificant and their role is mainly limited to lower canals in terms of organizing and managing water uses and water users.

Around 40% of the sample households belong to users-and-agency managed system in this study (Figure 2.2), among these, around 8% of them were irrigated by female headed

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[20] The Koga irrigation scheme is located in Lake Tana sub-basin in the Upper Blue Nile Basin. Even if the original plan was to benefit 7000 households of smallholder farmers during irrigation seasons, the maximum actual irrigated area was 73.5% of the design command area in 2016/17.

[21]Tibila Irrigation-based Integrated Development Project is located in Oromia region of Arsi zone. The construction works were started in 2008. Currently, the project is operational in two woredas of Jeju and Sire. However, the construction of the irrigation infrastructure for the command area in the Merti district is yet to begin. So far, about 2,500 ha of land has been irrigated. When the project is completed, its gross command area is expected to increase to 7,000 ha, with net irrigable area of 6,000 ha. Tibila Irrigation Scheme Management Unit (TISMU) is in charge of the distribution and management of irrigation water up to secondary canals.

[22]The Kobo valley pressurized irrigation project is run by Kobo-Girana Valley Development Project. The irrigation methods practiced are drip and sprinkler irrigation.

[23] The Golgol Raya Development Project has developed deep well groundwater irrigated agriculture based on state-community managed approach. So far, hundreds of deep wells have been drilled and a few of them are installed with modern pressurized (drip and sprinkler) infrastructures.

households (Table 2.2). Most of irrigators in this irrigation managed system use river (53%) and dam (30%) as a source of irrigation water (Table 2.3). They apply mainly gravity irrigation (78%) to distribute water. In around 15% of the cases, they use electric pumps in pressurized systems. More than half of the irrigators (57%) in users-and-agency managed system apply flooding irrigation type to apply water on their fields. This suggests that there is a need for training to beneficiary farmers on efficient water application and use at field level.

In both users-managed and users-and-agency managed systems, the farmers with the help of local government irrigation agencies collectively prepare and agree on a set of rules of restricted access to water and make arrangements for financial, labour or other contributions needed for the management of the resource; and lay out a system of enforcement of the restrictions and beneficiaries' contributions. It is observed that there are differences in the naming of local irrigation institutions at several irrigation schemes in the country. In some places there are irrigation water executive committees whereas in other schemes there are "water fathers". With the help of a water distributors (operators) and group (block) leaders, the water executive committee is in charge of enforcing the restricted rules and regulations. The next sub section discusses the nature of collective actions done by farmers and investigate their performance.

Table 2.3. Characteristics of users-managed and users-and agency managed irrigation schemes

	Users-managed irrigation schemes	**Users-and-agency managed irrigation schemes**
Type of water source		
River	163(53%)	197(47%)
Dam	23(7.5%)	125(30%)
Pond	3(1%)	0
Groundwater	88(29%)	72(17%)
Spring water	29(9%)	21(5%)
Type of water lifting mechanisms		
Gravity	195(64%)	328(78%)
Manual	22(7.2%)	0
Diesel pump	35(11%)	23(6%)
Electric pump	54(18%)	64(15%)
Type of water application mechanism on irrigated fields		
Surface(flooding)	118(38%)	236(57%)
Sprinkler	17(6%)	21(5%)
Drip	18(6%)	27(6%)
Furrow	153(50%)	132(32%)
Total	306(100%)	415(100%)

Source: Author's computation using own survey data
Note: Figures in the table show number of irrigated plots in the sample, with their shares from the total sample in brackets.

(i) Membership

The rule of exclusion or inclusion of users is an important principle that guides collective use and management of natural resources such as irrigation water (McCay & Acheson, 1987; Ostrom et. al., 1999). Issues related to membership are defining characteristics of irrigation institutions (Lamperier et al 2014). As stated in Irrigation Water Users' Associations Proclamation No. 841/2014, membership should be mandatory for irrigation beneficiaries and is linked to having an irrigable land or land use right within the command area. As most irrigators use common irrigation water sources and lifting mechanisms in the country, membership is fundamental in order to avoid free riding. The findings of the study show that only 82.6% and 95% of plots of the sample farm households who are in users-managed and users-and-agency managed irrigation systems, respectively, are members of IWUAs (see Table 2.4). IWUA members find it difficult to enforce the laws such as irrigation water fees and participation in maintenance activities among non-members, which creates opportunity for free riders. Hailesselassie et. al., (2016) reported irrigation schemes in which up to 40% of the beneficiaries are non-members of the existing institutions. While comparing the membership across gender, female headed households (92%) are more likely to be formal members of WUA than their male counterparts (81%). In the contrary, in the farmer-and agency managed irrigation systems, around 96% male headed households are formal members of WUA (see Table 2.5).

(ii) Written by laws

In both users-managed and users-and-agency managed irrigation systems, there are rules and regulations which in many cases are not written or well documented. Experience elsewhere in Ethiopia suggests that by-laws are developed and imposed particularly when IWUA are directly linked to cooperatives (Yami, 2016). Our findings reveal that one fifth and one tenth of users-managed and users-and-agency managed members of IWUA, respectively, do not have full knowledge on the by-laws under which their system is functioning. As indicated in Table 2. 4, only half of the irrigated plots in users-managed systems and a third of the plots in users-and-agency managed systems participated and contributed in cash, labour or in-kind at the initial stages of the construction of the infrastructure.

A penalty system for violation of rules and regulations of the association forms part of the general written by-laws. Farmers were asked the number of times they violated the law and got penalized in 2015/16. The average number of times they were penalized in both management systems is more or less the same (0.2) and the maximum number of penalties received goes up to 5 times in 2015/16 irrigation season (Table 2. 4). The most frequent violation of rules and regulations is livestock grazing and crossing irrigated fields of others and irrigation structures, stealing water turns, overuse of irrigation water, and not participating in annual cleaning and maintenance of canals and other irrigation structures.

(iii) Contribution to Operation and Maintenance (O&M)

Each year farmers organize themselves to clean and maintain canals for smooth and efficient flow of irrigation water. The contribution can take the form of cash, labour or in kind. On average, farmers contributed around 7.4 days for O&M in both management systems in 2015/16. Beneficiaries also contributed in cash and in kind for O&M of irrigation water as needed. In 2015/2016, irrigators in the study contributed around USD 19.28 (ETB 429) and USD 11.08 (ETB 247) in user-managed and user-and-agency managed systems, respectively. Contributions are higher for users-managed schemes because the more traditional structures need more maintenance before the start of each irrigation season. The result also shows that female headed households contribute as much as male headed households for the day-to-day O&M of the irrigation schemes. They pay their contribution for the committee as much as possible on time as compared to male members of the association. This result is not in line with other studies. For instance, Bekele (2008) found that female farm decision makers who practice irrigation have faced financial as well as labour constraints in both farm and forum level activities. In some cases, if their economic status and family labour constraint is realized by IWUC and other members of the association, female headed households are excused for not participating in O&M activities of the irrigation system.

Around 70% and 80% of farmers who are in users and users-and-agency managed systems, respectively, claimed that contribution and mobilization of maintenance and clearance of canals and other irrigation structures is made equally by all members of WUA. However, informal discussions with irrigators suggest that tail-end users often contribute more than head and middle-end users. Usually, farmers in a traditional irrigation system clean the canals two to four times a year in order to prepare the structure for irrigation during the dry season. According to the by-laws of IWUA, starting from the uppermost part of the scheme, every irrigator must participate in cleaning and maintaining of structures until the lower-most canal that serves for a common use. However, the result of FGDs with irrigators reveals that the head-enders usually stop maintenance work once the head-end part is done. The rest of the O&M activity is up to the tail-enders. This result is similar to a study by Bekele (2008) which focused on communally managed irrigation systems in two woredas (Atsebi Wemberta *woreda* in Tigray region and Ada'a *woreda* in Oromia region) of the country. Because of lack of effective enforcement of rules and regulations, some beneficiaries contribute more for the day-to-day O&M of irrigation schemes.

Table 2. 4. Nature of collective actions across users and users-and-agency managed irrigation schemes

Type of collective action	Users-managed irrigation system	Users-and-agency managed irrigation system
Contributed to the construction of the infrastructure, 1=yes, 0=no	168(56%)	135(33.4%)
In cash, 1=yes, 0=no	40(23.81%)	51(37.7%)
In kind, 1=yes, 0=no	16(9.52%)	16(11.85%)
In labour, 1=yes, 0=no	112(66.67%)	68(50.37%)
A member of WUA, 1=yes, 0=no	246(82.55%)	381(95.01%)
Contributed labour for O&M during the 2015/16 irrigation season, 1=yes, 0=no	197(66.11%)	206(51.37%)
No. of days contributed in labour during irrigation season 2015/16	7.6 (9.09)	7.4(9.9)
Contributed cash for O&M during the 2015/16 irrigation season, 1=yes, 0=no	93(31.21%)	134(33.42%)
Value contributed in cash during the 2015/16 irrigation season	19.28	11.08
Contributed in kind for O&M during the 2015/16 irrigation season, 1=yes, 0=n	33(11%)	32(8%)
Farmers' perception on whether all beneficiaries contribute equally for O&M, 1=yes, 0=no	206(69%)	318(79.3%)
Good knowledge of the written by-laws, 1=yes, 0=no	244(82%)	376(93.8%)
Whether there was conflict with an irrigator neighbour, 1=yes, 0=no	81(30%)	126(31.42%)
Whether there was conflict with a farm neighbour on other matters, 1=yes, 0=no	24(8.05%)	46(11.48%)
No. of times penalized for violation of by-laws	0.23(0.7)	0.2(0.6)
No. of times meetings attended	2.58(1.45)	2.1(1.14)
Participation in election of WUC, 1=yes, 0=no	195(65%)	349(87%)
Farmers' perception on the quality of the irrigation infrastructure		
Very good	59(20%)	108(29%)
Good	96(32%)	163(39%)
Fair	64(21%)	38(9%)
Poor	62(21)	66(16%)
Very poor	17(6%)	25(6%)
Whether attended training on natural resource management	115(39%)	165(41%)

Source: Author’s computation based on own survey

Note: Figures show number of irrigated plots in the sample, with their shares from the total sample and standard deviations in brackets.

Monetary values are in USD

Table 2. 5. Collective action participation among female and male household heads

Type of collective action	Users-managed irrigation systems		Users-and-agency managed irrigation systems	
	Female	Male	Female	Male
Contributed to the construction of the infrastructure, 1=yes, 0=no	18(48.65%)	154(57.25%)	15(45.45%)	128(33.51%)
A member of WUA, 1=yes, 0=no	34(91.89%)	219(81.41%)	28(84.85%)	364(96.07%)
Contributed for O&M during the 2015/16 irrigation season, 1=yes, 0=no	28(75.68%)	174(64.68%)	16(48.18%)	199(52.09%)
Good knowledge of the written by-laws, 1=yes, 0=no	29(78.38%)	223(82.90%)	32(96.97%)	358(93.72%)
Whether there was conflict with an irrigator neighbour, 1=yes, 0=no	4(10.81%)	81(30.11%)	11(33.33%)	118(30.89%)
Meetings attended (sometimes and above)	25(67.57%)	114(42.39%)	15(45.45%)	137(35.86%)
Farmers' perception on the quality of the irrigation infrastructure (fair and above)	24(65.86%)	122(45.35%)	8(24.24%%)	127(33.25%)
Whether attended training on natural resource management	19(51.35%)	100(42.39%)	7(21.21%)	164(42.93%)

Source: Author’s computation using own survey data
Note: Figures show number of irrigated plots in the sample by gender, with their shares from their respective total sample in brackets.

(iv) Irrigation water use fee and water pricing

Cost recovery has not been enforced in irrigation schemes, even though it is specified in water resources policy of Ethiopia (MoWR, 1999). There have been attempts to implement cost recovery in some irrigation sites. For example, irrigators who apply pressurized technology to lift groundwater in Alamata *woreda* have made some attempt to recover the cost. However, due to the high electricity cost, almost all the fees collected from the farmers go towards paying the electricity bill.

(v) Conflict occurrence and resolution mechanism

One of the tasks of IWUC is resolution of conflicts among irrigators. Major causes of conflict between users are water theft due to shortage of water, and lack of a comprehensive and documented by-law. Contrary to our expectation, in 2015/16, a higher number of conflicts was observed among farmers in users-and-agency managed schemes than farmers in users-managed schemes. The main reason reported was water theft during the driest season (January to March) of the year. In addition, as discussion with irrigators in user-managed irrigation system implies they prefer to resolve disputes on the water distribution and management informally at lower level before it erupts into serious conflicts. However, one thing worth mentioning is that the incidence of conflict occurrence among female headed households is three times less than their male counterparts (see Table 2.5).

Conflicts also occur among users and service provider institutions. It happens when the agreed irrigation service cannot be met as per the agreement for water allocation and use. The result of FGDs with beneficiary farmers indicates that there were times when the institution in charge of primary and secondary canal water distribution failed to carry out its tasks as expected. There were cases of severe conflicts, where some farmers attempted to destroy the irrigation infrastructure.

(vi) Participation of members in meetings and election of water users committee

According to the by-laws of the irrigation schemes and FGDs with irrigators, members shall meet frequently (mostly once a month) and water users committee (WUC) once every two weeks to address problems irrigators face, and once a year to elect new executive committee members and individuals who would be responsible for water distribution in the following year. In practice, these schedules are barely practiced. The only occasion that brings farmers and WUC to meetings is when they discuss canal cleaning, when the irrigation system ceases to function, or an urgent action is needed. As shown in Table 2.4, in 2015/16, the average number of times beneficiaries attended meetings was only twice.

Discussions with WUC show that though meetings of the general assembly are rarely undertaken, majority of members have regarded attending meetings as an obligation rather than an opportunity to widen their network and information. As a result, most of the time, the majority of them have been absent. Especially, the attendance and participation rate of women who are in male household heads in associations' meetings has been almost nil.

All irrigation water users in WUAs can participate equally in all meetings, which are led by irrigation water users' committees (IWUCs). The Water Users Committee is an official link between irrigators and government officials at the local level. The committee is an executive group within a WUA. They represent irrigators and not the government and are appointed by the water users. Ownership of land within the command area, active participation within the community, age, and status in the community are important considerations to be appointed as an executive committee member. Moreover, all members of WUAs (women and men) have equal rights to vote and to be elected to serve as an executive committee, water distributor (operator) or block leader, even if more than 92% of executive WUCs are male and most of the time the voters themselves are male household heads. There were only five women who were serving as executive IWUC. Three of them were cashiers and the rest were serving as secretaries in their respective WUAs

(Table 2.6). There was no female who was in charge of water distribution or block(group) leader.

Table 2. 6. Irrigators in leadership by gender of household head

Type of water management	Gender of household head	Irrigation Users	Those who participate in election of WUC	Water Users Committee
Users-managed irrigation systems	Female	37(12.09%)	21(56.76%)	2(6.67%)
	Male	269(87.91%)	177(65.80%)	28(93.33%)
Users-and-agency managed irrigation systems	Female	33(7.95%)	29(87.88%)	3(8.57%)
	Male	382(92.05%)	331(86.65%)	32(91.43%)

Source: Author's computation using own survey data
Note: Figures show number of irrigated plots in the sample by gender, with their shares from the total sample in brackets.

Our FGDs with irrigators in users-and-agency managed schemes indicate abuse of power and corruption by the IWUCs and government agencies in charge. As stated in Huppert & Wolff (2002), irrigation management usually faces adverse motivational structures deep-rooted in the organizational design of users-and-agency managed irrigation system. The sub-optimal performance of particularly large and medium irrigation schemes all over the world is explained by "principal-agent "problems, that results in rent-seeking behaviour and corruption among key players. The result suggests a need for interventions that promote transparency among those in charge of water allocation and management of irrigation schemes.

In general, the study reveals that farm households have long years of irrigation water use (ranges 2-71 years) in farmer-led irrigation system. The construction of medium and large-scale irrigation schemes (such as Koga irrigation project, Tibila Irrigation-based Integrated Development Project, Kobo-Girana pressurized irrigation project, Golgol Raya Development Project) for smallholder farm households is a very recent phenomenon in Ethiopia. In this kind of irrigation system, governmental agencies play a major role at the establishment and construction of the schemes. Farmers' contribution to maintenance, planning and implementation of water allocation and management is limited to beyond the lower reaches (third and fourth canals). Both users-managed as well as users-and-agency managed systems have written by-laws for provision and appropriation of water and to make arrangements for financial, labour or other contributions needed for the management of the resource. They also lay out a system of enforcement of the by-laws. The result show that 83% and 95% of irrigation users in users-managed and users-and-agency managed systems are formal member of WUAs, respectively. Similarly, a greater number of irrigators in users-and-agency managed systems are knowledgeable about the written by-laws (90%). Regarding, capacity building, less than half of the sample farm households in both kinds of irrigation systems attended training on natural resource management at least one time in 2015/16 fiscal year. Contribution for O&M of the system is higher in user-led schemes. Even if in the water resources policy of Ethiopia (MoWR, 1999), enforcement of cost recovery is specified clearly, so far, it has not been implemented in users-and-government managed irrigation schemes, except few attempts. In addition, higher number of conflicts among farmers is observed in users-and-agency managed schemes than among farmers in users-managed schemes. Furthermore, there are times conflicts occurred among users and service provider institutions in users-and-government managed irrigation schemes. It happens when the agreed irrigation service cannot be met as per the agreement for water distribution and use.

The best starting point to enforce the new Proclamation of IWUA, i.e., Irrigation Water Users' Associations Proclamation No. 841/2014, in respect of cost recovery and conflict prevention and resolution mechanisms could be to learn from traditional irrigation systems, especially from the institutional and legal aspect of water administration and management. Since users in traditional irrigation systems have long years of experience, they may provide the opportunity to understand the evolution, development, and function of traditional WUAs in an Ethiopian context with insights as to how to organize and develop modern irrigation associations. Studies suggest that for a successful user and users-and-agency managed irrigation schemes, the economic and financial costs of sustainable self-management must be a small share of its additional benefits, the transaction cost of the organization must be vital to the improvement of livelihoods for large number of members. In addition, developing and promoting of local leadership skills for irrigation management is a key factor for successful user and users-and-agency managed irrigation systems (Ostrom et al 1994; Gebremedhin & Peden 2002; Tang 2002; Meinzen-Dick et al 2002).

2.7. Conclusions and Policy Recommendations

Ethiopia has undergone remarkable transformations in both political and socio-economic terms. Policy reforms on decentralization and devolution of natural resources management have been undertaken throughout the country. The water sector has not been an exception in this regard. Institutional changes within the water sector, particularly to the irrigation sector, have aimed at decentralizing and devolving of the governance structure. Yet, there has been a concern regarding the overall performance of the existing irrigation institutional set-up in the country. Therefore, this study explores the institutional arrangements for irrigation water management at national, regional, and local levels in the country and identifies the existing gaps at each level. The study employed data collected from multiple sources such as reviews of published and unpublished sources, KIIs and FGDs. The study analysed nature and characteristics of local institutions for irrigation water management using a comprehensive household and plot level survey conducted in ten districts.

Our findings reveal that even if the policies, strategies, and the legal instruments are well specified, and the relevant institutions and organizations have been established, the organizations in place fail to meet their expected functions and are unable to enforce the rules and regulations. A careful examination of the profile of ministries depicts that there are overlaps in mandates between different ministries that oversee the sector. Insights from KIIs reveal that the current horizontal and vertical information-sharing mechanisms in place do not ensure institutional harmony nor efficient information and resource flows. Horizontal and vertical communications between ministries and bureaus across different sectors are rare. This implies the importance of immediate intervention from both government and development partners. It requires coordinated effort and long-term commitment from all relevant stakeholders. Capacity building programs should be implemented to strengthen the whole institutional set-up of the irrigation sector at each level. As the result of KIIs indicates more frequent training is needed to experts at each level to build interdisciplinary and integrated water resource management to address problems related to the weak enforcement capacity due to inadequate staff. Furthermore, as indicated in the discussion with experts at federal level, instead of making numerous reforms repeatedly in the sector, evidence-based reforms and interventions should be encouraged.

The result of the study also shows that despite in principle, irrigation water users' associations (IWUAs) are supposed to be self-managed organizations governed by their members and executive committees, the existing irrigation institutions in users-and government managed system fail to meet their expected functions and unable to enforce the rules and regulations regarding cost recovery and conflict prevention and resolution mechanisms. Traditional user-managed systems may provide insights on the organization and development of the institutional and legal aspects of administration and management of modern irrigation associations, as they have long years of experience in using and managing the resource. In addition, the finding of the study depicts that only few farm households have attended training regarding natural resources. Therefore, provision of trainings for irrigation beneficiary farmers, their executive committees and irrigation experts at each level will improve the efficiency and sustainable use of irrigation water.

3. JOINT ESTIMATION OF ROLE OF IRRIGATION TECHNOLOGIES AND WATER MANAGEMENT SYSTEMS FOR NET FARM RETURNS: EMPIRICAL EVIDENCE FROM ETHIOPIA

3.1. Introduction

Investment in agricultural water management technologies is a key strategy to reduce climate risk, improve crop productivity and household income (Awulachew, 2007; IWMI, 2007; Namara et al., 2007; 2010; Hagos et al., 2009; 2012). Studies also pointed out that agricultural growth fostered by technological change in irrigation plays an important role in growing rural incomes, rising food consumption and nutrition and ultimately alleviating poverty (von Braun et al., 1989; Pingali et al., 1997; Bhattarai et al., 2002; Demenech & Ringler, 2013; Mekonnen et al., 2019). In the last three decades, the adoption and diffusion of small-scale irrigation and rainwater harvesting practices have been central to Ethiopia's policy and strategy in agricultural and rural development. In addition to the traditional irrigation systems adopted by farmers or developed by communities, the government and several development partners are much involved in the diffusion of shallow and deep wells, micro-dams, and river diversions (Rämi, 2003; Awulachew et al., 2007; 2008; MoFED, 2006; 2010; Hagos et al., 2012). The government also has embarked on development of medium and large-scale irrigation systems throughout the country.

The impact of irrigation on farm productivity and other related outcomes depends both on the technical components of the irrigation system as well as the institutional arrangements that govern the management of irrigation water (Meinzen-Dick, 2007; Ostrom & Basurto, 2011; Burney & Naylor, 2011; Cofie & Amede, 2015; Haileselassie et al., 2016). Locally, there are different management systems for irrigation water; examples include private users, water users' associations, and schemes jointly managed by users and government agencies. Each of these irrigation water management arrangements has implications on production (efficiency) and distribution (equity) considerations (Cofie & Amede, 2015). Production (efficiency) refers to the application of irrigation water to plots based on crop requirements taking into consideration soil type, crop type, and stage of growth, while equity refers to the fair distribution of irrigation water to all beneficiary farmers on time and at the needed amount. Improving irrigation water use through institutional innovations (such as devolving irrigation water management systems) has been identified as a way to increase agricultural production. Thus, equitable and efficient distribution of water among users and sustainable O&M of irrigation systems requires capable irrigation water management (Haileselassie et al., 2016; Cofie & Amede, 2015).

Even though the establishment of appropriate water management systems would enhance the operation, maintenance and management of irrigation systems, the water distribution, allocation and scheduling and maintenance aspects of irrigation schemes also critically depend on the adoption of complementary irrigation technologies. These agricultural water management technologies create opportunities for farmers in accessing water for increased crop production and income. There are various kinds of water lifting technologies such as gravity (canal), motor pump (electric, gasoline or diesel), treadle pump and rope and washer pumps in use to withdraw water from rivers, lakes, ponds or wells, and dams (Hagos et al., 2012). Irrigators then use various mechanisms such as drip, sprinkler, furrow, or flooding irrigation to spread water onto crops.

This study considers irrigation as a socio-technical system: the water management systems, organizations, and institutions are as important as the technical dimensions of a scheme in determining the performance of an irrigation system. One salient feature of irrigation that has not been studied in detail is which combination of irrigation water management systems and irrigation technologies can maximize on-farm net returns for irrigators. Farmers are faced with different irrigation water management arrangements and technology alternatives that can be used as complementary options to deal with the various constraints such as sufficient and timely application and distribution of irrigation water. Previous studies on choice and impact of irrigation systems have focused on either institutional or technical components independently. Thus, there is limited evidence on the synergies between various irrigation management systems and irrigation technologies in improving returns from using irrigation. Ignoring the inter-relatedness of these two components may underestimate or overestimate the effect of water management systems the farmers in or technologies on their own. Treating the technological and managerial components jointly, rather than as isolated decisions is important in order to suggest options for better understanding of the synergistic effect of the social, institutional and technical components of the irrigation system. This is important information for policy makers and development practitioners because it enables them to promote components of the irrigation system that are performing well together.

Using data from cross-sectional household survey conducted in Ethiopia, this study has two interrelated objectives. First, the differences between rainfed and irrigated systems regarding cropping pattern, input use, output and market participation is studied. Second, the joint effect of various water management systems and water lifting technologies on farm net returns is analyzed. To estimate the effect of various combinations of irrigation water management and technologies on net farm return, this study follows the multivalued treatment effects approach of Imbens (2000); Wooldridge (2007; 2010) and Cattaneo (2010). This method allows to estimate the treatment effects when there are more than two alternatives (treatment levels) among the individuals in the sample. Moreover, the method allows to compare the outcomes between each paired combination of irrigation water management and technology.

This chapter proceeds as follows. The next section provides a brief review of literature, followed by the description of the data. It then discusses the identification strategy, empirical model, and estimation of multivalued treatment effects as well as average treatment effects. The result section discusses descriptive as well as econometric analyses while the last section of the chapter presents the conclusions and policy recommendations of the study.

3.2 Literature Review

The literature on irrigation-poverty nexus is well established in sub-Saharan African as well as in Asian countries[24]. Yet, evidence on the impact of irrigation on poverty reduction across water management systems and technology types has been neglected in the literature.

It has been argued that access to micro-irrigation technologies such as small pumps have a greater chance to reach and involve many smallholders than large-scale, scheme-level irrigation systems, as they can be more widely distributed across the landscape whereas river or reservoir fed-system, by design have a more limited geographic extension (Rydzewski, 1990; Abric et al., 2011). As stated in Awulachew (2006) and de Fraiture & Giordano (2014), this category of technologies have the following advantages: (i) they do not depend on collective action of farmer groups, therefore, they are more easily adopted and used by individual farmers; (ii) they are affordable at farm household level with low capital and operating costs (per farm, not necessarily per hectare) (iii) they have usually high water productivity (efficient in water use), improve crop quality and reduce labour costs and (iv) they do not depend on public investment.

Experience from sub-Saharan Africa shows that investments in large scale irrigation schemes in the 1970s and 1980s did not meet targets set for increasing food production and productivity (Adams, 1991; Kay, 2001; Inocencio et al., 2007) due to problems related with high capital investment, constraints by government bureaucracy and management costs including problems related with collective action often observed in public or communal irrigation schemes (de Fraiture & and Giordano, 2014). Beginning in the 1980s and 1990s, more attention has been given to smallholder irrigation using simple technologies, such as low power motorized pumps (Abric et al., 2011; Kay, 2001). Low-

[24] Silliman & Lenton 1985; von Braun et al., 1989 ; Rosegrant 1992; Gebremedin & Pender, 2002; Hussain et al., 2001 ; 2006; Hussain, 2007; Huang et al., 2006; Van der Berg & Ruben, 2006; Namara et al., 2007; Hagos et al 2008; Hanjra and Gichuki, 2008; Hanjra et al., 2009; ; Bacha et al., 2009; Saleth et al., 2009; Gebregziabher et al 2009, Namara et al., 2010; Burney et al. 2010; Aseyehegn et al 2012; Hagos et al 2012; Domenech and Ringler, 2013; Hagos et al., 2013; de Fraiture & Giordano, 2014; Namara et al ., 2014; Gebregziabher et. al., 2014; Domenech, 2015; Hagos et al., 2017, Garbero & Songsermsawas,, 2018

cost manual irrigation technologies such as treadle pumps had also been suggested as promising interventions in sub-Saharan Africa with significant positive impacts, in terms of improvements of labour efficiency, increases in area under cultivation, cropping intensity and production volume, increases in farm income and food security (Perry, 1997; Mangisoni, 2008; Adeoti et al., 2007; Van Koppen et al., 2005; Van Koppen et al., 2012). Ofosu et al., (2010) also highlight that small-scale irrigation technologies are more effective, competitive, and financially sustainable than large-scale irrigation because they provide income opportunities through employment and enhance participation of women. Moreover, Namara et al., (2007) underscore that the use of micro-irrigation technologies results in a significant productivity and economic gain over traditional surface irrigation methods.

On the other hand, there are several studies which show large-scale irrigation schemes in sub-Saharan Africa that achieve relatively high yields. Nakano et al., (2011) and Njeru et al., (2014) suggest that even if small-scale irrigation development is a current trend in sub-Saharan Africa, large scale irrigation schemes also have high potential under proper management and are equally important. By considering both small and large-scale irrigation schemes, Sakurai (2016), contrary to other studies, found that farmers in large-scale irrigation schemes achieve significantly higher yields and profits than those in village-based collective irrigation schemes and private irrigation schemes in the case of irrigated rice fields of the Senegal River Valley. A similar study in Ethiopia by Solomon & Ketema (2015) highlights that among the different irrigation technology user groups, per capita consumption expenditures of irrigators relying on diversions is higher than that of motor pump users and treadle pump users. They recommended that in areas where the landscape permits, priority should be given to the promotion of canal irrigation due to its minimum operation costs and ability to reduce poverty.

In addition, studies reveal that pressurized sprinkler and drip systems improve the efficiency of water application, increase the use of complementary inputs as well as crop production, reduce energy consumption, have lower labour cost, improve disease and pest control, are feasible for hilly landscapes, and reduce soil salinity (Camp et al., 1997; Camp, 1998; Micheal, 2008; Tagar et al., 2012). However, these kinds of technologies are very expensive for smallholders. Using gross margin analysis, in conjunction with cost-benefit analysis, Mupaso et al., (2014) evaluated the financial and economic performance of farmers in Zimbabwe. The result shows that flood system was the most desirable technology compared to drip and sprinkler systems from financial and economic points of view because of its low operational costs. However, this could be offset by negative environmental impacts.

In Ethiopia, there is hardly any evidence of analysis of the impact of irrigation management systems and complementary technologies on farmers' welfare following adoption. Some studies have explored the determinants of successful use of various irrigation technologies and their impacts (Gebregziabher et al 2009; Hagos et al 2012; 2013; Garbero & Songsermsawas 2019). These studies do not explore the simultaneous impact of irrigation technologies and irrigation institutions. Therefore, the main objective of this study is to understand the impact of various combinations of irrigation technologies and water management practices on net farm returns following adoption of irrigation. This chapter is intended to answer the following research questions: is there a difference among rainfed and irrigated agricultural systems in crop pattern, input use, output, net farm return, income and market access in the study areas? Is there a difference among various combinations of water management systems and adopted irrigation technologies in crop pattern, input use, output, net farm return, income, and marketing access in the study areas? Which joint effect leads to higher net farm return?

This study has at least three novel features compared to earlier studies in this field. First, it systematically documents information on irrigation technologies and management practices in Ethiopia. Second, the study jointly analyses irrigation technologies and management systems for a series of different irrigation schemes. Third, this study extends the focus from the impact of access to irrigation to a multivalued treatment effect approach to identify which combination of water management and lifting technology leads to relatively higher net return.

3.3. Data and study areas

The data for this study comes from a cross-sectional survey of smallholder irrigators in four regions of Ethiopia, i.e., Tigray, Amhara, Oromia and Southern Nations, Nationalities and Peoples Region (SNNPR) that was conducted in 2016/17 with the objective of analysing the economics of irrigation systems from technological and management perspectives. The sample is composed of 464 irrigation beneficiary farm households and their plots which were cultivated during *Meher* (rainy season) as well as irrigation season of 2015/16. Information was gathered on 1,037 irrigated and 1,580 rainfed plots, of which 496 were cultivated in both seasons of 2015/16. The data were collected using a multi-stage stratified random sampling method (see section 1.8). The survey data were merged with Landsat images and climate variables based on geo-referenced households and plot level latitude and longitude coordinates for the period 1981-2016 (see section 1.8). In addition, qualitative information was gathered using open-ended questions by undertaking focus group discussions and community level surveys, in order to enhance the validity and reliability of the household data. The qualitative and community surveys augment the results of the econometric analysis.

3.4. Theoretical framework and hypothesis

The theoretical framework for this study is based on the theory of induced institutional innovation-Hayami & Ruttan (1985); the theory of collective action and self-governing irrigation systems -Ostrom (1990); Ostrom & Gardner (1993); Baland and Platteau (1996); the socio-technical theory - Veldwisch et. al., (2009); Mollinga, (2010); Vincent (1997); Vincent & Roth (2013); principal-agent theory- Huppert et. al., (2002) and Huppert (2013); as well as previous similar theoretical and empirical works by Jagger, Pender & Gebremedhin (2005); Namara et al., (2005); (2007); Gebregziabher et al., (2009); Hagos et al., (2012); Hagos et al., (2013); Domenech & Ringler (2013); Meinzen-Dick (2014).

Investment in agricultural water management constitutes a potential pathway out of poverty in a country like Ethiopia where the main economy heavily depends on rainfed agriculture. Farmers are faced with different institutional arrangements, management systems and technology alternatives that can be used as complementary options to deal with the various constraints such as sufficient and timely application and distribution of irrigation water. Appropriate combinations of institutions and technologies are required in order to maintain sustainable irrigation system (Meinzen-Dick, 2014). Managing and using of irrigation systems over the long term also needs consistent contributions in labour, fees or in kind, even of it is hard to measure and dispersed benefits over time and space (Ostrom & Gardner, 1993). According to North (1990), institutions are the rules of the game in a society. They are social arrangements that form and regulate human behaviour and continue to affect individual human lives and intensions

Ostrom (1990) suggested that for a common pool resource where property right is difficult to define or enforce, collective action is needed to achieve sustainable land and water management. Scarcity of a resource and market access may be drivers of the emergence of property rights. Ostrom (2007) discussed that given the right conditions, individuals and groups perform rationally and can work towards a common goal even if it means sacrificing for personal gains, though, individual utility maximization is considered as a necessary condition of rationality, subject to constraints on the welfare outcomes (Weirich, 2008).

Focusing on jointly managed irrigation water management systems by users and government agencies, Huppert & Urban (1999); Huppert et al (2002); Svendsen & Huppert (2003); Huppert (2009; 2013) noted that appropriation and provision of irrigation water is more than technical tasks. They perceived the appropriation and provision of irrigation water as services supplied by a provider- an agent which often is provided by irrigation agency or a water user association and a client (receiver), in this case, a farmer or a group of farmers. The authors suggested that in examining irrigation services, we need to be aware of the underlying exchange relationship between agent and principal (service provider and receiver) which they called Principal-Agent approach. When this relationship functions well, the service can be delivered efficiently. On the other hand, Knox et al (2002) argued that coordination can be provided by the state, the market or collective action which highly depends on the scale of irrigation under consideration and the exiting property right.

The central hypothesis in this study is household managed micro-irrigation systems are more effective for improving smallholder farm returns in Ethiopia, even if it is considered that collectively managed irrigation systems would benefit the greatest number of people. Community managed natural resources may be better suited to meeting subsistence production rather than production for markets (Baland & Platteau, 1996). This is due to the large number of households who are entitled to share the limited resources at the same time. Hence, it is hypothesized that collectively managed irrigation systems are more focused on subsistence production for members; while household (privately) managed micro-irrigation technologies are likely to grow high value crops and then yield the greatest returns. Jointly managed irrigation systems that were established by the government or development partners usually have more modern irrigation structures than farmer managed irrigation schemes in either pump or canal lifting mechanisms which affect efficient distribution of irrigation water. However, as Huppert et al 2002; and Huppert 2013 argued the performance of the irrigation system highly depends on the underlying exchange relationship between the agent and principal (service provider and receiver).

3.5. Components of irrigation systems

The study considers four types of irrigation water management systems and two types of irrigation technologies. The irrigation water management systems constitute privately managed system, users (farmers) managed system, jointly (users-and-agency) managed system and open access irrigation water management system. The two irrigation water lifting technologies considered are gravity(canal) and pump.

(i) The privately managed irrigation system is a "micro-scale private irrigation". It is mainly characterized as individualized small-scale technologies for storing, lifting, conveying, and applying irrigation water. Around 17% of the plots included in this study are under this category. The findings of the study show that small farm households significantly rely on hand dug and drilled wells (88%) as well as rainwater harvesting and ponds (12%) as a source of irrigation water. Multiple trials are needed before a well is successfully dug and used. Beneficiaries who have developed private irrigation wells noted that they obtained assistance from *kebele* and *woreda* offices to dig and prepare shallow wells which were usually dug using manual labour (66% of the wells) or drilling machines (34% of the wells in the sample). In the study sites, about 63% of micro-scale private irrigation beneficiaries use groundwater which has less than 7-meter depth, while the remaining one third have ground water wells with depths of between 8 and 50 meters. Regarding digging and constructing of wells, there are problems such as collapse of dug wells during construction (particularly in clay soil areas) and drilling may fail to get through stones. They apply treadle (3%), hand bucket/hose (20%) and motor pumps (73%) to lift water. Usually, those farm households who have developed their shallow well or water harvesting pond privately may share the water with their neighbouring farmers with free of charge or some compensation.

(ii) The users managed system are irrigation schemes where farmers and their association have full control and responsibility from inception to construction and implementation of the scheme, including the allocation, distribution and management of the irrigation water. Usually, this kind of schemes fall in small scale irrigation system. Around 1/3rd of the sample farm plots fall in this category. Most of them (64%) apply gravity to lift irrigation water and around 36% of them use pumps. Those farmers who apply canal(gravity) irrigation method are often found in traditional irrigation schemes constructed using diversion weirs made from local materials and need annual maintenance. There are also farmers who develop shallow well in groups to share water collectively. Similar to canal farm-led irrigators, they coordinate themselves to the management and utilization of irrigation water from a self-developed well using motor pumps to withdraw irrigation water.

(iii) The jointly (users-agency) managed irrigation systems are medium or large-scale irrigation systems that a government agency has control of the water to the delivery point, the use and management of water beyond is under the control of the farmers and their association. The main irrigation method is gravity with water drawn from canals (79%). In around 21% of the cases, electric pumps and pressurized systems with drip and sprinkler appliance mechanisms are used.

(iv) The open-access irrigation system: Irrigation is practiced from nearby openly accessed water sources such as river and spring water without developing any irrigation structure and operates without schedule or turn. There is no water users' association (water users committee, 'water fathers') or any governmental agency involved in the management of the resource. Almost all of them use technologies like motor pumps to lift water from a source. In this case, irrigation is an individualized undertaking in which there is no established institutional arrangement to manage the resource. The main difference between this type of irrigation users with "micro-scale private irrigation" is the latter ones develop drilled and hand dug wells or water harvesting ponds to store water for irrigation and they may apply treadle, hand bucket/hose and motor pumps to lift water. Our results also show that farmers who do not have farmland adjacent to a river or spring water and do not own motor pumps get access to water and water lifting technology through sharecropping arrangements and rentals which generate income for farmers who possess motor pumps. The rental cost of motor pumps is in the range of around USD 18 to USD 336 per irrigation season (ETB 400 to ETB 7490) plus the cost of fuel which is around USD 211 (ETB 4695) per irrigation season. Farm households also rent farmlands adjacent to a water source. The average price of renting land was USD 246 (ETB 5,487) per *Timad* (a quarter of a hectare) and the most common kind of sharecropping arrangement (around 90%) is sharing costs and benefits equally.

Four irrigation management systems and two irrigation water lifting technologies jointly lead to 8 possible combinations that an irrigation farm household can be part of. However, due to the very few observations of two of these combinations[25], only six combinations are used. Table 3.1 presents the proportions of each combination in the study sites.

Table 3.1. Combined alternatives of irrigation technologies and water management systems included in the analysis

Choice	Alternatives	No of plots	%	Cum.
1	Private+pump	168	16.45	16.45
2	Users+pump	111	10.87	46.43
3	Users+gravity	195	19.1	35.55
4	Joint+pump	87	8.52	86.88
5	Joint+gravity	326	31.93	78.35
6	Open access+pump	134	13.12	100
	Total	1,021	100	

Source: Author's compilation using own survey data.

3.6. Descriptive statistics of relevant variables

Table 3.2 reports basic household, farm and scheme level and bio-physical characteristics of the plots included in this study. Household heads who are in privately managed and open access pump irrigation systems are more likely to be younger and to have more years of formal education compared with household heads in the other alternatives. Gravity irrigators (12 years) have more years of experience in using irrigation water than the other alternatives (around 5-9 years). Among all farmers included in the study, households who are in open access pump irrigation are also better off in terms of different indicators of wealth, they have the highest livestock and farmland size.

[25] Privatey managed+gravity and open access+gravity only have seven observations each.

Table 3.2. Summary statistics of relevant variables by the six combinations of water management and technology alternatives sub-groups

Variable Name	**Private +pump**	**Farmer +pump**	**Farmer +gravity**	**Jointly +pump**	**Jointly +gravity**	**open +pump**
Household Human capital						
1= if the household head is male	0.98	0.84	0.90	0.90	0.92	0.98
Age of the household head (years)	42.11	44.83	46.67	44.40	45.54	40.81
Education level of the household head (years)	6.25	4.18	4.51	3.99	4.99	7.57
Education level of the spouse(years)	3.57	4.37	2.68	2.89	3.17	5.18
Family size, (number)	6.92	5.93	6.01	5.71	6.06	5.69
Years of experience in using irrigation water	4.82	6.34	12.60	8.72	12.32	4.76
Number of training attended in 2015/16	0.67	1.13	1.32	0.71	1.36	0.86
Frequency of contact to extension worker in 2015/16, (number)	18.39	19.23	16.80	13.6	16.89	15.10
Household physical capital						
Livestock ownership (TLU)	4.02	3.30	4.80	3.30	5.96	6.87
Total farm size (ha)	1.8	1.96	1.61	1.67	2.50	3.12
Household financial capital						
1= If there is access to credit	0.32	0.82	0.43	0.92	0.32	0.30
Village level characteristics						
Distance to the woreda market in min, one way (min)	28.89	33.98	44.97	19.67	40.58	27.55
1=if there was adverse weather condition in 2015/16	0.35	0.72	0.35	0.78	0.24	0.23
Plot characteristics						
Irrigation plot size (in ha)	0.23	0.30	0.19	0.37	0.33	0.51
1=if the soil type loamy	0.79	0.59	0.51	0.67	0.57	0.55
1= if the plot is flat	0.98	0.97	0.96	0.94	0.87	0.94
1=if the plot is allocated by the government	0.17	0.54	0.49	0.69	0.44	0.24
1=if the plot is certified	0.97	0.98	0.81	0.92	0.74	0.77
Distance of the plot from the farm household residence(min)	6.96	30.02	14.34	41.67	12.13	18.80
Distance from the water source (km)	1.43	1.71	2.15	1.94	1.73	0.54
Fragmentation	6.24	4.17	5.36	3.61	5.29	6.63
Irrigation water application mechanism on the plot						
Surface/flooding	0.44	0.25	0.40	0.04	0.61	0.11
Pressurized system	0.07	0.40	0.00	0.63	0.01	0.02
Furrow	0.49	0.34	0.60	0.33	0.38	0.87
Bio-physical variables						
Meher precipitation anomaly	-0.07	-0.33	0.22	-0.46	0.43	0.38
Belg precipitation anomaly	-1.64	-0.71	-1.20	-0.57	-1.33	-0.74
Temperature anomaly	1.09	0.56	0.77	0.45	0.79	1.32
Meher precipitation coefficient of variation (CV)	16.9	20.5	24.8	20.7	26.5	23.7
Belg precipitation CV	15.1	27.1	16.1	29.6	12.1	14.2
Mean annual temperature	17.4	18.7	17.1	19.1	17.0	15.1
Meher mean total precipitation	528	445	726	439	781	747
Belg Mean total precipitation	366	220	254	189	243	257
Elevation	1764	1698	1973	1571	1843	2049
Normalized Difference Vegetation Index(NDVI)	0.34	0.18	0.21	0.14	0.23	0.12

Source: Author's computation using own survey data.

While access to credit is very limited for households in privately managed pump and jointly managed gravity irrigation, around 82% and 92% farmers managed and jointly (farmers and agency) managed pump irrigators have access to credit, respectively. There are significant differences between the alternatives with respect to average travel time to the nearest woreda market and all-weather roads. Gravity irrigators in farmers and jointly managed systems travel, on average, more than 40 minutes to the nearest woreda market. Irrigated farms are similar in terms of plot characteristics such as soil type and slope across all groups. Even if most of the farmers operate on registered lands, only around 17% and 24% of irrigated plots that are in privately managed and open access systems are allocated by the local government. Farmer-led irrigators+gravity and open access pump users are located at higher elevation than farms which are in the other alternatives. Farmer-managed pump irrigators receive lower precipitation than irrigators in the other groups, however, high *Belg* and *Meher* rainfall variability is observed in areas where farmers managed pump users and jointly managed gravity-irrigation farmers are located. Overall, most of the NDVI reported in the study areas are very small that represents land cover with shrubs and grasslands. Irrigated farmlands that are in privately managed systems have slightly higher values than the irrigated lands in the other alternatives in 2016.

3.7. Identification strategy

To estimate the impact of various combinations of irrigation water management systems and technologies on net farm returns, this study follows the multivalued treatment effects approach of Imbens (2000), Wooldridge (2007; 2010) and Cattaneo (2010). This method allows to estimate the treatment effects when there are more than two levels of alternatives (treatment) among the individuals in the sample. Moreover, the method enables us to compare the outcomes between each pair of treatment alternatives (private, individual irrigators with pumps, farmer-managed pump system, farmer-managed gravity system, government and farmer jointly managed gravity system; government and farmer jointly managed pump system and individual farmers accessing an open source, such as a river or lake). Plots that are in one of the alternatives did not benefit from the other one. Each plot is in only one kind of water management and technology combination.

In this study, out of the three parameters often applied to measure treatment, the potential-outcome means (POMs) and the average treatment effect on the treated (ATT) are computed. The POM for each alternative is an average of each potential outcome:

$$POM_{ik} = E(y_{ik}) \quad (1)$$

Where y=is the outcome of interest for any plot *i*, k = 1, 2,...,K represents the indicator of alternative (treatment) status.

Following Wooldridge (2007, 2010), Inverse Probability Weighted Regression Adjustment (IPWRA) estimation method is employed to define the POM of each combination of water management and technology alternative and to make pair-wise comparison to find ATT. It addresses the endogeneity problems and self-selection bias arise from unobserved characteristics such as expectation, managerial skills, motivation which might be correlated with the outcome variable. Estimators of IPWRA employ probability weights to compute outcome-regression parameters that account for the missing-data problem arising from the fact that each observation occurs in only one of the potential outcomes. The adjusted outcome-regression parameters are used to compute means of treatment level predicted outcomes. The contrasts of these means give estimates of the treatment effects. The IPWRA estimators use the first step model to predict treatment status and in the second step, the outcomes would be predicted, since IPWRA estimation technique has the double-robust property, only one of the two models must be correctly specified for the estimator to be consistent.

As the first step, the conditional probability model is constructed to predict the likelihood of irrigated plots i *(i=1, ...,N)* being in each treatment level *k* (1=private +pump, 2=farmer managed +gravity, 3=farmer managed+pump, 4=jointly managed+gravity, 5=jointly managed+ pump, 6=open access+ pump). Hence, we can write this likelihood function as follows:

$$T(k) = \begin{cases} 1\ if \Gamma_k' Z + \epsilon > 0, \\ 0 if\ otherwise \end{cases} \qquad (2)$$

where k = 1,2,3,4,5,6 (indicates alternative status); Z is the matrix containing household, plot, village, scheme and climate covariates. It is an $n \times m$ matrix of the attributes of the covariates where there are m *(m=1,...M)* attributes, and ϵ is the error term. It is assumed that the error term ϵ is independently and identically distributed (iid) and follows the logistic distribution. Thus, multinomial logit model was used to estimate the probability that plot i is in treatment level k:

$$P\left(K = \frac{k}{Z}\right) = P(k) = \frac{\exp(\Gamma_k' Z)}{1+\sum_{j=1}^{2} \Gamma_j' Z'} \qquad (3)$$

The basic assumption here is that selection is largely based on observable characteristics of the households, plots, and scheme characteristics. There is sizable common support between the conditional probability densities of the plots in all alternatives. To produce unbiased results, the IPWRA estimator is well suited to remove the endogeneity bias arising from households self-selecting themselves into the different alternatives. In the next step, net return of each alternative in year 2015/16 is analyzed, using a linear regression, to specify the potential-outcome model with six levels of treatment as follows:

$$NetReturn_i = \beta + \alpha XH_i + \delta XF_i + \sigma XV_i + \upsilon XS_i + \vartheta XC_i \tag{4}$$

Where $NetReturn_i$ is net return (in USD/ha) of using a particular combination of water management and technology (i). It is highly influenced by a vector of exogenous factors (X) which includes household characteristics (XH), farm characteristics (XF), village characteristics (XV), scheme characteristics (XS), agro-ecological and climate factors (XC).

In the IPWRA estimation technique, first, a logistic model is employed to predict the treatment status and then the outcome variable (net return/ha) is modelled as a linear function of the covariates.

Estimation of average treatment effect on the treated

The challenge in impact evaluation using observational data is to estimate the counterfactual outcome, the outcome the adopters of a particular alternative could have earned had they adopted different alternatives. The expected outcome for adopters of a particular alternative had they adopted a different combination of water management and lifting technology, is a counterfactual outcome in our case. A point worth mentioning is, this analysis compares the alternatives to each other, there is no reference group to be compared with. The ATT indicates how the mean outcome would change if everyone who received one particular alternative (treatment) had instead received another particular alternative (treatment).

The ATT is the average effect among those subjects that receive treatment level $k^{\sim}$ of giving each subject treatment $k^{\wedge}$ instead of another treatment (in our case other treatment alternatives, the outcome the irrigators who adopt a particular alternative could have earned had they adopted different alternatives):

$$ATT_{k^{\wedge}k^{\sim}} = E\{(y_{k^{\wedge}} - y_0)/k = k^{\sim})\} \tag{5}$$

Where $y_{ki}$is the realization of the random variable y_k. Let y_0 denote the potential outcome of a subject that receive any other alternative (in our case other treatment alternatives, the outcome the irrigators who adopt a particular alternative could have earned had they adopted different alternatives) and i subscripts denote realizations of the corresponding unsubscripted random variables. To handle the case of multivalued treatments, we extend the definition of the unobservable, individual-level treatment effects to be $y_k - y_0$ for $k\ \epsilon\{1 \ldots\ldots K\}$. Defining the ATT in the multivalued treatment case needs three different treatment statuses: $k^{\wedge}$defines the treatment level of the treated potential outcome (a particular alternative); another alternative potential outcome(1,...,5); and $k = k^{\sim}$ restricts the expectation to include only those individuals who actually receive treatment level = $k^{\sim}$. While comparing the outcomes between each pair of treatment levels, the basic assumption here is price of crops grown by irrigators is held constant.

3.8. Results

3.8.1. Descriptive Statistics

3.8.1.1. Input use and value of output

In this section, the results of the statistical summary of important variables on input use, value of output and income for rainfed and irrigated plots are reported. These descriptive results serve as indicative measures of the effect of access to irrigation water. In the sub-section that follows, results from a more systematic analysis will be presented.

Table 3.3-3.6 and Figure 3.1-3.2 present statistical summaries of important variables on input use, operation cost and value of production from rainfed and irrigated plots as well as on various combinations of irrigation management and technology types. As can be seen from the mean difference test in Table 3. 3, agricultural net return from irrigated and rainfed crop production shows statistically significant differences. The mean total value of production from irrigated plots was around USD 1,416/ha (ETB 31,364/ha) which is much higher than the mean total value of production from rainfed agriculture USD 990/ha (ETB 22,074/ha). This result is similar to studies by Belay and Bewket, (2013); Hagos et al., (2012; 2013); and Gebregziabher et. al., (2016). There is also a statistically significant difference in input use between rainfed and irrigated plots. However, when we observe the benefit-cost ratio, rainfed agriculture has a higher ratio (2.6) than irrigated farms per ha. This is due to farm households tend to apply more inputs on irrigated fields. For instance, they applied USD 51/ha (ETB 1137/ha) value of agro-chemicals on irrigated plots compared to USD 4.5/ha (ETB 100/ha) on rainfed plots. Similarly, the values of improved seed, chemical fertilizer and labour used were significantly higher on irrigated than rainfed fields. It suggests that due to access to irrigation water, there is increased intensification of agriculture. This is expected to have an effect on factor markets which have wider effects on the economy.

Table 3. 3. Mean separation tests of input use and output variables of plots with and without access to irrigation

Input used	Rainfed Mean	Rainfed SE	Irrigated Mean	Irrigated SE	Rainfed vs Irrigated
Value of local seed Value of local seed per ha	18.30	0.80	14.21	0.64	***
Value of improved seed per ha	8.19	0.57	20.29	1.35	***
Value of chemical fertilizer per ha	76.18	2.93	129.60	5.41	***
Value of agro-chemicals (herb/pest/fungicides) per ha	4.50	0.24	51.03	3.11	***
For motor pump users					
Fuel cost per hectare			426.39	24.90	
Motor pump rent			79.86	8.43	
Repair			32.39	3.05	
Value in kind contribution for O&M **(for gravity users)**			11.17	3.05	
Cash contribution O&M of the structure **(for gravity users)**			2.16	3.05	
Family Labour days (in adult equivalent) per ha	71.46	1.37	107.50	1.96	***
Hired Labour days per ha	21.04	1.04	45.76	2.73	***
Exchange labour days per ha	5.15	0.40	4.35	0.51	
Total labour days per ha	101.10	1.30	155.17	2.90	***
Total value of labour per ha[26]	280.19	6.63	337.34	6.33	**
Total operation cost per ha	380.66	8.84	680.89	12.83	***
Total value of output per ha	990.31	18.03	1416.09	54.06	***
Total net value of output per ha	583.67	41.86	753.07	53.34	***
Benefit-cost ratio (Total operation cost /total value of output)	2.6		2.07		
Number of observations	1580		1037		

Note: *, ** and ***indicate statistical significance at 10%, 5% and 1%.
All values are given in USD

Table 3. 4. Output variables of plots with and without access to irrigation by terciles

	Terciles	Rainfed Mean	Rainfed SD	Irrigated Mean	Irrigated SD
Total value of output/ha (in USD)	1	152.22	116.52	508.88	232.91
	2	559.60	133.40	1366.39	277.98
	3	2353.63	1979.80	2379.69	1929.66
Total		990.31	1474.56	1416.09	1661.25
Total net value of output/ha (in USD)	1	79.69	276.15	307.83	341.07
	2	317.74	130.22	791.36	219.76
	3	1353.05	2018.00	1162.63	1014.19
Total		583.67	1540.57	753.07	1017.32
Total revenue/ha (in USD)	1	0.00	0.00	220.58	79.45
	2	340.61	72.73	941.31	187.95
	3	1190.00	856.32	1488.42	2784.94
Total		509.37	683.17	883.34	924.32

Source: Author's computation using own survey data

[26] In our study areas, daily wage rates for rainfed agriculture activities are more than wage rates during irrigated agriculture activities, due to high demand for labour during *Meher* season.

This result is consistent with numerous studies in Ethiopia Gebregziabher & Holden (2011), Hagos et al., (2012; 2013). A study by Jin et al., (2012) in India found compared to rainfed plots, expenditures on fertilizer and agrochemicals are almost double on irrigated plots. Similarly, von Braun et al., (1989) found water-controlled rice irrigation-a relatively new technology introduced in West Africa-required about 15 times the variable cost per hectare compared with swamp rice and about three times variable cost per ton of paddy rice cultivation.

Overall, less variation of input use is observed among different alternative management and technology types (see Table 3.5). Yet, plots in all management systems with pump irrigation have higher improved seed expenditure. Farmer-managed plots that rely on gravity irrigation show the highest local seed expenditure. Moreover, agro-chemical investment is low among private+ pump users and farmers managed +gravity irrigators.

Labour requirement of irrigated and rainfed agriculture differs both in quality and technical quality. Our results show that the amount of labour needed in irrigated agriculture (155 labour days/ha) is substantially higher than that of rainfed agriculture (101 labour days/ha). The result further underscores that if farm households face labor shortages, they acquire additional labour through hiring and labour exchange mechanisms. However, farm households acquire hired labour more for their irrigated fields (46 labour days) than their rainfed fields (21 labour days). Insights from focus group discussions show that they employ labour from rainfed farmers within the same *kebele/woreda* and from nearby *kebele/woreda* that have limited irrigation sources. This result indicates that irrigation intensifies labor use and has a strong role in employment creation in rural Ethiopia. This result is in line with numerous studies. A study by Jin et al., (2016) found that irrigation stimulates more labour use in agricultural production, with the largest increase in the use of hired labour than rainfed agriculture, 90 and 57.5 labour days per ha, respectively. The result by Van Der Wijngaart et al., 2019 in the Niger River Basin is also in line with the above findings.

The most frequent contribution for the day-to-day O&M of irrigation water provision and appropriation of canal irrigators is in labour, cash, and in-kind contribution for the construction and maintenance of irrigation structures. The average value of the total in-kind and in-cash contribution for management and maintenance of a typical irrigation scheme in 2015/16 was around USD 13.82 (ETB 308) per ha. Motor pump users also face operation and maintenance costs. The dominant cost is for fuel which was around USD 426.38 (ETB 9504) per hectare in the irrigation season of 2015/16. Those who do not own a motor pump, rent pumps from owner-renters. On average, farmers paid USD 79.86 (ETB 1780)/ha/irrigation season and had maintenance cost of around USD 32.39 (ETB 722)/ha/irrigation season.

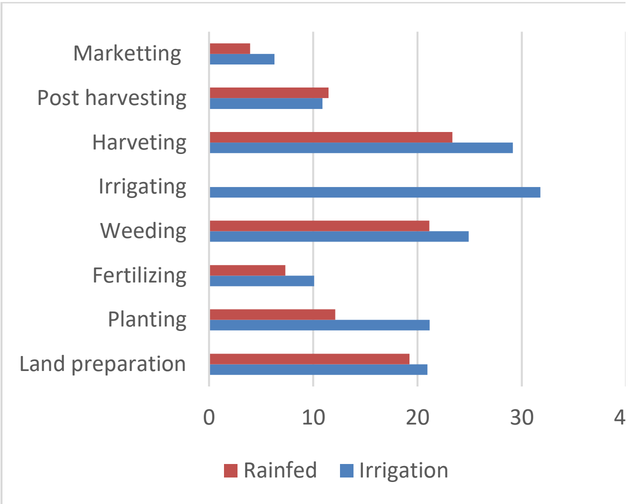


Figure 3. 1. Labor-days required for irrigated and rain-fed agriculture across different agricultural activities (per ha)

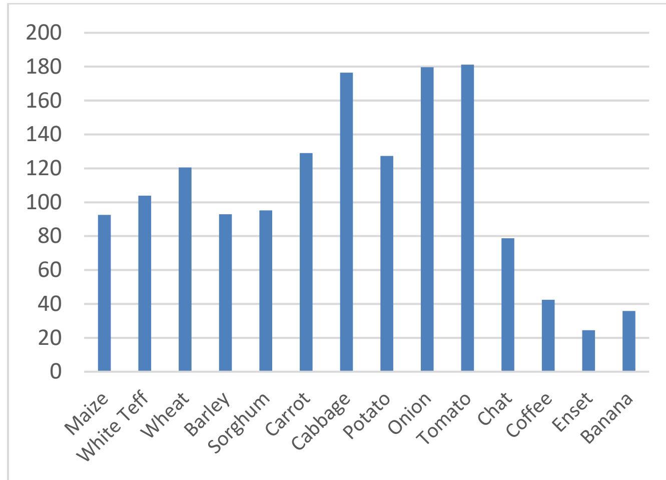


Figure 3. 2. Total labor-days required for main irrigated crops (per ha)

There are also irrigators who extract water from drilled and hand-dug wells who incurred fixed costs for construction of the irrigation structure at the commencement of the irrigation system (which is not included in the computation of net value of output here). A well can be accessed by an individual household or a group of farm households. The cost for manually drilled wells varies depending on well depth. The cost ranges from approximately from USD[27] 18 to USD 200 (ETB 402 to ETB 4458). It is significantly less expensive than motorized drilling, which costs approximately USD 1200 to 1600 (ETB 26,750 to ETB 35,670) for a 6-12-meter depth. The result is similar to studies by Weight et al., (2013) and Onimus et al., (2010).

In order to lift the water from the source, the majority of the farmers in the sample use motor pumps (72%), followed by buckets or hose (20%). As presented in Table 3. 7, around 60% of motor pump users own their pumps, among them, 1/3 of them purchased the pump from own savings. The average cost of a motor pumps was around USD 471 (ETB 10,498). Other related costs, such as cost for installation and accessories, was approximately USD 48 (ETB 1065), with a large variation between the minimum (getting free service) and the maximum amount (around USD 404~ ETB 9,000).

[27] At the time of the data collection (December 2016-March 2017), the average exchange change rate USD to ETB was 22.29.

Table 3. 5. Average input use and output data from irrigated plots with various water management and technology combinations (in USD)

	Private+ pump	Farmers+ pump	Farmers+ gravity	Jointly pump	Jointly+ gravity	Open access+ pump
Value of improved seed per hectare	25.33	19.24	17.79	25.51	17.81	21.62
Value of local seed per hectare	13.06	17.10	18.29	11.88	15.33	12.30
Value of chemical fertilizer per hectare	119.36	102.39	127.50	93.26	135.46	135.38
Value of agro-chemicals per hectare	32.75	52.41	44.39	47.10	51.27	59.37
Total value of labour	334.86	299.73	341.59	305.52	353.34	356.80
Total O&M cost	520.01	386.63	326.78	229.83	233.69	454.69
Total cost	854.88	686.36	668.37	535.35	587.08	811.49
Total value of output per hectare	1621.86	1457.5	1230.75	1346.21	1197.30	1646.17
Total net value of output per hectare	764.29	770.48	558.14	810.86	605.74	770.93
Crop revenue per hectare	881.61	894.03	658.37	868.95	667.21	923.39
Number of observations	168	111	195	87	326	134

Table 3. 6. Mean output data from irrigated plots with various water management and technology combinations by terciles (in USD)

Outcomes	Terciles	Private+ pump	Farmers+ pump	Farmers+ gravity	Jointly+ pump	Jointly+ gravity	Open access+ pump
Total value of output per ha	1	635.63 (191.47)	702.01 (149.65)	428.05 (122.66)	587.08 (170.90)	478.98 (153.95)	221.55 (152.25)
	2	1477.20 (247.52)	1589.47 (195.85)	1299.06 (193.71)	1178.51 (306.30)	923.16 (136.15)	1730.94 (487.97)
	3	2752.7 (1217.51)4	2081.01 (1214.12)	1975.18 (1063.92)	2273.08 (636.72)	2191.99 (1972.70)	3004.12 (1386.44)
	Total	1621.86 (1999.62)	1457.50 (1728.92)	1230.75 (1527.76)	1346.22 (1007.56)	1197.30 (1503.57)	1646.17 (1582.41)
Total net value of output per ha	1	346.27 (478.14)	474.76 (344.27)	214.68 (421.63)	456.17 (213.64)	262.34 (306.46)	92.77 (439.16)
	2	655.59 (343.78)	750.14 (328.53)	515.18 (175.63)	799.04 (318.89)	601.40 (128.13)	886.83 (426.53)
	3	1302.29 (822.49)	1107.29 (709.23)	1005.12 (863.55)	1219.72 (591.57)	1003.46 (1126.03)	1337.87 (1268.47)
	Total	764.33 (1979.60)	770.59 (1074.92)	558.13 (1520.32)	810.86 (1001.85)	605.87 (1484.05)	770.92 (2083.14)
Total revenue	1	169.27 (43.78)	333.28 (40.51)	0.00	279.45 (79.45)	176.78 (69.18)	124.68 (75.63)
	2	845.28 (440.93)	885.38 (140.51)	598.10 (125.51)	792.91 (192.91)	652.21 (105.75)	896.00 (244.55)
	3	1630.47 (1857.85)	1469.15 (1015.01)	1372.34 (1603.52)	1537.41 (1435.62)	1174.30 (2692.11)	1746.84 (3554.03)
	Total	881.63 (2015.49)	894.02 (1648.75)	658.39 (1760.11)	868.97 (179.45)	667.21 (1786.49)	923.39 (2526.42)

Note: *, ** and ***indicate statistical significance at 10%, 5% and 1%. Standard Deviations in parenthesis
All values are given in USD

Table 3. 7. Costs related to irrigation pumps

Related costs	Observation	Mean	Std. Dev.	Min	Max
Price of the pump when purchased (USD)	76	470.93	226.24	51.59	1570.21
Installation cost (USD)	76	47.78	87.93	0	403.77
Source of money to purchase pump: 1=own saving, 0=other sources	76	0.03	0.02	0	0.04
Cost of renting a pump (USD)	52	79.86	87.93	0	333.78
Cost of maintenance and repair (USD)	128	32.39	55.99	0	358.91

Source: Author's computation based on own survey.

3.8.1.2. Crop diversity and pattern

Figure 3. 3 shows crop types grown in the study areas during the rainy (*Meher*) and irrigation seasons in 2015/16. During the rainy season the main crop category grown was grains which took around 67% of the total cultivated plots. From the grain category, white teff, a staple food in the country, took the lion's share (22.2%), followed by maize (13%), wheat (7.51%) and sorghum (7%). Perennials were also grown on 25% of the rainfed plots such as *enset*[28] (6.45%), *chat*[29] (4.9%), coffee (3.5%), banana (2.7%) and avocado (1.5%). In rare cases, roots /tubers and vegetables such as onion, potato, tomato and cabbage were grown on rainfed plots. However, during the irrigation season of 2015/16, plots in the irrigation sites were covered with different crops (see Figure 3. 4). The major types of crops were vegetables, such as onion, tomato, and cabbage and pepper which accounted for 35% of the plots included in the study. The lion's share was taken by onion (18.4%) and tomato (10.9%). Next to vegetables the most frequently grown crops in the irrigation seasons were perennials (26%). *Chat* (10.3%), *enset* (3.7%), banana (2.66%) and coffee (2.4%) were among the major perennial crops in the plots included in the study sites. Roots and tubers (13%) such as potato (8%) took the third place. Studies by Alaofe et. al., (2016) in Northern Benin and Namara et. al., (2007) in India show similar result. In India, micro-irrigation adopters grow high value and water-intensive crops such as banana, while non-adopter produce the traditionally drought-tolerant cereals.

[28] *Enset* is an African crop that currently provides the staple food for approximately 20 million Ethiopians (Borrell et. al., 2019).

[29] *Chat* is a perennial crop and its leaves are chewed for a stimulating effect.

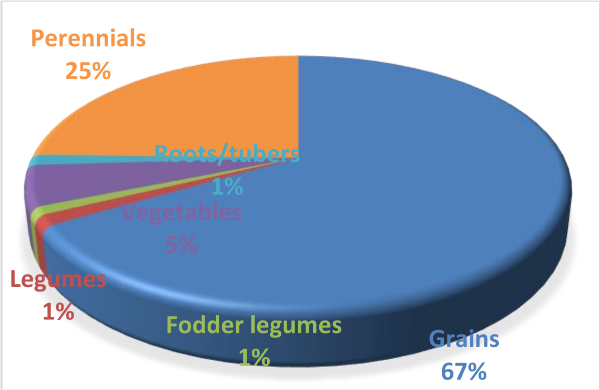


Figure 3. 3. Crops grown during Meher season

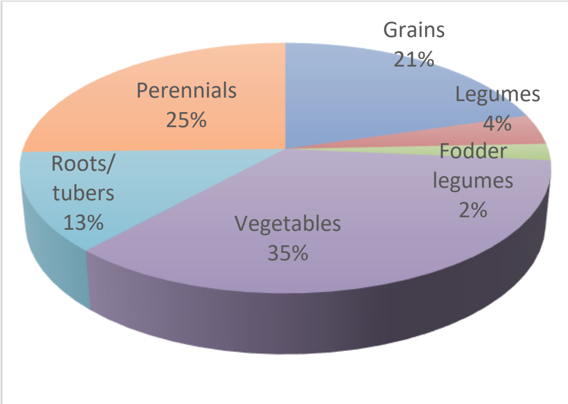


Figure 3. 4. Crops grown during irrigation season

Irrigated crops do not significantly vary by agro-ecological zone (Figure 3. 5). Vegetables and root and tuber crops are the largest category of irrigated crops during the dry season in all the agro-ecological zones, except in moisture reliable, highland-*Enset* areas, where *enset* is the main staple food. Regarding alternative combinations of water management systems and water lifting technologies, there are differences across systems. As depicted in Figure 3. 6, in the private+ pump and open access+ pump systems, there is very limited production of grains, unlike in schemes that are managed collectively. As the result of FGDs with irrigators suggests this is mainly due to problems related with the reliability of irrigation water supply which is aggravated by a higher number of irrigators drawing from the same source of water in collectively managed irrigation systems. In these systems it is difficult to deliver water throughout the dry season. Furthermore, they indicated that this water shortage has forced them to shift from cultivating high value crops to traditional crops which require smaller amount of water. This would have multi-dimensional implications on general welfare of farm households as well as on the community.

Figure 3. 5. Crops grown in irrigation season of 2015/16 by agroecological zone

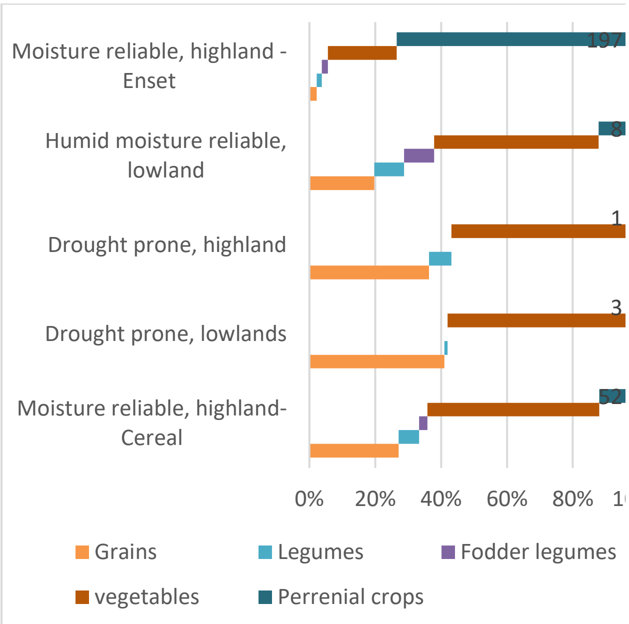
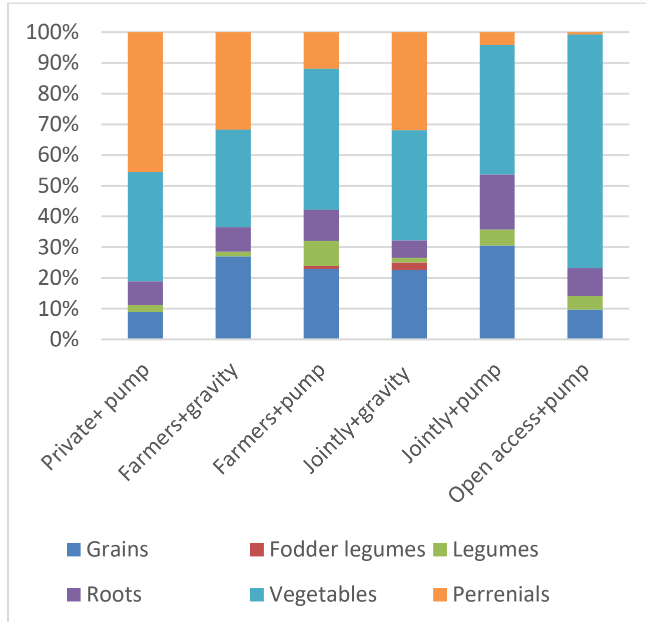


Figure 3. 6. Crops grown in irrigation season of 2015/16 by management and technology type



3.8.1.3. Market participation

The results suggest that the use of irrigated agriculture enables crop production during the dry season, which increases the number of harvests per annum and leads to increased yields and crop diversification. Irrigators produce crops twice a year, and sometimes even three times per year. Furthermore, results from focus group discussions with irrigators and development agents at *kebele* level in the study areas reveal that farmers have started to grow crops which were not grown in those areas previously, such as kale, spinach, and lettuce. Moreover, the results indicate that initially, most irrigators had concentrated on specific crops, such as onion. Over time, the types of crops have increased in number as well as in area coverage; in particular, cash crops such as vegetables, roots and perennial crops were added. In addition to producing new and a greater variety of cash crops than before, using irrigation water have enabled farm households to expand production of existing crops for income generation. According to beneficiary farmers the main criteria for adopting new types of crops and crop varieties were the income generating potential of the selected crop and early maturing nature of the varieties. Besides, crop types which could be produced at a time of high food demand like potato, tomato and onion have high prices.

Insights from FGDs depict that irrigated agriculture also enhances market participation of farmers (Table 3.8). This result is in line with a study by Hagos et al., (2008) that suggests farmers with irrigated fields supply more marketed crops and earn more income than farmers operate in rainfed fields. Households in traditional irrigation systems and in modern schemes earn an average income of USD 83 and USD 95, respectively from crop sales in contrast to rainfed USD 57. Higher yield, higher cropping intensity and all year-round farm production support farm households to increase market-oriented production. Of the total households surveyed, about 43 percent participated in markets by selling a product they produced during the rainy season and earned an average of USD 509.37 (ETB 11,346) per ha. Yet around two thirds of the same farm households sold their irrigated produce through various marketing channels, mainly district markets, at village markets or directly on farm and earned USD 883.37 (ETB 19,690.32) per ha. The gross value of sales gained by households varies greatly as can be seen from the high variance (see Table 3.8). Of note, farms in gravity irrigation system earned the lowest income at USD 658.39 (ETB 14,675) per ha and USD 667.21 (14,872 ETB) per ha for farmer-managed and jointly managed systems, respectively (see Table 3.5 and 3.6). A study by Garbero and Songsermsawas (2018) pointed out that modern irrigation users earned by far more total crop revenue (USD 440 per farm) compared with traditional irrigation (USD 228 per farm) and rainfed users (USD 114 per farm). In line with the input used result, access to irrigation water increases market participation of farm households. This suggests its contribution to the whole economy through the agricultural output market

Table 3. 8. Market access and participation

Relevant variables	Rainfed		Irrigated	
	Freq	%	Freq	%
Households who sold their product in the market	677	43%	716	66%
Main place where the product was sold				
- On farm/at home	115	17.11	267	37.29
- Village market	211	31.40	107	14.94
- District market	315	46.13	304	42.46
- Regulated market	9	1.34	18	2.51
- Roadside	20	2.98	16	2.24
- Cooperative	7	1.04	4	0.56
The main buyer of the product			.	
- Farmer/consumer	132	19.50	90	12.57
- Trader	528	77.99	582	81.28
- Processor	5	0.74	20	2.79
- Cooperative	12	1.77	24	3.35
	Mean	Std. Dev.	Mean	Std. Dev.
Distance to the place where crop was sold, in minutes, one way	24.60	25.50	22.10	28.50
Crop revenue per hectare in USD	509.37	683.17	883.34	924.32

Source: Author's computation using survey data

As focus group discussions with farm households indicate, in the previous years (in years immediately after starting to irrigate), the main source of income and livelihood for smallholders in the study areas had been rainfed agriculture. Irrigation was usually used to generate supplementary income. However, currently, the situation has changed. Using irrigation has not only enabled farmers to increase their income but also to diversify their income sources as well as to improve the living standards of their families. However, one thing worth mentioning in this case is the magnitude of benefit gained to irrigators significantly depends on access to market and infrastructure (transport), since most of the crops grown in the irrigation sites are perishables (see Figure 3.4). Unless these products reach consumers immediately after harvest, their market value decreases, or a total loss might be incurred. As stated in von Braun and Kennedy (1986), the success of farmers that produce cash crops highly depends on the proper functioning of input supply and output market systems.

Moreover, the result also reveals that only few irrigators have started growing fruit trees. It was thought that one advantage of having access to irrigation would be to produce cash crops, such as fruits. The lack of broader diversification could be due to a lack of available seedlings and information on how to grow and market fruits. In addition, emphasis should be given to strengthen Farmer Training Centers (FTCs) in providing training to farmers on agronomic practices, irrigation management, planting, advantages of cultivating diversified types of irrigated crops and marketing. Furthermore, in many drought prone areas, even if farmers want to cultivate crops which have high market value, they are unable to produce such crops due to shortage of water during the dry season or dry spells. Therefore, some irrigators have moved from producing cash crops to traditional cereal crops which require less water. Moreover, price fluctuations for vegetables that are higher than those for cereals are a further factor limiting investment in vegetable crops. The next section discusses results from the econometric analysis.

3.8.2. Econometric analysis- Multivalued treatment effect results

As the first step to estimate the impact of adopting various combinations of water management systems and irrigation technologies, a conditional probability model was constructed to estimate the likelihood that each irrigated plot would be in each given alternative. In the second step, the conditional means (the average potential net return for the specified alternatives) of net farm return is calculated using Inverse Probability Weighted Regression Adjustment (IPWRA) estimators. Further, pairwise comparisons of the estimated parameters of the ATT of the alternatives if they would have been in some other alternatives are computed. The pairwise differences denote the changes in net farm return with respect to the change in different alternatives (going from one alternative to another). Table 3. 9 presents the potential mean outcome (net farm return in hundred

USD/ha) of each combination of water management and technology alternative and the pair-wise comparison of the average treatment effect on the treated (ATT) result. In the specification, the set of covariates used to predict alternative (treatment) status is gender, age and educations level of the household head, family size, years of experience in using irrigation, number of training attended, access to extension service, asset as proxies for wealth (TLU and total farm size), distance to the nearest woreda market, whether adverse weather condition occurred, slope, if the farm is certified, whether the parcel was allocated by a governmental authority, scheme characteristics, elevation, average precipitation and coefficient of variation for both season (*Belg* and *Meher*), and NDVI.

The findings of the study show that using motor pumps in privately developed water sources not only yields the highest average potential net farm return (USD 17.87 hundred ~ 39.83 thousand ETB/ha) among the alternatives given, but also greater than all the values of net farm return compared to what they would have been if farm households had adopted another alternative. This implies that farm households who are in private micro-irrigation systems would not have been in a better position if they had adopted another combination of water management system and lifting technology. Perhaps, this is due to the multi-dimensional benefits of those kinds of technologies. Since the main source of water is a self-developed shallow well that can be accessed as needed as long as water is available. The estimated ATT of going from moving privately accessed pump irrigation to farmer managed + pump, farmer managed + gravity, joint + pump and joint + gravity alternatives result in a loss of USD 10.16, 12.87, 16.69, 13.32 per ha, respectively. All these effects are statistically significant. This indicates that using motor pumps on privately developed water sources can be a viable option in agroecological zones with sufficient groundwater. This result is consistent with studies done by Namara et al., 2007; Gebregziabher et al., 2009, Hagos et al 2012 that show household level micro-irrigation technologies are more likely to bring higher returns per hectare than gravity applied irrigation schemes.

For plots that are in pump applied farmers managed irrigation system, the result shows instead of practicing irrigation individually they are in a better position by making a decision to irrigate collectively in groups. The estimated average potential net farm return is around USD 17.09 hundred (ETB 38.09 thousand) per ha. This indicates that self-organization and management for irrigation water distribution is one strategy to enhance the benefit from irrigation and to minimize costs related with construction of wells and fixed and variable cost of using pumps. Moreover, the result also suggests that irrigators who are in this kind of system would not have been in a better position if they had adopted another combination of water management system and lifting technology.

Despite high returns gained from using pump irrigation individually as well as collectively from privately or communally accessed wells, the findings from FGDs with irrigators and discussions with *woreda* and *kebele* irrigation experts reveal that the most serious challenges associated with private as well as communal pump irrigation relate to lack of appropriate and accessible repair and maintenance services for farmers. Beneficiaries who live in remote areas like Billi *kebele* in Illu *woreda* and Walga *kebele* in Wonchi *woreda* travel up to three hours to find pump repair services. As a result, farmers prefer their pumps repaired by easily accessible but less skilled service providers in their villages. To the extreme, there is also a case where the whole *kebele* dis-adopted the use of lifting technologies like treadle pump and rope and washer pumps due to the absence of appropriate and accessible repair and maintenance services. Farmers also complained about the unreasonably expensive payment and delayed pump and accessories repair service delivery especially during critical irrigation seasons. They added that lack of access to proper repair services has discouraged other farmers from acquiring those kinds of irrigation lifting mechanisms. This result agrees with a study by Gebregziabher et al., (2016) which shows that motor pump service seekers need to wait before their pump repaired for an average of 21 days. This duration can easily wipe out an irrigated crop. Likewise, information from ATA indicates that the average waiting time for maintenance and repair services was about 48 days.

Moreover, based on our discussions with private as well as collective shallow well users, access to finance to develop a well and to purchase the technology plays important role as the groundwater potential of the area in terms of determining who has access to a privately managed irrigation. Other problems encountered by farmers in such type of irrigation systems are lack of appropriate studies at initial stage of constructing wells that end up with collapsing and rising of water tables.

The results of the research also suggest that households in farmer-managed canal irrigation would have been better off if they had adopted a farmer-managed pump irrigation system. The estimated average potential net return is lower than most of the alternatives given, i.e., around USD 8.25 hundred (ETB 18.40 thousand) per ha. Usually, this kind of irrigation schemes are largely traditional irrigation systems that were constructed using local materials which cause large seepage losses of canals and resulting lower water volumes available to some farmers in the system. Irrigation water is being diverted using stones and soil bunds to farm fields. There are no modern flow control structures to support equitable water distribution across all fields. This affects equity and efficiency of water distribution and water delivery across irrigators. This result does not support the studies by Solomon & Ketema (2015) which found that diversion irrigation technology has a strong poverty reduction potential, and recommended priority should be given to promote the technology because of its minimum operation cost and ability to reduce poverty.

Table 3. 9. Estimated average potential net return (in hundred USD/ha) and average treatment effect ATT of adoption of various combinations of water management systems and water lifting technologies

	Average potential outcome $(POM_t = E(y_t))$		Average treatment effect among those that receive the treatment (a particular combination $ATT = E\{y_1 - y_0/t = 1 \ldots 6\}$)	
Outcome	**Mean**	**SE**	**Mean**	**SE**
Private+ Pump (1)	17.87***	5.60		
2 vs 1			-10.16*	5.89
3 vs 1			-12.87**	5.83
4 vs 1			-16.69**	6.25
5 vs 1			-13.32**	6.00
Farmer +Pump (2)	17.09***	6.02		
1 vs 2			-9.44*	6.18
3 vs 2			-10.46*	6.27
4 vs 2			-8.08	6.84
5 vs 2			-11.63*	6.17
Farmer + Gravity (3)	8.25***	1.91		
1 vs 3			1.01	2.41
2 vs 3			10.46*	6.27
4 vs 3			2.38	3.84
5 vs 3			-1.18	2.36
Joint+ Pump(4)	13.49***	3.33		
1 vs 4			-1.37	3.64
2 vs 4			8.08	6.84
3 vs 4			-2.38	3.84
5 vs 4			-3.55	3.59
Joint + Gravity (5)	5.46***	1.44		
1 vs 5			2.51	2.05
2 vs 5			10.87*	6.00
3 vs 5			4.48*	2.48
4 vs 5			-10.95*	5.59
Open access + Pump(6)	17.93**	10.46		
1 vs 6			-10.29	10.56
2 vs 6			-2.48	12.29
3 vs 6			-9.68	10.62
4 vs 6			-20.05	12.18
5 vs 6			-11.85	10.57

Source: Author’s estimation using own survey data
Note: 1=Private+ Pump, 2= Farmer +Pump, 3=Farmer+Gravity, 4=Joint +Pump, 5=Joint+Gravity, 6=Open access +Pump
*.** and *** indicate statistical significant at 10%, 5% and 1%, respectively.

Jointly managed pressurized irrigation systems[30] by users and a government agency generate around USD 13.49 hundred (ETB 30.08 thousand) per ha net return. Our focus group discussions with users of jointly managed pressurized irrigation systems around Alamata district (Tigray region) and Kobo district (Amhara region) reveal that through time the benefits from these systems have been declining due to worn out pipes and laterals which hinder the smooth flow of water. Sustaining high returns from such irrigation systems requires closer attention by all stakeholder, as its operational and maintenance complexity, absence of skilled manpower and spare parts in the market, and cost of energy are the fundamental reasons for limited expansion of pressurized system in Africa (Lebdi, 2016).

As observed during the field work, the role of different stakeholders involved has not been identified clearly. For instance, the Raya and Kobo Valley Irrigation Projects were developed with the aim of tackling agriculture water stress problems in drought prone areas. The respective regional governments in collaboration with development partners introduced and constructed the multi-million dollar integrated pressurized irrigation systems (sprinkler and drip) in the community. As stated in Awulachew et al., (2010), in most irrigation schemes in Ethiopia, issues like water fees, water rights, conflict resolution, incentives for collaboration between different hierarchical levels of government and incentives for accurate reporting of current projects lack a regulatory framework. As shown in studies by Brown (2011), Tilahun et al., (2011), and Yami (2013), public investment in irrigation has been given high emphasis to physical and technical development, very little attention has been provided to capacity building, O&M and long-term sustainability issues in Ethiopia. Therefore, adequate user involvements and strengthening of institutional set-up for proper operation, maintenance and irrigation service provision is needed to meet the expected outcome and for the sustainability of those kinds of huge irrigation investments.

Among the given combinations, the lowest average net farm return is recorded by farm households that adopted jointly managed canal irrigation which is around USD 5.46 hundred (ETB 12.16 thousand) per ha. This category includes farm households who

[30] A pressure piped irrigation system is a network installation consisting of pipes, fittings and other devices properly designed and installed to supply water under pressure from a source of water to an irrigable area. This kind of irrigation system needs huge investment at initial stage by the government and partner development organizations. Farm households are also expected to invest on laterals and irrigation pipes which is installed on their farm field. The piped system conveys and distributes the irrigation water in closed pipes by pressure following the most convenient route, regardless of the slope and topography of the area. Once it is set, it is expected that the water will be used efficiently and can be used in any topographic condition and will result in higher production and yield level. The water is distributed at small rates over a very large area.

participate in large scale irrigation schemes such as Koga and Tibila irrigation projects. This result highlights that large investments by the government and development organizations at the initial development of irrigation projects may not be sufficient to obtain large and long-term benefits for communities; instead, active engagement and participation of all stakeholders in the management and use of the irrigation schemes is needed. Result of FGDs with irrigators in various large-scale schemes indicate that users complain about abuse of power and corruption by the officers in charge of water distribution and management at higher level. As a result, they have experienced frequent shortages of water during irrigation seasons which led them to shift from production of high value crops to growing more traditional crops. This finding is in line with studies by Adams 1990 and Lam 1996 that suggest that bureaucratic management, rather than the scale itself is the key cause of the poor performance of this kind of irrigation system.

As stated in Huppert & Walff (2002) and Huppert (2013), jointly managed irrigation schemes usually face adverse motivational structures inherent in the organizational design of this kind of irrigation system. This is the main cause for the suboptimal performance of this type of schemes which is related with the principal-agent problem. This results in highly dysfunctional motivation pattern on the key players, i.e., the government and the farmers. Such problems invite rent-seeking behaviour and corruption and providing a solution for this kind of complicates problems is a delicate matter. Therefore, it is essential to be aware of such problems and to devise ways to avoid them. The problem is well understood at the policy level, as the Proclamation of IWUA (FDRE 2014) states that there is a high need of supervision of the irrigation schemes from the state. Since the main role of IWUA is appropriation of irrigation structures and provision of irrigation water to its members, they have a public interest nature and each stakeholder that has various interests should contribute to the common goal by taking into account their degree and level of involvement in O&M of the system. Especially, high emphasis should be given to beneficiaries' participation and empowering them to varying degrees to take responsibility for their schemes.

Pumping in open access systems provides the highest average potential net return (USD 17.93 hundred ~ ETB 39.97 thousand per ha). As stated in Burney & Naylor (2012), Giordano & de Fraiture (2014), it is the fastest growing irrigation sector in sub-Sharan Africa. Indeed, farmers' genuine interest is demonstrated by their willingness to initiate and finance this type of irrigation themselves. On top of the existing weak local governance systems, smallholders desire to avoid high transaction costs of communal and jointly managed irrigation systems and strive for independence and flexibility in crop production and water use decision and clear indicators of why this system currently works in many places. Moreover, the local availability of affordable irrigation technologies, low initial investment, and high profit margins are the driving forces for its high adoption rate.

However, this spontaneous and unregulated spread of open access pump irrigation is leading to growing competition for scarce water supplies, conflicts among farmers and mining of water sources. Insights from focus group discussions with irrigation water users reveal that there are emerging sustainability concerns in open access water uses without the necessary operational and institutional arrangements. With a growing number of pump users on the Teji River (in Illu *woreda*), for instance, there is high competition for water to irrigate resulting in limited duration of water availability and creating water shortages. Discussion with irrigators, elders, and irrigation experts indicated that there has been a growing shortage of water to both open access users and adjacent farmer-led gravity irrigators. There were times that availability of limited amount of water led to complete failure of irrigated crops such as onions and *chat* (a stimulant cash crop). These water shortages have also brought about conflicts among farmers within the same system and across different systems (open access irrigators and those who are in farmer-led irrigation system). This kind of water usage has forced irrigators to shift from water intensive cash crops to cereals crops which require smaller amount of water.

Studies by Shah (2009), de Fraiture et al., (2013), Giodano & de Fraiture (2014), and Dessalegn & Merrey (2014) also show similar results. The uncontrolled expansion of individual irrigation may lead to environmental damage i.e., mining of water sources, resource degradation and pollution from agro-chemicals. On the other hand, the social and institutional context and framework for managing this kind of irrigation system has been largely overlooked. This phenomenon deserves more attention than it currently receives. Otherwise, it may lead to serve threats to the sustainability of pump irrigation in terms of livelihood benefits as well as management and use of the limited natural resources.

3.9. Conclusions and Implications

Improved access to irrigation water plays a vital role for sustainable livelihoods of rural households in developing countries. Recognizing the country's water resource potential, rehabilitation, upgrading and establishment of small, medium, and large-scale irrigation and adoption and diffusion of rainwater harvesting practices have become central to Ethiopia's policy and strategy on agricultural and rural development in the last three decades. In addition to the traditional irrigation systems which have been developed by communities, the government and several development partners are involved in the development of shallow and deep wells, and micro-dams and river diversions. Despite all these investments, their impact has not been systematically assessed. The main objective of this chapter is to understand the impact of using irrigation water and identify which combinations of water management and lifting technology lead to relatively higher net farm returns. This study considers irrigation as a socio-technical system. The water management systems, organizations and institutions in irrigation are as important as the technical dimensions of a scheme. The importance of such a study is to identify irrigation practices (including irrigation technologies and management systems) that are promising for future investments considering a number of factors into consideration. For this purpose, the study utilizes data from a cross-sectional survey which was conducted in 2016/17 with the objective of analysing the economics of irrigation systems mainly focusing on the technological and management perspective. Descriptive as well as econometric methods are used in the analysis, which are augmented with qualitative information from focus group discussions.

The finding of the study shows that there is a statistically significant difference in input use among rainfed and irrigated plots. The value of improved seed, chemical fertilizer and labour used were significantly higher on irrigated than rainfed fields. This suggests that due to access to irrigation water, there is increased intensification of agriculture which is expected to affect factor markets and the wider economy positively.

Moreover, the use of irrigated agriculture enables farm households to increase the number of harvests per year, improve yields and diversify cropping patterns. Insights from FGDs indicate that in the previous years (in years immediately after starting to irrigate), irrigation was usually used to supplement income largely generated from rainfed agriculture. This situation has been changed in many cases with irrigation becoming the main source of agricultural income for these households. Farm households' average total value of production grown using irrigation was around USD 1,416.09 per ha in the 2015/16 irrigation season compared to the average total value of production from rainfed agriculture (using only rainwater) at USD 990.31 per ha. Furthermore, higher yields, higher cropping intensity and all year-round farm production lead farm households to increase market-oriented production which enhances farm households market participation. About 43 percent of the households sold their rainfed agricultural products in 2015/16 (earning an average of USD 509.37 per ha). Yet, around 2/3 of the same farm households sold their irrigated products through various marketing channels, mainly district market, village market or directly on farm and earned, on average, around USD 883.34 per ha, with significant variation along various irrigation practices. The results of this study show that the magnitude of benefits gained from irrigation depends on accessibility of markets and infrastructure since most of the crops grown in the irrigation sites are perishable. Hence, functioning, and accessible markets, specifically for agricultural inputs and outputs are vital to reap the impact from irrigation. Hence, improving market access should be a crucial part of rural development strategies.

While access to irrigation clearly indicates positive impacts on farm households' welfare, this study also investigates the joint effect of the various water management systems and irrigation extraction methods on net farm returns. This study uses a multivalued treatment effect and employs Inverse Probability Weighted Regression Adjustment (IPWRA) estimators to define the potential mean outcome of each combination of water management and technology alternative and to make pair-wise comparison to find ATT.

Our estimate of the conditional average adoption effects for combinations of irrigation technology and water management systems on farm net return suggests that using motor pumps in privately developed water sources leads to the highest net crop return (USD 17.87 hundred ~ 39.83 thousand ETB/ha) among the alternatives given. The findings also indicate that in cases where farmers do not have the resources to develop privately accessed irrigation water source, adoption of collectively managed pump irrigation (USD 17.09 hundred ~ ETB 38.09 thousand per ha) becomes essential and can be a feasible alternative. Instead of practicing irrigation individually, communal irrigators are in a better position by sharing costs for construction and maintenance of wells and pumps and other operating costs. It indicates that self-organization and management for irrigation water distribution should be encouraged, since it could be one strategy to enhance benefits from irrigation and to minimize costs related with the construction of wells and fixed and variable cost of using pumps. These findings imply that using motor pumps in privately as well as collectively developed water sources can be a viable option in agroecological zones with sufficient groundwater. Moreover, the policy to support groundwater exploitation and importing micro-irrigation technologies free of duty further supports the spread of the highest-return irrigation methods. The finding of the research also implies that the promotion of privately accessed and micro irrigation technologies such as motor pumps by the government and development partners needs to be accompanied by ways to provide appropriate and accessible repair and maintenance services of irrigation lifting technologies and accessories to beneficiary farmers.

In the case of farmer-managed canal irrigation, the estimated average net return is lower than most of the alternatives given, i.e., around USD 8.25 hundred (ETB 18.40 thousand) per ha. This is perhaps due to the local material used to construct the irrigation structure that results in considerable seepage losses of canals and uneven distribution of water volumes to members. This finding underscores the need for interventions in replacement of structures by modern ones.

The study furthermore finds that the lowest average net farm return is recorded by farm households that adopted jointly managed canal irrigation which at around USD 5.46 hundred (ETB 12.16 thousand) per ha. This category includes farm households participating in large scale irrigation schemes such as Koga and Tibila irrigation projects. This result highlights that the large initial investments by the government and development partners for the development of irrigation projects may not be sufficient to achieve long-term positive returns for irrigation communities; instead, active engagement and participation of all stakeholders at each step in the management of the irrigation schemes is essential. This can help to avoid the principal-agent problem which is persistent in this kind of irrigation management system and to enhance a sense of belonging by irrigators with the system.

Plots that are in jointly managed pressurized irrigation systems (jointly managed by pump irrigators) generate on average around USD 13.49 hundred (ETB 30.08 thousand) per ha net return. This kind of irrigation system needs large investments at the initial stage, requires skilled manpower for its O&M and involves high energy cost. Therefore, adequate user involvement and strengthening of institutional set-up for proper operation, maintenance, and irrigation service provision is needed for the sustainability of such systems.

Using open access pump irrigation system also provides the highest average potential net return (USD 17.93 hundred ~ ETB 39.97 thousand per ha). However, the benefit obtained are offset by its negative environmental and social effects. The results from the FGDs point out that the spontaneous and unregulated spread of open access pump irrigation is leading to growing competition for scarce water supplies, conflicts among farmers, and mining of water sources which may negatively affect the sustainability of irrigation in terms of livelihood benefits as well as management and use of the limited natural resource. Hence, emphasis should be given to immediate mobilization of irrigators and establishment of local level institutions for irrigation water management to efficient and equitable use of the natural resource and for its sustainable use. In line with this, a focus on R&D is needed to provide relevant information on streamflow and aquifer levels to guide the sustainable use of water resources.

4. LOCAL EMPOWERMENT, IRRIGATION TECHNOLOGIES AND DEVOLUTION IN ETHIOPIA

4.1. Introduction

Devolution of natural resource management is believed to have the potential to empower rural communities and smallholders by increasing their decision-making power and providing mechanisms to develop local governance structures which may lead to more sustainable use and management of natural resources (Ribot, 2002). Several conditions have been identified in the literature as being essential for the effective management of natural resources by users and local communities. For example, users must be capacitated with the knowledge, information, and incentives to manage and conserve the resource on which they depend; there must be a strong and repeated dependence of users on the resource; the value of output from resource management must be greater than the cost of investing social capital through community resource management; users should contribute and participate in decision-making processes from the initial stages of design to implementation, use and management of the resource; and users should have sustainable and clear rights and sanctions over the resource to ensure accountability (Agrawal & Gibson, 1999; Ostrom, 1990; Vermillion, 1997).

Policy reforms designed for devolving the management of natural resources from government agencies to local administrations, user groups and individuals have been observed in several countries of Sub-Saharan Africa (Lind & Cappon, 2001). Similarly, in Ethiopia, since 1991, the role of local rural communities and households in natural resource management has been increasing, particularly in the management of water for irrigation (Gebremedhin et al., 2003). There has been implementation of policy reforms that encourage irrigation management at a lower level and the adoption of irrigation technologies at micro and small scales to farm households. This includes issuing proclamations in transferring responsibility for managing irrigation water at local levels. For instance, irrigation water users' associations (IWUAs) Proclamation No. 841/2014 creates a specific legal basis for the establishment of IWUAs as a legal entity for the operation and management (O&M) of irrigation systems (Federal Democratic Republic of Ethiopia, 2014). Moreover, as of April 2019, the government has allowed irrigation equipment, including micro-scale irrigation pumps, tools, and spare parts, to be imported duty-free into the country

Studies by Yami and Snyder (2012) and Haileslassie et al. (2016) pointed out that lack of capacity and empowerment at the local level to take over the responsibilities following the decentralization process affected the sustainability and further investment in smallholder irrigation systems in Ethiopia. Still the existing irrigation institutions at the lower level are far from meeting the criteria of self-governance because of insufficient attention given to strengthening local institutions, transforming top-down approaches in the agricultural extension system to more participatory and higher degree of decision-making autonomy. However, there is limited evidence for the role of local-level institutions, organizations and management systems that have taken on additional responsibilities and obtained additional rights for empowerment of local users in the use and management of natural resources, except the few studies by Jagger et al. (2005) and Yami (2013; 2016).

This study explores the factors that affect smallholder's empowerment through increased rights and responsibilities in using and managing irrigation water in Ethiopia. The research question to be pursued is: Do irrigation water management systems and irrigation technologies influence individual and collective empowerment of using and managing irrigation water? Our contribution focuses on two areas: First, the chapter explores the concept of empowerment in the context of irrigation water users, expanding on the traditional usage of this term which has been focused on women and the poor. Second, the chapter analyses –for the first time– the combined effect of irrigation water management and complementary technologies on empowerment of irrigators. The study considers multiple scales of irrigation water management (private, farmer managed, jointly managed and open access) and technologies applied (storage structures, lifting mechanisms from a source and farm field application systems). It complements the literature on institutions and technology adoption by shifting attention to what happens after technology adoption and setting up of institutions and management systems. In addition, the findings of this study will be useful to identify policy interventions that can help in the process of designing and implementing institutions, practices and technologies that empower natural resource users.

4.2. Sources of data

The data for this study come from a cross-sectional survey of irrigators in four regions of Ethiopia, i. e., Tigray, Amhara, Oromia, and Southern Nations, Nationalities, and Peoples' Region (SNNPR) that was conducted in 2016/17. The sample includes 1037 irrigated plots from 464 farm households. The data were collected using a multi-stage stratified random sampling method. The survey data were merged with climate variables based on geo-referenced household and plot level latitude and longitude coordinates for the period 1981-2016 (see section 1.8 for detail). In addition, qualitative information was gathered using open-ended questions through focus group discussions and community level surveys, in order to enhance the validity and reliability of the household data. The qualitative and community surveys augment the results of the econometric analysis.

4.3. Conceptual and analytical framework

4.3.1. Conceptualizing empowerment

There are several definitions of empowerment in the literature[31]. The most widely cited and influential analytical treatment of this subject is by the German social scientist Max Weber (1904). He defined power as "the probability that someone in a social relationship will be able to achieve his or her will, that is, whatever is desired, despite resistance, and regardless of the bases upon which this probability rests". Other definitions from the works of Kabeer (2001), Narayan (2002) and, Alsop et. al. (2006) are also frequently used. Kabeer (2001) explains empowerment as "the process by which those who have been denied the ability to make strategic life choices acquire such an ability". She categorizes empowerment into three inter-linked dimensions: (i) resources which include not only access, but also future claims, to both material and human (including social) resources; (ii) agency that incorporates processes of decision making, as well as less measurable manifestations of agency such as negotiation, deception, and manipulation, and (iii) achievements which are explained as well-being outcomes.

Alsop et. al. (2006) explain empowerment as "enhancing the capacity of an individual or group to make purposeful choices and to transform those choices into desired actions and outcomes". This definition includes two elements. The first one is agency based on Amartya Sen's[32] (1985) definition as "the ability to act on behalf of what you value and have reason to value". The second element is associated with the institutional environment, which offers people the ability to exert agency fruitfully (Alkire, 2008; Ibrahim & Alkire, 2007). Narayan (2002; 2005) refers to empowerment as "the expansion of assets and capabilities of poor people to participate in, negotiate with, influence, control, and hold accountable institutions that affect their lives". She emphasizes four main elements of empowerment: access to information, inclusion and participation, accountability, and local organisational capacity. There is similarity between the definitions given by Kabeer (2001) and Alsop et al., (2006) as both include the concept of agency and capacity. However, Narayan's definition is broader as it includes the relationship between people and institutions.

Considering the above general definitions and explanations of empowerment, in this study, local level irrigation empowerment is defined as the ability and capacity of rural

[31] For a comprehensive review refer Ibrahim and Alkire 2007

[32] Sen (1985) refers agency as what a person is free to do and achieve in pursuit of whatever goals or values he or she regards as important. In his view, it constitutes a process freedom (Sen 1999). The other key concept in Sen's framework is that of opportunity freedoms or capacities -the various combinations of functioning (beings and doings) that the person can achieve (Sen 1992). The expansion of both types of freedoms-processes and opportunities -is the objective of development.

farm households in acquiring information, making decisions, participating in, and strengthening local organizations[33] (local governance structures) in developing, using, allocating and managing of irrigation water. In choosing outcome indicators for measuring local level irrigation empowerment, previous studies by Kabeer (1999, 2001), Narayan (2002; 2005); Khwaja (2005); Malhotra & Schuler (2005); Narayan & Petesch (2007); Alsop et al. (2006); Ibrahim & Alkire (2007); Alkire et al. (2013), and Meinzen-Dick et al. (2019) that propose domain-specific measures of empowerment obtained from household and plot level surveys were considered. In the process of selecting local level irrigation empowerment indicators, the following concepts are taken into account:

Intrinsic or instrumental: Empowerment approaches focus on enhancing poor people's freedom of choice and action (Narayan, 2002). The literature on empowerment considers two understandings of the concept. Empowerment is understood as a means to a specific end (such as increased welfare of the empowered agent) as well as an end (valuable for its own sake) (Narayan (2002), Khwaja (2001), Khwaja (2005), and Alsop et al., (2006)). In this study, empowerment is considered as an end (a component of an agent's welfare or utility), in line with other outcomes such as income generation, environmental sustainability and resilience building. It is considered as a key objective of development policy in its own right and it is one of the main pillars to the sustainable use and management of natural resources.

Context-specific: Empowerment is inherently context-specific and multidimensional (Malhotra & Schuler, 2005). Especially, the analysis of local-level irrigation empowerment highly depends on the existing type of irrigation technology adopted and the water management regime. It may be difficult to find indicators to make comparison across irrigating households and plots in various water management systems that are applying diversified kinds of technologies.

Level of application and measurement: Although indicators of empowerment may be measured at a farm, household, group, community, regional or national level, this study focuses on farm level analysis. This study is interested in measuring empowerment of farm households based on plot and household level data collected.

Method of assessment: Empowerment has objective as well as subjective dimensions (Alkire, 2013; Ibrahim & Alkire, 2007; Holland & Brook, 2004; Meinzen-Dick et al., 2019). Nevertheless, the validity of self-reported indicators is questioned frequently, since they may be subject to biases due to several reasons such as the reference frame applied, the structure and sequence of questionnaires conducted, knowledge and experience on the

[33] Narayan (2002) defines local organizational capacity as the ability of people to work together, organize themselves, and mobilize resources to solve problems of common interest.

subject, or the presence of others during the interview. On the other hand, because empowerment is such an individually located concept, we may fail to incorporate the entire measurement indicators, if we undermine using self-reported indicators (Alkire et al., 2013). Hence, the analysis of this study on irrigation empowerment incorporates both objective and self-reported indicators.

4.3.2. Econometric approach, model specification and estimation

An irrigation system may be established for several positive outcomes. Let $\{M_1 \dots \dots M_i\}$ denote these *M* irrigation project outcomes, and $i's$ indicates the outcome (local level empowerment, income generation and environmental sustainability). It is assumed that *M* is an increasing function of each irrigation outcome, $M_1 \dots \dots M_i$, such that

$$M = (M_1, \dots M_i) \quad (1)$$

Enhancing local-level empowerment is one of the outcomes among the many long- and short-term benefits or outcomes of establishing an irrigation project. As discussed in the previous section, this study considers local-level empowerment as an important outcome on its own because it is part of the overall welfare or well-being of rural farm households, since the expansion of capabilities in decision-making and strengthening local governance structure have value even if it does not influence any other aspect of welfare. In other words, the assumption is that empowerment is valuable because it is an end by itself and one component of the overall welfare of a farm household.

Mathematically, the relationship between a particular aspect of empowerment is given by the following equation:

$$U_i = \text{f}(E_i, H_i) \quad (2)$$

where *Ui* is an agent *i*'s measure of welfare from using and managing irrigation water; *Ei* is a measure of how empowered she is; and *Hi* is a list of other factors that directly affect her welfare after the establishment of the irrigation project. The farmer's utility obtained from developing, allocating, using, managing and conserving water resources in the irrigation project is not observed. Rather, we observe the benefit from it.

However, developing, allocating, using, managing, and conserving irrigation water incurs fixed as well as variable costs, $D_{i,}$ either by an individual farm household, F_i, a group of farmers, C_i, and/ or by an external agency (by a government agency or a development partner), A_i. D_i is a concave and increasing function. The cost is incurred from all the parties.

$$D_i = d_i(F_i, C_i, A_i) \quad (3)$$

Finally, empowerment in irrigation water use and management is influenced by a vector of exogenous factors (*X*) which includes household characteristics (*XH*), farm characteristics (*XF*), village characteristics (*XV*), scheme characteristics (*XS*), and agro-ecological and climate characteristics (*XC*). The *i's* indicate the different variables included in the vectors:

$$E_i = f(XH_i, XF_i, XV_i, XS_i, XC_i) \quad (4)$$

In the literature of empowerment, several indicators have been used in the context of poverty reduction (Alkire, 2008; Alsop & Heinsohn, 2005; Ibrahim & Alkire, 2007). Some common proxy measures include literacy, membership in an organization, employment history and ownership of land (Alkire, 2008; Alsop & Heinsohn, 2005). The primary reason for selecting such proxies is that they are objective, concrete and tangible, yet represent a complex concept.

In choosing indicators for measuring local-level irrigation empowerment, the conceptual plurality of its nature suggests that multidimensional measures might work best. Because empowerment in such experiences is implemented with different achievements and can be described and measured with different domains, Alkire (2005) suggests that most measures of agency and empowerment should be domain specific. The dimensions are likely to distinguish the kind of empowerment goal sought (Alkire, 2008)

Since empowerment in the case of irrigation users in Ethiopia contains multiple scales of irrigation water management with various complementary irrigation technologies, the analysis is divided into two parts. In the first part of the analysis, all irrigators are included, and empowerment is analysed as an individual's achievement. In the second analysis, only user-managed and users-and-agency managed irrigation systems are incorporated, since in these cases irrigation water is treated as a common pool resource. Therefore, considering the above concepts, local level empowerment is measured through irrigation, E_i, by the following two domains:

(I) Empowerment as an individual's achievement refers to access and decision-making power for managing and conserving irrigation water which includes:

- satisfaction level of farmers in using and managing the irrigation systems
- quality of irrigation infrastructure
- whether vegetables/perennials (marketable crops) grown
- yield of onion

(II) Collective empowerment indicates participation in and strength of irrigation governance structure that is represented by: whether the beneficiary household operates on the farm:

- contributed at initial establishment of the scheme (either in cash, in-kind or in-labour);
- contributed to operation and maintenance of the scheme (in-labor) during the 2015/16 fiscal year;
- is a formal member of the WUA
- has a conflict with an irrigation neighbour in 2015/16 irrigation season -indicates the failure of the existing irrigation governance system
- meetings attendance rate of members of the WUA

The outcome equation for each indicator of empowerment, E, is given as:

$$E_{ihk} = XH_{ihk} + XF_{ihk} + XV_{ihk} + XS_{ihk} + XC_{ihk} \quad (5)$$

Here, E_{ihk} is a vector of the outcome variable, defined as indicators of empowerment, of the i_{th} farm of, h_{th}, household for indicator, k. Since local level irrigation empowerment is defined as the ability and capacity of making decisions, participating in and strengthening local organizations (local governance structures) in developing, using, allocating and managing of irrigation water, the empowerment outcome variables are defined at plot level, instead of at household level. Around 2/3 of the households in the sample have more than one irrigated plot that may belong to different combinations of irrigation management system and technology type.

The type of regression model to use depends on the nature of the dependent variable (indicator of empowerment). Least squares regression is used to explain for yield of onion produced in the 2015/16 irrigation season, since this variable is continuous. Probit models are used to examine the determinants of binary outcomes such as whether marketable crops were grown; if the farm household contributed at initial establishment of the scheme and for O&M of the scheme; whether the household is a member of the WUA; and if there was a conflict with an irrigating neighbour during the 2015/16 irrigation cropping season. To identify determinants of the satisfaction level of farmers in using and managing irrigation water, the quality of the irrigation infrastructure, and frequency of meeting attendance of WUA, ordered probit models are applied. The ordered probit model has been used widely to analyse ranked responses (Greene & Hensher, 2010). In all the three cases, the dependent variables are measured using a 5-point Likert-scale. The analysis to identify determinants of satisfaction level of farmers in using and managing irrigation is conducted using a five-item scale: (1) very dissatisfied, (2) dissatisfied, (3) fair, (4) satisfied and (5) very satisfied, whereas quality of the irrigation infrastructure is analysed using a five-item scale: (1) very poor, (2) poor, (3) fair, (4) good and (5) very good.

Frequency of meeting attendance of WUA is measured as (1) none, (2) very rarely, (3) sometimes, (4) often, and (5) all the time.

The analysis was implemented at the plot level to capture more spatial heterogeneity and minimize omitted variable bias. Due to a collinearity problem between water management systems and interaction terms, a separate effect of a water management system on empowerment indicators was omitted. Thus, only interactions of the various irrigation water management systems and complementary irrigation technologies are captured. We tested whether there is a problem of multicollinearity among explanatory variables, but it was found only among the climate variables as one would expect. The correlation between these variables was leading to high variance inflation factors (VIFs) of between 3.83 and 69.71. However, all the variables in the models are included since they are statistically significant coefficients. Moreover, omitting one of the variables would result in omitted variables bias. The other variables had a variance inflation factor of < 2.08, indicating that multicollinearity was not a major concern for these variables (Gujarati, 1995). The White heteroscedasticity-robust covariance matrix (White, 1980), which is robust to heteroskedasticity of unknown form, was used. It was also tested if there is a problem of incorrect functional form. The result demonstrated that there was no evidence of functional form misspecification. The study chose to use the Shapiro–Wilk normality test, since the number of observations included in the analysis is less than 2000 observations. The necessary adjustments were made to identified outliers. Specifically, to the Probit models the overall rate of correct classification is estimated to be 81.60%, 77.48%, 73.57%, 80.10% and 91.75%, with 41.82%, 83.95%. 94.33% and 29.17% of the normal weight group correctly classified (specificity) and 92.67%, 69.03%, 82.08%, 31.17% and 98.16% of the low weight group correctly classified (sensitivity), for the dependent variables: whether marketable crops are grown; if the farm household contributed at initial establishment of the scheme and for O&M of the scheme; if a conflict with an irrigating neighbour had occurred and whether the household is a member of the WUA, respectively. Furthermore, the Pearson goodness-of-fit test was performed; all the probit models fit reasonably well.

4.4. Descriptive Statistics

4.4.1. Outcome variables

The study includes both subjective and objective dimensions to measure empowerment of irrigating farm households. Tables 4.1 to 4.4 present descriptive statistics of empowerment indicator variables by irrigation management system and technology used. Farm households were asked about their satisfaction level of using and managing irrigation water. In the process of rating, they were told to take into consideration performance measures such as mechanisms of water control, allocation, and delivery[34] that constitute flexibility, reliability and equitable irrigation water distribution and use. Of the 1037 irrigated plots considered in the analysis, the majority report higher satisfaction level (strongly satisfied and satisfied). It is interesting to note also that households who have plots in open+ pump irrigation systems are relatively less satisfied (37.7%) with the use and management system, compared to other alternatives, which suggests the reliability and flexibility problems persist in this kind of system.

Table 4. 1. Indicators of access and decision-making power of irrigators

Individual household level empowerment indicators		Private+ Pump	Farmers+ pump	Farmers+ gravity	Joint+ pump	Joint+ gravity	Open+ pump
Farmer's level of satisfaction in using and managing irrigation water (%)	Strongly dissatisfied	0.58	1.15	1.40	0	2.64	16.91
	dissatisfied	9.20	8.05	7.91	8.33	8.21	20.74
	Moderately satisfied	5.17	22.99	47.44	6.94	27.27	11.03
	Satisfied	39.66	39.08	21.86	31.94	25.81	19.12
	Strongly satisfied	45.40	28.74	21.40	52.78	36.07	32.21
Quality of infrastructure (%)	Very poor	14.09	5.75	5.58	2.78	6.77	
	Poor	26.17	9.20	25.58	4.17	19.71	
	Fair	14.09	9.20	26.98	1.39	10.88	
	Good	40.94	52.87	23.26	40.28	39.41	
	Very good	4.70	22.99	18.60	51.39	23.24	
Whether produce high value crops in irrigation season (%)		90.23	72.09	59.77	81.11	73.02	84.56
Onion yield(qt/ha)		103.50 (35.55)	97.03 (20.39)	85.48 (17.21)	105.07 (25.24)	92.66 (16.05)	91.60 (9.88)

Source: Author's compilation using survey data
Note: Standard errors in parenthesis

As indicated from our focus group discussion with irrigators, their main goal is to produce marketable crops like vegetables and perennials. Therefore, in the survey they were asked whether they grow high value crops and information on yields obtained. This kind of indicator helps us to point out the information they have and the decision-making autonomy they possess in using and managing irrigation water. In line with our expectation, the majority of irrigators (3/4th) produced vegetables, roots and perennials which have high market value. As depicted in Table 4. 1, around 90% of plots found in privately managed pump irrigation system produced mainly cash crops. Onion was the major type of crop grown in the 2015/16 irrigation season with average yield of 95 qt/ha.

[34] Water supply and delivery performance indicators reflect insight into the efficiency of water conveyance and use in the schemes (Greaves, 2007).

This figure is almost similar to the national average of productivity reported by CSA (2017/18) which was 97 qt/ha in 2016. There is variation among the alternatives, the highest was recorded by privately managed pump users (103.5 qt/ha) and jointly managed pump users (105 qt/ha), and the lowest by households with farmer-managed gravity-irrigated plots (85.48 qt/ha). Regarding the technology applied on the field, it is observed that those who use pressurized systems achieved average onion yield of 115.80 qt/ha (refer Table 4.2). It is noteworthy to mention the existing productivity variation among the conveyance systems applied, i.e., furrow (90.68 qt/ha) and flooding (84.88 qt/ha) irrigation systems. As expected, irrigated plots located in jointly managed pump (51%) and gravity (23%) irrigation schemes have higher quality of the infrastructure. Quality of infrastructure for open access irrigated plots is not included because there has been hardly any developed irrigation structure. The farmers utilize irrigation water openly without any schedule from a river or spring water.

Table 4. 2. Indicators of empowerment by irrigation technology

Individual household level empowerment indicators		Irrigation water source		Irrigation water application mechanism		
		Surface	**Groundwater**	**Flooding**	**Pressurized**	**Furrow**
Farmer's level of satisfaction in using and managing irrigation water (%)	Strongly dissatisfied	5.05	0.62	3.42	2.04	4.06
	dissatisfied	7.01	9.26	7.07	4.08	8.12
	Moderately satisfied	30.29	9.88	24.15	13.27	25.53
	Satisfied	23.61	37.35	28.05	40.82	25.53
	Strongly satisfied	34.57	42.90	37.32	39.79	36.75
Quality of infrastructure (%)	Very poor	6.23	9.241	10.68	1.14	5.37
	Poor	22.42	15.182	27.08	5.68	16.11
	Fair	17.26	9.241	17.4	1.14	14.58
	Good	32.92	45.215	29.43	54.55	40.67
	Very good	21.17	21.122	15.37	37.5	23.27
Whether high value crop is produced (%)		74.72	85.62	69.67	81.95	77.55
Onion yield(qt/ha)		90.63 (8.73)	102.16 (15.34)	84.88 (18.37)	115.80 (13.88)	90.76 (12.00)

Source: Author's compilation using survey data
Note: Standard errors in parenthesis

In farmer-managed and jointly managed (farmer and government agency) irrigation structures, operating and maintaining an irrigation system requires coordination among farmers starting from the initial development of the irrigation schemes. Each irrigator is required to contribute either in cash, in kind or in labour to maintain the system. Collective action problems usually arise when irrigators have the incentive to use more water and contribute less to the system. These problems can lead to poor maintenance as well as water allocation, which in turn can result in conflict. Thus, institutions should be developed that enable long-term and credible commitments among users. Therefore, in farmer-led and jointly managed irrigation systems, farmers have developed by-laws to specify rights and responsibilities among themselves with the help of the *kebele* extension worker. Farmers enforce these rules themselves with/out involving external authorities. These rules enable farmers to organize themselves and cooperate in the O&M of their irrigation system. Tables 4.3 to 4.4 present descriptive statistics of collective empowerment indicator variables by irrigation management system and technology used[35].

Table 4. 3. Indicators of collective participation, decision making capacity and strength of governance structure

Collective empowerment indicator (local governance structure)		Private + pump	Farmer + pump	Farmer + gravity	Joint + pump	Joint + gravity	Open + pump
Whether the household contributed at the initial establishment of the scheme in labor, cash and kind form (%)			26.44	67.91	13.89	38.42	
Whether the household contributes for O&M in labor (%)			41.38	76.28	19.44	58.36	
If the household is formal member of WUA (%)			71.26	87.44	94.40	95.31	
Whether conflict occurred (%)			20.69	33.02	29.91	37.5	
Frequency meeting attendance (%)	None		29.07	30.37	15.28	45.43	
	Very rarely		30.23	21.96	12.5	25.66	
	Sometimes		15.12	26.17	66.67	19.17	
	Often		0	4.21	1.39	4.42	
	All the time		25.58	17.29	4.17	5.31	

Source: Author's compilation using survey data
Note: Standard errors in parenthesis

Contribution at the initial stage as well as for day-to-day O&M of irrigation water provision and appropriation is more common in farmer-managed gravity irrigation schemes, around 68% and 76% farmers contributed at initial stage and for the day-to-day operation of the scheme in the 2015/16 irrigation season, respectively. The most frequent conflict occurrence was observed in jointly managed gravity irrigation systems, followed by farmers managed gravity systems. Even if it is expected that members of WUAs shall meet frequently (generally once a month) to discuss the operation and management of the irrigation system and to resolve problems, a large number of the households attended meetings very rarely.

[35] The whole detail explanation on the indicators is given in section 2.6.2.1.

Table 4. 4. Collective empowerment indicators by source of water and field application mechanism

Collective empowerment indicator (local governance structure)		Source of irrigation water		Irrigation water application mechanism on the plot		
		Surface	Ground-water	Flooding	Pressurized (drip/ sprinkler)	Furrow
Whether the household contributed at the initial establishment of the scheme in labor, cash and kind form (%)		50.27	20.63	50.78	14.46	43.53
Whether the household contributes for O&M in labor (%)		65.30	31.25	70.50	21.69	54.26
If the household is a formal member of WUA (%)		92.13	81.25	90.60	90.36	88.96
Whether conflict occurred (%)		30.77	31.88	37.90	23.34	33.74
Meeting attendance (%)	None	9.89	15.63	9.70	2.41	15.02
	Very rarely	4.68	0.63	2.20	1.21	6.07
	Sometimes	21.76	38.13	15.36	44.58	30.67
	Often	24.10	22.50	28.53	28.92	17.25
	All the time	39.57	23.13	44.20	22.89	30.99

Source: Author's compilation using survey data
Note: Standard errors in parenthesis

4.4.2. Explanatory variables

The choice of explanatory variables was based on economic theory and findings from earlier studies. Table 4.5 presents a descriptive analysis of variables included in the econometric estimation. The econometric model includes household level variables, such as age, education level of household head, number of training participated and years of experience of using irrigation water and contact of farmers with extension workers, which have positive effect on building farmers' knowledge, information as well as skill. These variables are expected to have the potential to empower smallholder irrigators.

A typical sample farm household in the study areas has a male household head (93%), 45 years old, with 5 years of schooling. The spouse has an average of 3 years of schooling. The average household size is 6 persons per household which is a little bit higher than the national average of rural households at 5.2 persons per household (CSA et. al., 2017). In the study kebeles households have considerable experience with irrigation, varying from a minimum of 2 years up to a maximum of 71 years.

Table 4.5. Summary statistics of explanatory variables

Variable name	Mean	Std. Dev.	Min	Max
Household Human capital				
Gender of the household head, 1= male, 0= otherwise	0.93	0.26	0	1
Age of the household head (in years)	44.54	12.27	20	85
Education level of the household head (in years)	5.35	5.08	0	19
Education level of the spouse (in years)	3.44	4.30	0	19
Family size, (in number)	6.09	2.24	1	15
Years of experience in using irrigation water	10.54	8.48	2	71
Number of training participated in 2015/16	2.82	2.42	0	15
Frequency of contact to extension worker in 2015/16, (in number)	16.96	29.33	0	265
Household physical capital				
Livestock ownership (in TLU)	5.08	5.69	0	51.61
Total farm size, (in ha)	1.62	1.64	0.002	12
Household social capital				
1=if any member of the household participates in labour sharing	0.25	0.43	0	1
Household financial capital				
Access to credit, 1=yes, otherwise=0	0.43	0.50	0	1
Village level characteristics				
Walking distance to woreda market (in min, one way)	32.62	25.72	0	120
Walking distance to all weather road (in min, one way)	36.20	35.37	1	300
1=if there was at least one adverse weather condition in 2015/16	0.31	0.46	0	1
Plot Characteristics				
Irrigation plot size, in ha	0.32	0.396	0.001	5
1=if the soil type is loamy	0.60	0.44	0	1
1=if the plot is flat	0.93	0.26	0	1
1=if it is allocated by government	0.41	0.49	0	1
1=if the plot is certified	0.84	0.36	0	1
1=if there is S&W conservation practice	0.5	0.50	0	1
Distance to the farm household residence(min)	16.26	19.95	0	150
Distance to the irrigation water source(km)	1.75	1.74	0	12
1=if improved seed was used	0.41	0.49	0	1
1=if pesticides/herbicides applied	0.39	0.48	0	1
1=if fertilizer was used	0.75	0.48	0	1
Scheme Characteristics				
Water Management System+lifting technology				
Private+pump	0.16	0.38	0	1
Farmers+pump	0.11	0.28	0	1
Farmers+gravity	0.19	0.41	0	1
Joint+pump	0.08	0.26	0	1
Joint+gravity	0.32	0.47	0	1
Open+pump	0.13	0.34	0	1
Irrigation water lifting mechanism				
1= Gravity, 0=Pump	0.50	0.50	0	1
Irrigation water source structure				
1= Groundwater, 0=surface	0.31	0.46	0	1
Irrigation water application mechanism on the plot				
Surface/flooding	0.40	0.49	0	1
Pressurized system	0.10	0.29	0	1
Furrow	0.50	0.50	0	1

Table 4.5. Continued

Variable name	Mean	Std. Dev.	Min	Max
Climate variables				
Meher precipitation anomaly	0.17	0.48	-0.676	0.9955
Belg precipitation anomaly	-1.17	0.60	-1.985	0.3949
Temperature precipitation anomaly	0.86	0.52	0.0728	1.4601
Meher precipitation coefficient of variation	23.22	6.88	15.107	36.463
Belg precipitation coefficient of variation	16.23	8.43	7.376	34.4378
Mean annual temperature	17.14	1.32	14.937	21.029
Meher mean total precipitation	670.04	273.49	338.66	1179.47
Belg Mean total precipitation	262.13	98.86	90.91	419.081
Elevation	1854	322.00	1245	2780
Number of observations (plots/households)	1021/464			

Source: Author's computation using survey data

In this study, wealth status of rural households is calculated using livestock ownership (in Tropical Livestock Units) and total size of farmland holdings. Farmers with higher physical capital in the sample data are assumed more likely to cover operation and maintenance costs and have better irrigation infrastructure than irrigators with fewer physical assets. Hence, households with greater physical capital are expected to be more empowered. On average, total cropland holding per household is around 1.6 ha, above the national average of 1.1 ha (CSA et. al., 2017). In rural Ethiopia, there is a custom of sharing labour[36] among farm households during the peak season of agricultural activities. This phenomenon is included in the study to explain social capital as well as agricultural labour supply of a farm household as it may lead to higher participation, decision making and improved local governance. Individuals learn more information about using and managing of the resource, the system they are in, and the behaviour of others involved when they have an extended social network. In the study areas, around 25% of households participate in these labour-sharing arrangements.

Another household factor, access to credit is assumed to lead to greater participation and decision-making capacity of irrigators. It helps farmers to ease their capital constraints enabling timely purchase of inputs. Approximately 43% of the sample farm households have access to credit, i. e., if they need to have a credit, they can obtain it.

Access to markets and all-weather roads is proposed to have a positive effect on empowering local irrigators. Better access to infrastructure and services may make the beneficiaries more empowered individually as well as collectively. The farther away the woreda market is, the less encouraging to produce high value crops and contribute for

[36] The two common types of labour sharing activities in Ethiopia are *Debo* and *Wenfel*. *Debo* refers to labour sharing group in which reciprocity to members is upon demand either within the same season or in the future, whereas *Wonfel* is labour sharing group that works in rotation for each group member and reciprocity within the same season.

O&M. Farm household members walk on average 33 minutes to get to a district market with substantial variation among farm households.

When the size of the irrigated area is very small, the return from irrigation agriculture may be low due to high fixed cost. When the size of the irrigated land holding is large, the return may also be low due to increasing variable costs of using and managing irrigation water. Hence, it is hypothesized that irrigators with medium-sized land holdings will be more empowered than households with low and very high land holdings. The effect of plot level factors such as soil quality and using modern agricultural inputs such as improved seeds and chemical fertilizers are expected to have positive effect on individual as well as collective empowerment. Besides, distance of the plot to the farm household's residence is expected to have a negative effect on participation, decision making capacity, and strength of irrigation governance. The longer the distance, the more household members get discouraged to fully use the available resources for irrigation agriculture and to participate actively in water distribution and management systems.

The average size of irrigated plots is around 0.32 ha in the study areas, though it varies from a minimum of 0.001 ha to a maximum of 5 ha. Approximately 60% and 93% of households perceived that their land has loamy soil and flat, respectively. Around 41% and 84% of households reported that their plot was allocated by the local government and has been formally certified, respectively. The average walking time from the irrigated plot to the household's residence is around ¼ of an hour with high variation up to $2\frac{1}{2}$ hours for a one-way trip.

Participation of irrigation beneficiaries starting from planning and construction to implementation of irrigation system enhances farmers' sense of belongingness of the entire system which may lead to effective resource management, greater decision making and well-established local governance structure. Therefore, farmer-managed pump as well as gravity irrigation systems may have higher empowerment potential. On the other hand, jointly managed irrigation systems that were established by the government or development partners usually have more modern irrigation structures than farmer managed irrigation schemes in either of the lifting mechanisms which can affect the efficiency of water distribution. This may in turn lead to higher yields and less conflict in irrigated agriculture. At the same time, more modern infrastructure might involve higher initial cost, government bureaucracy and issues related with collective action. Moreover, privately managed pump irrigation systems (micro-irrigation technologies) may favour active participation and greater decision-making power of irrigators, since they are solely in charge of managing the system. It is not clear, a priori, which system empowers farmers more. Furthermore, it is expected that groundwater is a more reliable, albeit likely more costly, source of irrigation water all year round than surface water. As such, groundwater systems might support improved decision making and stronger local irrigation governance.

Climatic variables are generated in the empirical model to capture whether differences in temperature and precipitation influence the degree of farmers' participation and decision-making capacity in using and managing irrigation water. Annual temperature and rainfall anomalies[37] are included to explain deviations of current observations from the long-term mean. In this study, it is hypothesized that long term changes in precipitation(declining) and temperature(warming) will lead to higher participation of farmers, starting from establishment to implementation of irrigation systems and well established and strong irrigation organizations. Similarly, it is expected that if the variation of coefficient of rainfall is high, it may result in higher participation and decision-making power and strong local irrigation organizations in using and managing irrigation water due to the need of irrigation to compensate for unreliable rainfall availability.

The descriptive results show that there has been a significant decline of rainfall in the *Belg* season for the past 36 years. which reaches up to -1.9 deviation of the long run mean from the current observations. Furthermore, rainfall (*Meher* and *Belg*) variability was computed using Coefficient of Variation (CV)[38] for the past 36 years. A higher value of variation of coefficient is an indicator of larger variability, and vice versa. According to Hare (2003), CV is used to classify the degree of variability of rainfall events as low (CV < 20), moderate (20 < CV < 30), and high (CV > 30). As shown in Table 4.5, the mean CV of *Belg* season is 16 which falls in the low degree of rainfall variability, and for *Meher* season, it is 23 which is moderate, with vast variation among sites. Similarly, mean annual temperature and mean annual total precipitation for *Belg* and *Meher* seasons is included in the analysis. The mean annual temperature of the study areas is 17 ^{0}C. The calculated mean annual total precipitation for the past 36 years suggests 670 ml and 262 ml for *Meher* and *Belg* seasons, respectively. The areas selected represent different agro-ecological settings and are characterized as highly varied topography with altitudes ranging from 1245 to over 2780 m above sea level.

[37] In this study, anomalies are measured as deviations of current observations from the long-term mean (O'Loguhin et al., 2012). For instance, the rainfall anomaly values are computed as the ratio of difference between the short-term (*Meher* and *Belg* seasons in 2016) and the long-term mean rainfall (*Meher* and *Belg* seasons for 1981-2015) to the standard deviation of the long-term rainfall.

[38] $CV = \sigma/\mu * 100$, where CV is the coefficient of variation; σ is the standard deviation and μ is the mean precipitation of the 1981-2016.

4.5. Econometric Analysis

This section investigates factors that influence the degree of empowerment over participation and decision-making capacity of beneficiary farmers, and effectiveness of local irrigation organizations. Indicators of empowerment are categorized into two, depending on the nature of the management system under discussion. The first part analyses factors that contribute to empowerment of farm households as individual irrigators. Hence, all irrigators are included in this analysis. The second part of the econometric analysis comprises only irrigators who are in farmers and jointly managed irrigation systems. The main purpose is to identify factors which affect collective participation, decision-making capacity and strength of governance structure of irrigation institutions of common pool users.

4.5.1. Factors influencing empowerment of farm households as an individual beneficiary in the case of multiple scales of irrigation management systems

In this subsection, factors that affect individual empowerment of irrigators, i.e., participation and decision-making autonomy in using, allocating, managing, and conserving of the resource is discussed. The econometric results are presented in Table 4.6. The findings show that older irrigators are more likely to have a higher satisfaction level in using and managing irrigation water than younger ones. This is perhaps due to their long years of experience in farming which enhances effective use and management of the resource. Younger male household heads are more likely to produce marketable crops and to score higher onion yield. This suggests that female-headed households and older household heads face labour constraints in their irrigation activities. Household heads with higher education level have higher quality of irrigation infrastructure. As expected, irrigation beneficiary households with larger family size are more likely to cultivate high value crops that demand high labour availability.

Number of trainings on crop agriculture and natural resources management significantly increases onion yield. This is similar to the findings of the literature, which documents the importance of training on crop production and productivity. However, unexpectedly, the yield of onion of those households who make frequent contact with extension workers is low. This suggests that it is the quality of extension services, not just contact with extension agents, is important for field improvement, or the extension workers may only focus on staple crops and not cash crops. Moreover, as years of experience of using irrigation increase, the quality of the infrastructure deteriorates. This implies the need of rehabilitation of older irrigation schemes. Surprisingly, total farmland holding decreases the likelihood of being at higher satisfaction level and leads to lower onion productivity.

Farmers with larger land holdings may have alternative source of livelihood which may affect opportunity cost of labour engaging in irrigation agriculture.

The role of social capital also included in the analysis. It is represented by whether the farm household participates in labour sharing activity(ies). Despite the expectation, it is negatively correlated with satisfaction level of beneficiary farmers in the irrigation system they are in and in their decision whether to produce high value crops using irrigation water. This implies that social networks may hinder local empowerment under certain circumstances, possibly because these sharing arrangements are highly time-intensive taking time away from activities on own irrigated plots. Unexpectedly, the finding of the research reveals that access to credit leads to lower productivity. This indicates that the provision of credit may not be demand driven in some rural areas of the country or may be provided to the purpose of other agricultural activities.

Regarding village level characteristics, farm households that are more remote from the *woreda* market are less likely to be empowered. As walking time to *woreda* market increases, farm households are less likely to be in the higher satisfaction level and to produce higher value crops. This suggests that the decision on what to produce and the degree of participation, is highly influenced by access to market. Since vegetables and perennials (such as chat, avocado and banana) are easily perishable items, the magnitude of the benefit gained depends heavily on market access. On the other hand, irrigation sites located nearby the *woreda* market have lower quality of irrigation infrastructure, suggesting that better market access may tend to undermine individuals' incentives to be engaged in other irrigation activities by increasing the opportunity cost of labour.

The results reveal that most farm level characteristics affect empowerment of irrigation beneficiaries. Contrary to the hypothesis given, it is noted that the size of the irrigated land holding and a decision to produce high value crops have a 'U'-shaped relationship. As expected, soil fertility and all empowerment measurement indicators have a positive association. Having fertile soil increases the likelihood of being at a higher satisfaction level, having higher quality of irrigation infrastructure and producing high value crops. This result underscores the fundamental role soil fertility plays in the performance of irrigated agriculture. Slope of the parcel is also included in the analysis. If the land is flat, it decreases the likelihood of being at higher satisfaction level, having quality of irrigation infrastructure and producing marketable crops. This result is not surprising, because less steep farms are more vulnerable to water logging and water salinity. Plots with soil and water conservation practices are more likely to have lower quality of irrigation infrastructure, suggesting that the effort put for maintenance of irrigation structures is replaced by investments in other land management practices. Similarly, plots that are remote from irrigation water sources have lower quality of irrigation structure.

Table 4. 6. Determinants of individual irrigators' empowerment

	Farmers' level of satisfaction		Quality of infrastructure		Whether high value crops produced		Onion yield	
	Coef	SE	Coef	SE	dF/dx	SE	Coef	SE
Household Human capital								
Gender of the household head, 1= male, 0= otherwise	-0.035	0.155	0.063	0.138	0.012	0.044	16.136***	6.102
Age of the household head (in years)	0.012**	0.003	0.004	0.003	-0.002**	0.001	-0.018	0.207
Education level of the household head (in years)	-0.004	0.007	0.015**	0.008	0.002	0.002	-0.372	0.326
Family size (in number)	-0.026	0.019	0.01	0.021	0.009*	0.005	0.086	1.112
Years of experience in using irrigation water	-0.002	0.006	-0.009*	0.006	7.43E-05	0.002	-0.16	0.337
Number of trainings participated in 2015/16	0.019	0.018	0.038**	0.015	-0.003	0.005	0.083*	0.04
Frequency of contact to extension worker in 2015/16	-0.0005	0.001	0.001	0.001	0.001	0.0003	-0.056***	0.019
Household physical capital								
Livestock ownership (in TLU)	-0.002	0.005	1.00E+01	0.006	0.0003	0.002	-0.373	0.368
Total farm size	-0.017*	0.013	0.004	0.008	0.005	0.004	-0.782**	0.302
Household social capital								
Participation in labour sharing activity	-0.227**	0.1	0.149	0.117	-0.061**	0.031	2.884	3.664
Household financial capital								
Access to credit	0.104	0.097	0.096	0.108	-0.037	0.028	-12.63***	4.773
Village level characteristics								
Access to woreda market(walking time in min, one way)	-0.003**	0.001	0.002*	0.002	-0.001***	0.0004	-0.064	0.071
Whether there was adverse weather condition in 2015/16	-0.021	0.085	-0.211*	0.113	-0.004	0.027	4.068	4.334
Plot characteristics								
Irrigation plot size (in ha)	0.023	0.21	-0.243	0.26	-0.47***	0.1	1.137	7.53
Irrigation plot size squared	-0.021	0.044	0.077	0.116	0.225***	0.073	-1.046	1.485
1= the plot is loamy	0.279***	0.105	0.204*	0.11	0.062**	0.03	-1.555	4.79
1=If the slope is perceived flat	-0.202*	0.153	-0.53***	0.159	-0.074**	0.025	-0.198	5.345
1=If the plot was certified	0.411***	0.118	-0.168	0.119	0.039	0.034	-2.43	6.657
Distance to the farm household residence	-7.4E-05	0.002	-0.002	0.002	0.001	0.001	-0.035	0.057
Distance to the irrigation water source	0.006	0.023	-0.054**	0.024	-0.002	0.006	0.029	0.829
If S & W conservation had been practiced	-0.059	0.081	-0.183**	0.092	0.006	0.024	2.374	3.607
Whether improved seed was used	-0.041	0.089	0.31***	0.099	0.006	0.026	4.852	5.756
If fertilizer was used	0.367***	0.096	0.277***	0.104	-0.047	0.028	0.61***	0.19
Scheme Characteristics								
Irrigation water management system+ lifting technology dummy	dummy, cf., open access +pump		dummy, cf., Joint+pump		dummy, cf., farmers managed +gravity		dummy, cf., open access +pump	
Private+pump	1.190***	0.382	-0.523**	0.248	0.030***	3.79	26.197**	12.541
Farmers+pump	0.832**	0.368	-0.467*	0.266	0.056*	-1.38	27.916**	10.671
Farmers+gravity	0.738**	0.372	-0.330**	0.134			5.453	8.387
Joint+pump	1.410***	0.391			0.064**	-2.39	27.817**	11.44
Joint+gravity	0.784**	0.371	0.03	0.306	0.035	-0.51	2.766	9.307
Open+pump					0.033***	3.06		

Note: *, ** and *** indicate statistical significant at 10%, 5% and 1%, respectively.

Table 4.6. Continued

	Farmers' level of satisfaction		Quality of infrastructure		Whether high value crops produced		Onion yield	
	Coef	SE	Coef	SE	dF/dx	SE	Coef	SE
Irrigation water source structure, dummy, cf; ground water								
Surface water	-0.306**	0.134	0.032	0.19	-0.12***	0.044	20.095**	9.494
Irrigation water application mechanism on the plot, dummy, cf; flooding								
Furrow	0.039	0.163	0.152	0.179	0.086**	0.028	2.021	6.114
sprinkler/drip	-0.091	0.089	0.038	0.027	0.35***	0.094	0.833	6.586
Biophysical and climate variables								
Meher precipitation anomaly	1.665***	0.554	1.379**	0.599	-0.079	0.121	23.194	24.621
Belg precipitation anomaly	0.801***	0.293	0.353	0.286	-0.139*	0.084	50.45***	15.088
Temperature anomaly	-0.299	0.388	-0.095	0.442	0.305***	0.119	15.197	16.033
Meher precipitation coefficient of variation	-0.077**	0.038	8.32E-05	0.042	-0.008	0.01	-2.313	2.169
Belg precipitation coefficient of variation	-0.18***	0.05	-0.035	0.065	-0.005	0.014	-7.709***	2.929
Meher mean total precipitation	0.005***	0.001	0.002	0.002	5.09E-05	0.0004	0.045	0.045
Belg Mean total precipitation	0.010***	0.003	0.005	0.003	-0.001	0.001	-0.266**	0.129
Mean annual temperature	-0.127	0.187	0.426**	0.211	0.016	0.051	5.086	7.563
Elevation	0.010***	0.002	-0.001	0.003	0.002**	0.001	-0.128	0.141
Elevation squared	-2.81E-06 ***	6.33E-07	3.06E-08	8.64E-07	-3.55E-07 *	1.81E-07	3.29E-05	3.94E-05
Constant							302.789**	150.472
/cut1	5.371	3.431	3.726	4.132				
/cut2	5.971	3.437	4.743	4.128				
/cut3	6.921	3.434	5.245	4.13				
/cut4	7.76	3.436	6.481	4.129				
No. of observation/plots	1021		887		1021		186	

Source: Author's estimation using own survey data
Note: *, ** and *** indicate statistical significant at 10%, 5% and 1%, respectively.

Improved seeds and fertilizer use have a significant positive effect on empowerment of farm households. The use of chemical fertilizer increases the likelihood of being at a higher satisfaction level and having higher quality of irrigation infrastructure. It also leads to increased yield. Our result supports previous studies that confirm the critical role played by improved inputs in the overall performance of irrigated agriculture.

Regarding scheme level factors, our evidence points out consistently that compared to open access pump irrigators, all other farmers are more likely to be in a higher satisfaction category. Irrigators with pump irrigation technologies in either of the management systems score higher onion yield as well. These results indicate the implications of open resource use on the performance of irrigated agriculture, particularly on flexibility, reliability, efficiency and on equitable water allocation and delivery. Compared to jointly managed pump irrigation schemes, all other irrigation sites have lower quality of irrigation structure. This result is not surprising because jointly managed irrigation schemes tend to have more modern structures that were constructed and later are manged by a government agency at higher level.

The study also found that compared to plots located in farmer-managed canal irrigation systems, all other plots are positively associated with producing marketable crops, indicating the unreliability of irrigation water supply in farmer-managed canal irrigation system. This is in line with the result of FGD with irrigators in farmer-managed irrigation systems. Due to high number of irrigation users and the traditional irrigation structures, there has been limited water supply during irrigation seasons. The study found that farms that are irrigated from surface sources are less likely to be in the higher satisfaction category and to grow marketable crops, whereas they are more likely to have high onion yield. The result of the study provides evidence that plots with pressurized irrigation system (drip and sprinkler) and furrow irrigation water conveyance systems are more likely to grow vegetables and perennials crops than irrigated areas with flood irrigation.

With respect to climate variables, the findings reveal that plots located in areas where there is rising precipitation overtime and higher annual rainfall with less variability are associated with higher satisfaction level of farmers in management and use of irrigation water. Moreover, plots which are found in areas with rising *Belg* rainfall overtime and lower variability of rainfall have higher onion yield. These results are contrary to the hypothesis provided in the previous section. The result points out that farmers who are facing more reliable rainfall patterns in both seasons are more empowered. The findings highlight the effect of consistent and reliable rainfall patterns during both rainy seasons on frequency and amount of irrigation water distribution, that in turn, influences the degree of participation and decision-making capacity of farm households in the management and use of the natural resource.

4.5.2. Factors influencing collective empowerment in the case of farmer only and jointly managed irrigation systems

Devolving rights to local communities to manage resources, establish use rules and regulations, and the mechanisms to enforce the rules have the central goal of strengthening the rights, capabilities, and governance of local communities. In this sub-section, factors which influence collective empowerment of irrigation beneficiaries and their irrigation governance structure are analysed. Only farmer and jointly (farmer and government agency) managed irrigation schemes are included, since they have a character of a common pool resource. Table 4.7 presents the econometrics results.

The results suggest that household-level characteristics affect collective empowerment of irrigation beneficiaries and their irrigation governance structure. Plots with female-headed households are more likely to have less conflict with their irrigated neighbours and to be a formal member of WUAs than male-headed households. This is perhaps due to their preference to solve their irrigation-related problems through informal discussions and to abide by the rules and regulation and to avoid free-riding. Larger family size leads to higher level of collective empowerment. This means households with large average family size made contributions at the initial establishment of the irrigation scheme; contribute to annual O&M of the scheme; and are formal members of WUAs. This is likely due to the higher relative availability of family labour that enables households to participate in several collective activities of irrigation water use and management. Thus, the availability of manpower is a fundamental factor for the greater collective empowerment of irrigation beneficiaries and supports governance of irrigation systems. Having more years of irrigation experience correlates positively with contributing to O&M and with being a member of a WUA, indicating that over time beneficiary farmers have realized the benefit of abiding by the rules and regulations of WUAs. This likely explains why older households are less likely to have conflict with their irrigation neighbour(s). The education level of household heads and contact with extension workers increase the likelihood of contributing to the establishment as well as the day-to-day O&M of the system they are in, whereas it decreases the likelihood of conflict occurrence with an irrigating neighbour(s). Moreover, a positive association is also observed between the number of trainings and attendance in WUAs' meetings. These findings imply that human capital and access to extension services support collective empowerment of irrigators and irrigation governance. Thus, provision of training, capacity-building and access to information by both governmental and non-governmental organizations will have a positive impact on enforcing use rules, active participation of users and strengthening the governance system.

Wealth measurement indicators are also important determinants of collective empowerment. While having a higher number of livestock increases the probability of contributing to the establishment of the system, both asset ownership indicators (total agricultural land holding and TLU) are associated with a reduced likelihood of contributing to the day- to-day O&M of the irrigation system and with increased likelihood of having conflict with irrigation neighbour(s). Perhaps the focus on the non-farm activities of farmers with higher asset ownership shapes these outcomes.

As expected, the social capital variable, which in this case is proxied by participation in labour-sharing arrangements, has a positive correlation with most indicators of empowerment. This indicates the role social capital can play in strengthening local governance structures of irrigation systems, by lowering transaction cost via trust and offering access to information through networks of contacts. This implies that an emphasis should be given to the support of local institutions such as the labour-sharing arrangements of *Debo* and *Wenfel*. Surprisingly, farm households who have access to credit are less likely to contribute to the initial stage of the irrigation schemes and to be formal member of WUAs.

Access to *woreda* markets has a significant effect on collective empowerment. Irrigators whose farms are more remote made greater initial contributions for the establishment of the irrigation infrastructure. However, they are less likely to be registered as formal members of WUAs, more likely to participate in meetings of WUAs and experience a higher probability of conflict occurrence. It indicates that even if irrigation beneficiaries who are closer to the *woreda* market did not contribute to the initial establishment of the infrastructure, once it is developed, they are most likely to participate in and scramble for the maximization of their benefit from irrigation water use, whereas the lower rate of meeting attendance may be due to the high opportunity cost of labour associated with a closeness to markets and other income opportunities.

The occurrence of adverse weather conditions is positively associated with conflict occurrence. Possibly, it is due to the high demand of less available irrigation water in times of extreme weather events and climate variability which is common in most regions of the country. Ethiopia has been experiencing climate change and extreme weather events such as frequent drought and floods, increased temperature, and erratic rainfall since the 1980s (FDRE, 2015).

Unlike the results from the previous section, only few plot-level variables influence collective empowerment. The study found that the occurrence of conflict is negatively associated with the size of irrigated land holding, but positively associated with irrigated land size squared. This finding suggests a 'U'-shaped relationship between size of irrigation land holding and conflict occurrence. The possible reason could be that as the size of irrigated land holding increases, conflicts may decline; however, as the irrigation land size increases further, the supply of irrigation water may not be sufficient, increasing the likelihood of conflict. This finding suggests that for households with larger irrigated farm size and more capital, the better option could be privately managed micro-irrigation which uses less water per unit of output.

Another important plot-level variable which has a positive and statistically significant association with collective local empowerment is land tenure security which is captured with plot tenure status (whether certified or not). The result suggests that formal titling of land encourages long-term investments by contributing at the initial development of the irrigation scheme, contributing to the smooth flow of irrigation water, being a formal member of a WUA and attending WUA meetings. Given the benefits from investing in irrigation infrastructures and management accrue overtime, the result highlights the importance of property rights in strengthening the participation of users and irrigation governance.

Compared with user-managed gravity systems, plots that are in farmer-managed pump irrigation systems and jointly managed irrigation schemes are negatively associated with household's initial contribution for the establishment of the irrigation scheme and day-to-day O&M of the system. In user-managed irrigation systems, it is the farmers who are in charge from the inception to the construction and implementation of schemes as well as of the distribution and utilization of irrigation water. On the other hand, compared with user-managed gravity systems, all other irrigators are more likely to be formal members of WUAs. Particularly, jointly managed pump irrigators are less likely to have conflict and more likely to have a high rate of meeting attendance. The negative correlation between being in jointly managed irrigation systems and contributing at the initial establishment and for the day-to-day O&M of the irrigation system indicates that the need for households to contribute to the development and O&M of the irrigation schemes is replaced by the payment made by external organizations such as governmental organizations and development partners.

This finding suggests, on one hand, that user-led irrigation enables beneficiaries to be engaged in different levels of activities starting from construction to allocation and management of the system which enhances farmers' sense of belongingness to the system. This has a high impact on strengthening the governance structure of the irrigation system. However, intervention is needed to include all the beneficiaries in WUAs. Especially, gravity irrigation users face the provision and appropriation problems usually associated with collective action arrangements of irrigation water use. The problem of provision arises in arranging the construction and maintenance of canals, while appropriation arises in water distribution. Hence, to enhance the collective empowerment of irrigation, users' membership should be compulsory, and members should have full knowledge of their rights and obligations. Otherwise, it makes the decision-making processes and the enforcement of rules and regulations for water use difficult to implement. It also creates opportunities for free riders which has immense impact on the sustainable use, management, and conservation of the irrigation system and the natural resource base in general. On the other hand, jointly managed pump irrigation schemes that are powered by petrol, diesel, or electricity, most of the time the expenses are covered by external organizations (governmental agencies or development partners). This indicates that there is still a heavy dependence of some irrigation schemes on external organizations for the management of the resource. Efforts should be exerted to enhance the self-sufficiency of irrigators in building their capacity and improve their access and utilization of irrigation water. Otherwise, the issue of sustainability will be compromised.
Consistent with the above results, using surface irrigation water sources, increases the likelihood of contributing at the initial stage as well as for the O&M of the systems, and for being a member of a WUA. Furthermore, those who apply sprinkler/drip irrigation experience fewer conflicts. This is possibly because of one of the advantages of using

sprinkler/drip irrigation is higher water-use efficiency which can reduce conflicts arising from illegal water diversions. Even in gravity systems, soil water monitoring tools such as wetting front detectors and chameleon soil moisture sensors are found to be promising in promoting efficient and equitable water use in other parts of Africa (Abebe et al., 2020; Chilundo et al., 2020; Mdemu et al., 2020; Parry et al., 2020; Pittock et al., 2020), a lesson that can be brought to improve gravity systems in Ethiopia. Thus, an emphasis should be given to build the capacity of irrigators on the application of irrigation water on their fields.

Most of the climate variables are significantly and positively associated with the decision to contribute at the initial stage of irrigation system development rather than influencing other indicators of collective empowerment. The initial contribution is more likely in areas with declining *Meher* rainfall overtime, increasing *Belg* rainfall variability and lower annual *Meher* precipitation and annual average temperature. This result is consistent with the hypothesis given, which was stated as long-term decline in precipitation and increasing rainfall variability will lead to higher participation of farmers. This highlights that farmers have participated in the establishment of irrigation schemes by considering irrigation as a risk-decreasing strategy in response to declining and erratic rainfall. Similarly, the occurrence of conflict is significantly and positively associated with rising temperature over time, higher variability in *Belg* precipitation, and higher mean annual temperature. This implies that rising temperature and change in rainfall patterns result in water scarcity for irrigation, which aggravates the incidence of conflicts that leads to less collective empowerment. Thus, our evidence indeed depicts there is a correlation between climate change and conflict occurrence in irrigation schemes.

Another relevant biophysical variable that has mixed effects on collective local empowerment is the location of the household with respect to altitude (elevation). The initial contribution of farmers for the establishment of the scheme has a positive association with elevation and a negative association with elevation squared. On the other hand, the relation of elevation to the contribution for O&M and being a member of WUA is 'U'-shaped, where the linear coefficients are negative and the quadratic term coefficients are positive. Possibly, as altitude increases, water availability and moisture increase as well. Consequently, households would be encouraged to contribute to the establishment of irrigation schemes. However, due to the higher agricultural potential of higher altitude areas, the return from rain-fed agriculture would be more attractive as well, eventually making irrigation a less interesting activity.

Table 4. 7. Determinants of collective irrigation beneficiary farm households' empowerment

Explanatory variables	If contributed at the initial stage (dF/dx)	Whether contributes for O & M in labour (dF/dx)	If the household is formal member of WUA (dF/dx)	Whether conflict occurred (dF/dx)	Meeting attendance (ordered probit)
Household human capital					
If the household head is male	0.036 (0.08)	-0.108 (0.075)	-0.103* (0.04)	0.1*** (0.028)	-0.099 (0.112)
Age of the household head (in years)	0.003 (0.002)	.0002 (0.002)	-0.002 (0.001)	-0.003*** (0.001)	0.004 (0.003)
Education level of the household head (in years)	0.010** (0.005)	0.007* (0.004)	0.005 (0.004)	-0.008*** (0.002)	-0.009 (0.007)
Family size, (in number)	0.026** (0.013)	0.031** (0.012)	0.03*** (0.006)	0.014** (0.006)	-0.04** (0.018)
Years of experience in using irrigation water	0.003 (0.003)	0.009*** (0.003)	0.013*** (0.003)	0.003 (0.001)	-0.001 (0.004)
Number of training attended in 2015/16	-0.018** (0.009)	0.008 (0.009)	0.006 (0.008)	-0.00005 (0.006)	0.069*** (0.014)
Frequency of contact to extension worker in 2015/16	0.002*** (0.001)	0.002** (0.001)	0.0003 (0.0003)	0.0008*** (0.0003)	-0.001 (0.001)
Household physical capital					
Livestock ownership (in TLU)	0.017*** (0.003)	-0.002** (0.001)	-0.002 (0.003)	0.005** (0.002)	0.004 (0.006)
Total farm size	0.004 (0.007)	-0.015*** (0.004)	0.014*** (0.003)	0.005** (0.003)	0.004 (0.007)
Household social capital					
Participation in labour sharing activity	0.229*** (0.059)	0.095* (0.056)	0.036 (0.032)	-0.034 (0.03)	0.218** (0.096)
Household financial capital					
Access to credit	-0.137** (0.058)	-0.031 (0.06)	-0.084** (0.039)	-0.044 (0.032)	-0.08 (0.094)
Village level characteristics					
Access to *woreda* market (walking time in min, one way)	0.002*** (0.001)	-0.0001 (0.001)	-0.002*** (0.0005)	0.001** (0.0004)	0.004*** (0.001)
Whether there was adverse weather condition in 2015/16	-0.092 (0.057)	0.045 (0.057)	-0.008 (0.035)	0.075** (0.032)	0.07 (0.088)
Farm level characteristics					
Irrigation plot size	-0.26 (0.233)	-0.302 (0.217)	0.004 (0.079)	-0.141* (0.078)	0.3 (0.197)
Irrigation plot size squared	0.310* (0.178)	0.179 (0.162)	0.013 (0.017)	0.087** (0.039)	-0.01 (0.053)
If the soil type is loamy	0.059 (0.064)	0.06 (0.064)	-0.014 (0.037)	0.025 (0.034)	-0.03 (0.095)
If the plot is perceived flat	0.221*** (0.066)	-0.092 (0.068)	-0.003 (0.07)	-0.013 (0.049)	0.095 (0.116)
If the plot had been certified	0.165** (0.065)	0.28*** (0.052)	0.109** (0.051)	0.078** (0.028)	0.292*** (0.105)
Distance to the farm household residence	0.002* (0.001)	-0.001 (0.001)	-0.001 (0.001)	0.001 (0.001)	-0.002 (0.002)
Distance to the irrigation water source	-0.018 (0.014)	-0.012 (0.014)	-0.005 (0.009)	-0.005 (0.007)	8.34E-05 (0.02)
If S & W conservation practiced	-0.042 (0.051)	0.106** (0.048)	0.004 (0.03)	-0.044 (0.027)	-0.168** (0.078)
Whether improved seed used	-0.055 (0.056)	0.012 (0.053)	-0.012 (0.033)	0.033 (0.03)	0.037 (0.09)
Fertilizer used (kg)	0.004 (0.059)	0.082 (0.058)	-0.058 (0.036)	-0.078** (0.036)	-0.071 (0.095)

Note: *, ** and *** indicate statistical significance at 10%, 5% and 1%, respectively. Standard errors in parenthesis

Table 4.7 Continued

Explanatory variables	If contri-buted at the initial stage (dF/dx)	Whether contributes for O & M in labour (dF/dx)	If the household is formal member of WUA (dF/dx)	Whether conflict occurred (dF/dx)	Meeting attendance (ordered probit)
Scheme Characteristics					
Water management system+ irrigation lifting technologies dummy, cf., farmers+ gravity					
Farmer+pump	-0.188* (0.098)	-0.246** (0.103)	0.102** (0.036)	0.032 (0.062)	0.242 (0.198)
Joint+pump	-0.18 (0.131)	-0.46*** (0.094)	0.183*** (0.025)	-0.279*** (0.105)	0.439** (0.18)
Joint+gravity	-0.34*** (0.055)	-0.31*** (0.057)	0.097** (0.04)	-0.042 (0.034)	-0.051 (0.088)
Irrigation water source structure, dummy, cf; ground water					
Surface water	0.168* (0.09)	0.22*** (0.079)	0.350*** (0.045)	0.15*** (0.035)	-0.06 (0.1)
Irrigation water application mechanism on the plot , dummy, cf; flooding					
Furrow	0.169 (0.124)	-0.055 (0.104)	0.079* (0.041)	0.08 (0.065)	-0.596*** (0.145)
sprinkler/drip	0.009 (0.059)	0.092 (0.056)	-0.038 (0.034)	-0.087*** (0.033)	-0.039 (0.097)
Biophysical and climate variables					
Meher precipitation anomaly	-0.542* (0.281)	-0.559* (0.303)	0.307* (0.172)	-0.219 (0.144)	0.039 (0.343)
Belg precipitation anomaly	-0.019 (0.169)	-0.112 (0.164)	0.024 (0.104)	-0.114 (0.088)	0.625*** (0.232)
Temperature anomaly	-0.379 (0.247)	0.273 (0.23)	-0.369** (0.162)	0.429*** (0.158)	0.463 (0.385)
Meher precipitation coefficient of variation	0.021 (0.022)	-0.006 (0.021)	-0.04*** (0.013)	0.001 (0.011)	0.099*** (0.029)
Belg precipitation coefficient of variation	0.138*** (0.035)	-0.044 (0.034)	0.004 (0.02)	0.040** (0.017)	-0.06 (0.042)
Meher mean total precipitation	-0.004*** (0.001)	0.001 (0.001)	-0.0004 (0.001)	-0.0001 (0.001)	0.002 (0.001)
Belg Mean total precipitation	0.003 (0.002)	-0.003* (0.002)	0.00004 (0.001)	-0.001 (0.001)	-0.003 (0.003)
Mean annual temperature	-0.274** (0.112)	0.141 (0.106)	0.057 (0.061)	0.184** (0.07)	-0.143 (0.156)
Elevation	0.003* (0.002)	-0.007*** (0.002)	-0.002** (0.001)	0.001 (0.001)	0.003 (0.002)
Elevation squared	-8.00E-07* (4.48E-07)	1.88E-06*** (4.63E-07)	5.67E-07** (2.80E-07)	-0.0001 (2.36E-07)	-8.06E-07 (5.82E-07)
/cut1					2.66(5.83)
/cut2					3.4(5.83)
/cut3					4.42(5.83)
/cut4					4.64(5.83)
Pseudo R2	0.5058	0.6472	0.4689	0.3115	0.1317
No. of observation/plots	719	719	719	719	719

Source: Author's estimation using own survey data
Note: *, ** and *** indicate statistical significant at 10%, 5% and 1%, respectively. Standard errors in parenthesis

4.6. Conclusion and Policy Implications

For the past three decades, institutional changes in transferring responsibility for managing irrigation water to local administrations and farmer groups have been implemented in Ethiopia. Generally, the government has accepted the central role that participation and empowerment of local communities can play in equitable benefit sharing among users, developing a sense of ownership and belongingness, and efficient use, management, and conservation of the resource base. However, the body of empirical literature on the role played by local level institutions and organizations on empowerment of local users in use and management of natural resources in general and in irrigation management in particular is very limited. Using econometric methods, this study analyses the effect of multiple scales of irrigation water management systems and complementary irrigation technologies, among the many variables, that affect empowerment. The analysis uses a unique household and plot-level survey conducted in ten districts of Ethiopia in 2016/17.

The findings of the study point out consistently that compared to openly accessed pump irrigators, all other farmers are more likely to experience satisfaction with water control, allocation and delivery mechanisms. Irrigators with pump irrigation technologies in either of the management systems obtain higher onion yield as well. These results indicate the implications of open resource use on the performance of irrigated agriculture and empowerment of irrigation beneficiaries, particularly on flexibility, reliability, efficiency and on equitable water allocation and delivery. Compared to jointly managed pump irrigation schemes, all other irrigation sites have lower quality of irrigation structure. The study also found that compared to plots located in farmer-managed canal irrigation systems, all other plots are positively associated with producing marketable crops, indicating the unreliability of irrigation water supply in farmer-managed canal irrigation system.

The results also show that irrigators who are in farmer-led irrigation systems and apply gravity technology are positively associated with initial contribution of households at the establishment of the irrigation scheme and day-to-day operation and maintenance of the system. This supports the governance structure of the irrigation system. On the other hand, compared to user-managed gravity systems, all other irrigators are more likely to be formal members of WUAs. This suggests that intervention is needed to include all the beneficiaries in WUAs as a member in farmer-led irrigation system. Membership should be compulsory, and members should have full knowledge of their rights and obligations. Otherwise, it makes the decision-making processes and the enforcements of rules and regulations for water use very difficult to implement by creating opportunities for free riders with potential adverse impacts on the sustainability of use, management and conservation of the irrigation system and the natural resource base in general. In addition, rehabilitation of irrigation infrastructure is needed in farmer-led traditional irrigation schemes that cause unreliable and inefficient water provision. On the other hand, in jointly managed pump irrigation systems, most of O &M expenses are covered by external organizations. This indicates that there still exists heavy dependence of some irrigation schemes on external organizations in the management of the resource. Efforts should be exerted to enhance the self-sufficiency of irrigators by building their capacity to how to use and manage the scheme and strength the local governance structure by ensuring limited government interference, otherwise, the issue of sustainably will be compromised.

Furthermore, irrigators who apply sprinkler/drip irrigation are more likely to be empowered. This is possibly because one of the advantages of this kind of application method is to improve water use efficiency which can reduce conflict from illegal water diversions. Thus, while emphasizing on the promotion and expansion of irrigation technologies, intervention is needed to secure credit for and build the capacity for advanced irrigation technologies.

The results also indicate that the degree of participation, decision-making and strength of local irrigation governance are affected by several policy relevant socio-economic and biophysical factors. The results on the effect of plot access (spatial plot distance from home, to the nearest woreda market), plot size and tenure security on individual as well as collective empowerment can be used as inputs in Ethiopia's irrigation land redistribution and land certification policy process. Moreover, the significant role of social capital and networks on collective empowerment suggests the need for establishing and strengthening of irrigation as well as other local institutions and extension systems to sustain use, management, and conservation of irrigation water. In a country where there is information asymmetry and both input and output markets are incomplete, local institutions can play a fundamental role in providing farmers with timely information and technical assistance. The evidence also supports other literature on the role played by improved inputs in the process of individual empowerment of using irrigation water. This suggests that the need of on time and reliable provision of improved inputs such as fertilizer is one component in the general performance of irrigation agriculture. They have significantly positive effect on empowerment of farm households.

Household level characteristics are also important factors for empowerment. Female headed households are more likely to have less conflict with their irrigating neighbours and to be a formal member of WUAs than male headed households. This is perhaps due to their preference to solve their irrigation related problems through informal discussions and to abide by the rules and regulation and to avoid free riding. This suggests that policy interventions are needed to encourage the participation of women at farm, associations, and leadership level of WUA and conflict resolution committees. The result of the study also demonstrates that the number of trainings on crop agriculture and natural resources management is positively and significantly correlated with onion productivity. Thus, provision of training, capacity building and access to information by both governmental and non-governmental organizations can support use rules, efficient utilization of irrigation water and generally, to improvement of livelihoods. However, the productivity of those households who make frequent contact to extension worker is low. This suggests that it is the quality of extension services, not just the contact with extension agents, that is important for yield improvement.

In the analysis of collective empowerment, most of the climate variables significantly and positively affect the decision to contribute at initial stage of irrigation system development rather than influencing other indicators of collective empowerment. This result highlights the role of climate variables in the decision to participate at the initial establishment of irrigation schemes. Farmers' initial contribution is more likely to be implemented in areas where there is declining *Meher* rainfall overtime, higher *Belg* rainfall variability and lower annual *Meher* precipitation. This underscores that farmers have participated in establishment of irrigation system by considering irrigation as a risk-decreasing strategy in response to declining and erratic rainfall for the purpose of building their resilience to climate change and variability. Similarly, the occurrence of conflict is significantly and positively associated with rising temperature overtime, higher *Belg* precipitation variability and high mean annual temperature. This implies that rising temperature and changes in rainfall pattern result in water scarcity for irrigation which aggravates the incidence of conflicts. Thus, our evidence indeed depicts there is a correlation between climate change and conflict occurrence in irrigation schemes. Therefore, intervention is needed to raise awareness of water efficient technologies for farmers who are in those sites that are experiencing climate change and weather extreme events.

5. THE EFFECT OF IRRIGATION MANAGEMENT SYSTEMS AND TECHNOLOGIES ON ENVIRONMENTAL SUSUTAINABILITY: EMPIRICAL EVIDENCE FROM ETHIOPIA

5.1. Introduction

Sub-Saharan African countries are trying to improve the sustainability of agriculture and land management within the context of severe poverty and food insecurity (Gebremedhin & Swinton, 2003; Nkonya et al., 2008). Vicious circles of poverty and land degradation coupled with transmission effects from rural poverty and food insecurity to macro economies, crucially impede the development process (von Braun et al., 2013). It has been recognized that with the land frontier for further agricultural expansion shrinking, future growth in agriculture will increasingly have to come from improvements in productivity and resource use efficiency rather than from area expansion (Eicher, 1995; FAO, 2017; Otsuka & Larson, 2012). Thus, innovative systems that protect and enhance the natural resource base, while increasing productivity have been fundamental requirements for sustainability (von Braun, 2014).

Irrigation projects in Ethiopia have several adverse environmental impacts that have threatened the sustainable production of agricultural goods, which is of major importance and interest in Ethiopia, since agriculture contributes 35 percent to Ethiopia's GDP employs 70 percent of the labour force and provides a livelihood to 80 percent of the more than 100 million people (NBS 2017/18). Despite efforts by the government and development partners, water management in medium and larger-scale irrigated areas is hampered by institutional, technological, capacity and market constraints (Awulachew et al., 2010). Most of the irrigation schemes in the country are in the arid and semi-arid lowlands of major river basins (Ruffeis et al., 2007). The challenge of sustainable irrigation is more substantial in these regions, where large production areas are impacts by soil salinity, inadequate subsurface drainage, and waterlogging (Wichelns & Qadir, 2015). In addition to soil quality degradation, Loiskandl et al. (2008) and Amdihun (2008) discussed the negative environmental impacts from land use change, including deforestation, and water quality deterioration in downstream areas. The increasing removal of vegetation cover from the areas surrounding irrigation systems results in high soil erosion and sediment transportation which, in turn, affect irrigation canals. Siltation of canals has been severe in some schemes. On the other hand, studies by Girma & Awulachew (2007) pointed out that after the establishment of some medium and large-scale irrigation schemes in Ethiopia, tree coverage increased compared to coverage in nearby rainfed villages. As a result, the surrounding microclimate has been improved.

While the potential benefits of irrigation are vast and multi-dimensional, the actual achievement in many irrigated areas of the country is substantially less than the potential due to poor water management leading to waterlogging, salinity, acidity, soil erosion, sedimentation, and related problems (Umali, 1993; Hordofa et al., 2008; Wallner, 2006; Ruffeis et al., 2007; Ulsido & Alemu, 2014; Gebrehiwot, 2018). Even before the fast expansion of irrigation in the last two decades, Tadesse (2001) reported that there are nearly 12 million ha of salt-affected soils in eastern and southern Ethiopia. In the Middle and Lower Awash Valley, development of large irrigation projects without appropriate water management systems and irrigation practices (over-application of water by farmers, excessive seepage throughout the irrigation system, absence of or inadequacy of drainage infrastructure) have led to secondary salinization (Taddese, 2001; Girma, 2005, Abebe et al., 2015). If practices do not improve, the problems may outweigh the benefits of irrigation projects.

Thus, in order to combat land degradation due to poor irrigation management, the promotion of various kinds of sustainable land management (SLM) practices has been suggested (Nkonya et al., 2016), with additional benefits in terms of several other sustainable development goals (SDGs), such as poverty eradication, zero hunger, and attainment of climate and biodiversity protection targets.

Investment in SLM practices both to revert already degraded lands to productive uses and to proactively reduce future land degradation are important for sustainable irrigation development, management, and use. This is particularly true in Ethiopia, where the government considers irrigated agriculture as a primary engine of economic growth and has made investments to increase the irrigated land through rainwater harvesting as well as small, medium, and large-scale irrigation schemes. Most available empirical studies regarding sustainable land management in Ethiopia have concentrated on the social, economic, institutional, and biophysical factors that affect adoption of SLM technologies by small-scale farmers (Gebremedhin & Swinton, 2003; Holden et al., 2004; Anley et al., 2006; Kassie et al., 2009; Tekelewold et al., 2013; Teshome et al., 2014; Gebreselassie et al., 2016); on the impacts of Soil and Water Conservation (SWC) technologies on crop production in the Ethiopian highlands (Pender et al., 2001; Pender & Gebremedhin, 2007; Kassie et al., 2008a; 2010; Tekelewold et al., 2013; 2019; Schmidt & Tadesse, 2019); on the contribution of SLM technologies to water security for both crop and livestock production (Kato et. al., 2019); on the impacts of SWC technologies on agricultural production risk (Kassie et. al., 2008b; Yesuf et. al., 2009; Kato et al., 2011), and on climate resilience (Tekelewold et al., 2017). These earlier works are all focused on rainfed agriculture, with SLM issues in irrigated agriculture being given very limited attention so far.

This study contributes to the literature by focusing on SLM in irrigated systems, considering how differences in irrigation water management and technology choice affect adoption of sustainable land management practices. Thus, this chapter asks two inter-related questions. First, what are the potential environmental impacts of using irrigation? Second, does the combined effect of irrigation water management systems and complementary technologies have effect on the adoption of SLM practices? Understanding the nature of changes in environmental conditions and possible strategies to overcome land degradation problems is important for policy makers and other key actors involved in designing and implementing policies that could stimulate sustainable irrigation agriculture all over the country.

The chapter is organized as follows: Section 5.2 provides the theoretical framework for our hypotheses. Section 5.3 describes the data employed. Section 5.4 discusses the method of analysis utilized, followed by section 5.5 which presents the result obtained from descriptive, NDVI and econometrics analysis. Section 5.6 concludes the chapter with a summary and discussion of policy implications of the study.

5.2. Conceptual basis and hypotheses

Improved access to agricultural water supply has multi-dimensional direct as well as indirect benefits for rural households in developing countries. Benefits of access to irrigation include lower food prices, higher employment and more rapid agricultural and economic development (Stockle, 2002; Molden, 2007; World Bank, 2008; Alberto & William, 2010). The spread of irrigation has been a key factor behind the near tripling of global grain production since 1950 (Oates et al., 2015; FAO, 2017). However, irrigation and water resource developments also have negative environmental effects. Since irrigation is characterized as a modification of natural conditions of a landscape by introducing man-made structures and features to extract water from an available source adding water to fields where there was none, or little irrigation projects and irrigated agriculture practices can impact the environment and natural resources in variety of ways.

The design, construction, use and management of irrigation schemes may affect the quality of the environment in either positive or negative ways. The positive impacts include improvements in water regimes of irrigated soils, vegetation cover and microclimate, provision of use and disposal of wastewater (Holy, 1993, Dougherty & Hall, 1995). On the other hand, there is evidence that irrigated agriculture has adverse environmental impacts on natural resources (De Fraiture et al., 2010) that include changes in soil quality such as water logging, soil salinity and ecological damage which have the potential to cause loss of soil fertility and productivity in irrigates agriculture (Rosegrant et al., 2009; The Montpellier Panel, 2018).

The United Nations 1992 Rio Earth Summit defines sustainable land management (SLM) as "the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions" (UN 1993). It is expected that adoption of sustainable land management practices to be affected by factors that influence farmers' awareness of different practices; the costs, benefits, and risks of the technologies; or the availability of productive factors used for the application of the practices.

Although the focus of this study is to analyse the combined effect of irrigation water management systems and complementary technologies on the adoption of SLM practices, household level factors, village level characteristics (market access), farm level (including land tenure security) and biophysical characteristics are also hypothesized to be particularly important in determining comparative advantages of practicing the SLM technologies. The choice of explanatory variables was based on economic theory and findings from earlier studies (Pender et al. 1999; Pender and Gebremedhin, 2007; Pender et al 2001; Kato et al 2011, Teklewold et al 2018). Investments in land management technologies are expected to be correlated with irrigation size, crop type planted, biophysical factors such as soil type and slope of the plot, rainfall, temperature and NDVI.

In addition to farm and biophysical characteristics, household level factors such as access to training on natural resource management and experience of using irrigation are important factors that determine adoption of SLM practices. Contact of farmers with extension workers may help farmers to learn and gain skills related to sustainable land and water use and management. Therefore, it is expected that farmers with regular extension contact may manage irrigated plots more efficiently that may lead to more intensive adoption of land management practices.

For the past three decades, the role of local rural communities and households in irrigation water management has been increasing. The government and development partners have committed to the implementation of policy reforms that encourage irrigation management at lower level and adoption of irrigation technologies at micro and small scale to farm households. This study proposes that the type of water management system and complementary irrigation technologies in use influence the adoption and intensity of sustainable land management practices applied on irrigated farms. The central hypothesis of this study is that using privately managed and open access irrigation schemes may lead to increased mismanagement of natural resources and lower adoption of sustainable land management practices due to differences in the private and social discount rates in resource use. On the other hand, irrigation schemes that are initiated and managed by farmers can more easily adopt sustainable land management practices.

It is also assumed that jointly managed irrigation schemes have a greater incentive to use and manage the resource efficiently and invest in land management technologies, since most schemes in this kind of system are equipped with modern structures. However, it is noteworthy to mention that the performance of each agricultural activity in these kind of schemes highly depends on the relation between the agents that manage the scheme at higher level of the irrigation infrastructure and the famers that use the irrigation water with the responsibility to manage the resource at a lower level.

5.3. Data description

The dataset for this study comes from a unique cross-sectional survey customized for capturing various aspects of irrigation management and use in Ethiopia. The survey was conducted in 2016/17 in the four regions of Ethiopia: Tigray, Amhara, Oromia and Southern Nations, Nationalities, and Peoples' Region (SNNPR) covering both irrigated and rainfed farmlands. The sample is composed of 464 irrigation beneficiary farm households and their 1,037 irrigated and 1,580 rainfed plots, of which 496 were cultivated in both seasons of 2015/16. The data were collected using a multi-stage stratified random sampling method (see section 1.8). The survey data were merged with climate variables based on geo-referenced plot level latitude and longitude coordinates for the period 1981-2016 (see section 1.8).

Furthermore, using geo-referenced points from the household and plot survey, Landsat images were extracted for each plot before and after they started to use irrigation to compute a normalized difference vegetation index (NDVI) which enables us to detect changes in biomass as a result of the start-up of irrigation activities in the study areas. The Landsat series of images were acquired from NASA/ U.S. Geological Survey Earth Observation satellites space-based images of the Earth's land surface. After feeding this data to ArcGIS 10.5.1, normalized difference vegetation index (NDVI) analysis was computed to detect the spatial and temporal change of vegetation biomass before and after using irrigation in the study areas. The Landsat images produce 30m pixel resolution imagery every 16 days, in which each scene represents a snapshot on the given acquisition date. After downloading the images, the Landsat data values for the study sample plots were extracted and interpolated from the gridded time series data and GPS coordinates. Thin plate spline interpolation technique was implemented to generate the Landsat data values at each farm level, following studies by Di Falco et al., (2012) that utilize the technique to interpolate climate variables.

In addition to the above data sources, in order to enhance the validity and reliability of the survey data, qualitative information was gathered through focus group discussions and community level surveys. The qualitative information is used to augment the results of the econometrics and GIS analysis (refer to section 1.8 for details).

5.4. Method of analysis

As implied from the above discussion, the analysis in this chapter focuses on two related issues. The first part assesses both positive and negative impacts of using irrigation on the natural environment. For this, we use both descriptive as well as NDVI analysis. The second section investigates the impact of various combination of water management systems and irrigation technologies on the adoption of sustainable land management practices. Following Imbens (2000), Wooldridge (2007; 2010), and Cattaneo (2010) multivalued treatment effect approach is employed for this analysis.

5.4.1. Normalized difference vegetation index (NDVI)

This research applies GIS and remote sensing techniques in order to assess the environmental impacts of using irrigation on vegetation cover of the irrigated plots and surrounding area. The normalized difference vegetation index (NDVI) analysis is used to detect the spatial and temporal changes of vegetation biomass before and after using irrigation in the study areas. Multispectral and multitemporal satellite imagery from Landsat series of Earth Observation satellites provide time series data on vegetation characteristics such as plant greenness, vigour, biomass and leaf area index (Huete et al., 2002; van Leeuwen et al., 2010; Sesnie et al., 2011). Landsat imagery offers high spatial and temporal resolution which produces 30m pixel resolution imaginary every 16 days, in which each scene represents a snapshot on the given acquisition date. Each of these sensors produces data in the red and near-infrared (NIR) spectral regions that distinguish photosynthetically active plant material (Tucker & Sellers, 1986). The difference between two images is calculated by finding the difference between each pixel in each image and generating an image based on the result. It was designed to quantitatively evaluate vegetation growth: higher NDVI values imply more vegetation coverage, lower NDVI values imply less or non-vegetated coverage, and zero NDVI indicates rock or bare land. NDVI is calculated as follows:

$$NDVI = \frac{\rho NIR - \rho red}{\rho NIR + \rho red}$$

Where ρ represents atmospherically corrected reflectance in the NIR, red and blue spectral regions (Jensen 2007).

5.4.2. Econometric estimation strategy: Multivalued treatment effects approach

To estimate the effect of various combinations of irrigation water management systems and technologies on the number of SLM practices adopted, the multivalued treatment effects approach of Imbens (2000), Wooldridge (2007; 2010) and Cattaneo (2010) is followed. This method allows to estimate the treatment effects when there are more than two treatments among the individuals in the sample. In our case, this includes private, individual irrigators with pumps; farmer-managed pump system; farmer-managed gravity system; government and farmer jointly managed gravity system; government and farmer jointly managed pump system and individual farmers open accessing a source, such as a river or lake. The potential-outcome means (POMs) of number of technologies adopted in each alternative are computed. The analysis is implemented at plot level to capture spatial heterogeneity across irrigated plots and to minimize omitted variables bias.

As the first step to estimate the impact of adopting various combinations of water management systems and irrigation technologies on SLM, a conditional probability model is constructed to estimate the likelihood that each plot would be in each given alternative[39]. In the second step, the conditional means (the average potential outcome for the specified alternatives) of the number of sustainable land management practices applied are estimated using Inverse Probability Weighted Regression Adjustment (IPWRA) estimators (refer section 3.7 for detail). In our specification, the full list of covariates to predict alternative (treatment) status include gender, age and education level of the household head, household size, number of trainings attended, access to extension service, assets as proxies for wealth (Tropical Livestock Unit), land tenure, distance to the nearest woreda market, whether adverse weather conditions occurred, elevation, average precipitation, and coefficient of variation for both seasons (*Belg* and *Meher*), and NDVI. Multinomial logit model is used to predict treatment status as a function of the covariates and then use Poisson models to estimate the outcome variables (number of SLM technologies applied). In the analysis, three kinds of SLM systems: sustainable cropping systems such as rotation and fallowing; chemical fertilizer with combination of manure or compost and soil and water conservation methods (physical land investments) such as contour ploughing, planting trees/bushes in rows (agroforestry), terraces, trenches, cover cropping, and strip cropping are included.

[39] The given alternatives in this study are private, individual irrigators with pumps, farmer-managed pump system, farmer-managed gravity systems, government and farmer jointly managed gravity systems; government and farmer jointly managed pump system and individual farmers openly accessing a source, such as a river or lake.

5.5. Analysis

5.5.1. Environmental impacts of irrigation

Farmers may face positive and/or negative environmental changes after the establishment of irrigation schemes. FGDs with beneficiary farmers indicated that the most frequent environmental externalities are changes in vegetation cover, water logging, soil salinity, soil fertility and soil erosion. Similarly, in the quantitative survey, irrigators were asked about their perception regarding changes in environmental conditions in the irrigation sites and plots since the year they started to irrigate. Descriptive results of environmental externalities and other relevant variables are presented in Table 5.1 and 5.6.

5.5.1.1. Descriptive analysis of positive environmental impacts of irrigation

Insights from FGD with irrigators suggest that prior to the establishment of the irrigation system, vegetation cover was in an extremely poor condition due to the combined effects of population and livestock pressure which led to land degradation. Following the establishment and use of irrigation, however, vegetation cover has improved. Farm households witnessed that the presence of irrigation water allows them to cultivate livestock feed along their plot's border and enables them to practice agroforestry on their plots. Irrigation impacts have transcended beyond the immediate irrigating households. There has been a change in the environment of the villages with irrigators compared to villages relying on rainfed agriculture only. Furthermore, insights from discussion with irrigators reveals that the biomass coverage of the scheme and adjacent areas has improved. As a result, these effects together with the available water at the source and lining canals attract different kinds of birds and other animals. This result is consistent with the household survey result that three in four irrigators confirmed that they have observed an increase in vegetation cover in their plots and surrounding area. Similar studies in Ethiopia (Woldeamlak, 2003; Liu et al., 2008; Munro et al., 2008; Nyssen et al., 2008; Alemayehu et al., 2009; Gebregziabher, et al., 2016) also reported that the development of integrated watershed management including establishment of irrigation schemes in different parts of Ethiopia improves vegetation cover of adjacent sites, reduces soil erosion and increases soil moisture. Based on multispectral and multitemporal satellite imagery from Landsat series**,** the next section discusses change in vegetation cover of irrigated plots by comparing the value of NDVI before farmers started to use irrigation water and afterwards.

Table 5. 1. Descriptive statistics of relevant variables

Variables	Mean	Std Dev.
Dependent variables		
1= if a negative change is perceived	0.457	-
1= if a positive change is perceived	0.751	-
Extension, information & experience		
Whether training attended in 2015/16	0.407	0.491
Frequency of contact to extension worker in 2015/16, in no.	17.504	37.316
Year irrigation started	2006	8.73
Plot level Characteristics		
1=if the soil type is loamy	0.602	-
Distance to the irrigation water source in km	1.75	1.819
Area of plot	0.32	0.396
Whether the plot is flat	0.932	-
No of parcels per household	5.434	2.796
Whether the land is certified	0.836	-
1=If owned the plot	0.408	-
Shock		
If there occurred any shock in 2015/16	0.364	-
Scheme characteristics		
1=If the lifting mechanism is pump	0.504	-
1=If the water source is underground	0.312	-
Irrigation water application mechanism on the plot, dummy		
1=Flooding	0.40	-
1=Drip + sprinkler (pressurized systems)	0.10	-
1=Furrow	0.50	-
Water Management System+lifting technology		
Private+pump	0.16	-
Farmers+pump	0.11	-
Farmers+gravity	0.19	-
Joint+pump	0.08	-
Joint+gravity	0.32	-
Open+pump	0.13	-
Irrigation water distribution and schedule		
1=Frequency the plot irrigated per season (in number)	19.138	15.753
Length of time the plot irrigated per rotation (in min)	158.839	92.012
Agro-ecology and climate, dummy		
Meher precipitation anomaly	0.168	.478
Belg precipitation anomaly	-1.169	.602
Temperature anomaly	0.863	.516
Meher precipitation coefficient of variation	23.219	6.88
Belg precipitation coefficient of variation	16.233	8.431
Mean annual temperature	17.137	1.321
Meher mean total precipitation	670.045	273.486
Belg Mean total precipitation	262.13	98.856
Elevation	1854.495	321.997
Number of observations (plots/households)	1027/464	

Source: Author's computation using survey data

5.5.1.2. Normalized difference vegetation index (NDVI) Analysis

The maintenance of biodiversity and sustainability of natural resources are important components of poverty alleviation and sustainable development. In highly degraded areas of Ethiopia, improvement in vegetation is perceived to be significant. This section investigates the change in vegetation cover of irrigated plots by comparing the value of NDVI before farmers started to use irrigation water and afterwards. Table 5.2-5.8 and

Figure 5.1 provide information on the normalized difference vegetation index (NDVI) before farmers started to irrigate and after, across various agro-ecological zones, irrigation water management systems, technologies, and years they have experienced irrigated agriculture.

As depicted in the Tables 5. 2, the overall trend observed in all irrigation sites included in the four regions of the country is that vegetation cover has been increasing since farmers started to use irrigation water. The NDVI analysis of the images of the irrigated farm sites included in the study reveals that there was less vegetation biomass on average, 0.05, in the study areas before irrigation started compared to the later years (0.22). This result is in line with the findings from FGD wtih irrigation beneficiaries which is discussed in section 5.5.1.1.

This result is not consistent with studies on large-scale irrigation projects in Ethiopia. Studies by Amdihun (2008) and Ruffeis et al. (2008) show that the NDVI results around the Irrigation Project in Finchaa Valley Area show declining vegetation biomass, because of large scale deforestation caused by expansion of agricultural lands and growing settlements. As depicted from Table 5. 2, different scales of irrigation are included in the study. Large-scale irrigation schemes such as Kobo valley pressurized irrigation project, Koga irrigation and watershed management and Tibila irrigation-based integrated development project are considered in the analysis. Our evidence shows that there has been improvement in vegetation cover in those large-scale irrigation schemes, even if there was clearance of land due to construction of the irrigation infrastructures in the areas.

Table 5. 2. The Normalized Vegetation index difference across salient feature of irrigation systems included in the study

Region	Woreda	Scale of irriga-tion	No. of household	No. of irrigated plots	NDVI before irrigation[40]	NDVI in 2016	NDVI difference
Tigray	Atsebi Wemberta	Small, micro	51	66	0.031 (0.009)	0.124 (0.003)	0.094*** (0.009)
Amhara	Raya Alamata	Small, micro	49	72	0.027 (0.013)	0.140 (0.0072)	0.113*** (0.014)
	Raya Kobo	large, Small, micro	38	78	-0.036 (0.007)	0.139 (0.0054)	0.175*** (0.006)
	Raya town	Large, small, micro	27	41	-0.057 (0.008)	0.120 (0.006)	0.178*** (0.010)
	Mecha	Large, small, micro	66	170	-0.029 (0.01)	0.132 (0.011)	0.161*** (0.016)
Oromia	Illu	Small, micro	60	130	-0.045 (0.008)	0.116 (0.004)	0.162*** (0.008)
	Wonchi	Medium, Small, micro	50	86	0.097 (0.016)	0.174 (0.005)	0.077*** (0.016)
	Sire	Large	12	37	0.046 (0.017)	0.298 (0.018)	0.252*** (0.020)
	Jeju	Large	8	17	-0.022 (0.012)	0.217 (0.017)	0.239*** (0.024)
SNNPR	Wondo Genet	Small, Micro	103	294	0.182 (0.008)	0.398 (0.003)	0.215*** (0.008)
4	10		464	1037	0.05 (0.005)	0.219 (0.005)	0.169*** (0.005)

Source: Author's computation from own survey and images acquires form NASA/US geological survey earth observation satellites
Note: Standard errors in parenthesis

Figure 5. 1 presents the spatial and temporal change of NDVI of irrigation systems included in this study across different agro-ecological zones of the country. Irrigation plots in humid moisture-reliable lowlands have registered the highest improvement in vegetation biomass among irrigation systems included in the study that is 0.25, followed by moisture-reliable highland (*Enset*) areas (0.22). The improvement in the moisture reliable lowlands is mainly due to the establishment of Tibila Irrigation-based Integrated Development Project in the Arsi zone of Oromia region. The results from FGDs with irrigators who live around the irrigation project indicate that since the establishment of the scheme, which was diverted from Awash river, the micro-climate of the surrounding area has improved and the intensity and number of rainy days in *Meher* has been also increasing. According to KII with the project administrative staffs, out of the total gross

[40] NDVI before irrigation refers to the value of NDVI on the year before they started to irrigate which differs plot to plot.

command area of 7,000 ha, 2,500 ha irrigated land has been developed so far, engaging around 5,000 households and total of 17,351 household members. The vegetation biomass improvement in the other agro-ecological zones has also been remarkable. For instance, average plots in cereal producing moisture-reliable highlands (0.0027), drought-prone lowlands (-0.0001), and drought-prone highlands (-0.0338), had negative and close to zero NDVI values before they started using irrigation, which corresponds to barren areas of rock and sand. However, the NDVI result in 2015/16 shows a complete improvement of greenness representing some shrubs and grasslands, at 0.134. 0.14, 0.13, respectively.

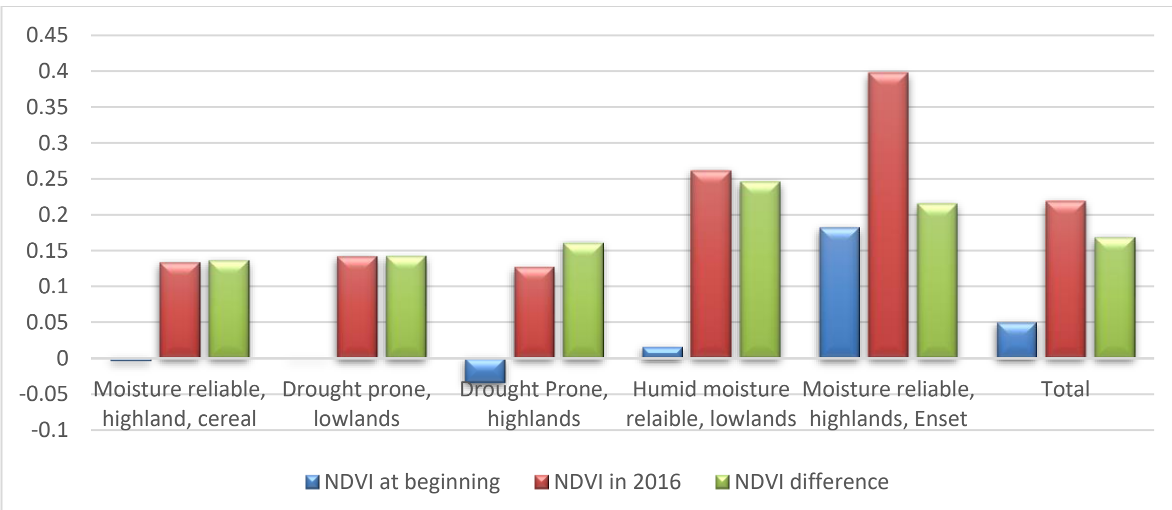


Figure 5. 1. Mean spatial and temporal change NDVI analysis of irrigation systems included in the study across different agro-ecological zones of the country.

Source: Author's computation from own survey and images acquires form NASA/US geological survey earth observation satellites

Table 5.3 provides information on changes in vegetation biomass of irrigation systems for various combinations of irrigation technologies and management systems since the year of their establishment. On average, the NDVI analysis results reveal that the general trend observed for plots in all types of irrigation water management systems has been increasing vegetation cover since irrigation commenced. Previously, it was hypothesized that, due to overexploitation (high discount rate) of the resource base, privately and open access irrigation schemes may be subject to environmental degradation due to lack of governance and collective management of the irrigation system. Surprisingly, the highest NDVI difference score is achieved in plots and surrounding areas that are in privately managed pump irrigated systems (0.237). Values are also positive for other systems. Jointly managed gravity irrigation system indicates a slightly less NDVI value difference (0.144).

Table 5. 3. Temporal changes in vegetation biomass of irrigation systems at varying level of devolution and technologies

Irrigation water management system	No. of plot	Before irrigation	NDVI in 2016	NDVI difference
Privately managed + pump	174	0.108 (0.008)	0.345 (0.009)	0.237*** (0.012)
Collectively managed + pump	87	0.018 (0.009)	0.176 (0.012)	0.159*** (0.01)
Collectively managed + Gravity	215	0.054 (0.012)	0.213 (0.008)	0.159*** (0.01)
Jointly managed+ pump	72	-0.035 (0.01)	0.141 (0.008)	0.176*** (0.01)
Jointly managed+ gravity	341	0.084 (0.009)	0.228 (0.009)	0.144*** (0.009)
Open access+ pump	136	-0.041 (0.008)	0.12 (0.00)	0.162*** (0.009)

Source: Author's computation from own survey and images acquires form NASA/US geological survey earth observation satellites
Note: Standard errors in parenthesis

Table 5.4 provides information on changes in vegetation biomass in irrigated plots across technologies applied. The result shows that plots that use irrigation water from groundwater sources reported major increases (0.207) in biomass. Similarly, among various irrigation water application mechanisms applied in the irrigated fields, the increase is larger for flood irrigation systems. This result is not surprising since flood irrigation (0.211) is a practice in which an entire field is covered with water. The excess water (overflow) is having a positive impact on the plots and the surrounding area. Plots under pressurized irrigation systems (0.163) perform a little better than those in furrow systems (0.136) in terms of changes in NDVI since irrigation began.

Table 5. 4. Change in vegetation biomass in irrigated plots and surrounding areas by irrigation water source and appliance method.

Types of Irrigation Technologies	No. of plot	Before irrigation	NDVI in 2016	NDVI difference
Irrigation water source structure				
Surface	713	0.05 (0.006)	0.202 (0.005)	0.151*** (0.006)
Groundwater	324	0.05 (0.006)	0.258 (0.008)	0.208*** (0.008)
Irrigation water application mechanism on the plot				
Flooding	410	0.082 (0.008)	0.293 (0.007)	0.211*** (0.008)
Pressurized system	106	0.006 (0.013)	0.169 (0.01)	0.164*** (0.009)
Furrow	521	0.037 (0.006)	0.173 (0.006)	0.136*** (0.006)
Total	1037	0.05 (0.0047)	0.219 (0.0045)	0.169*** (0.005)

Source: Author's computation from own survey and images acquires form NASA/US geological survey earth observation satellites
Note: Standard errors in parenthesis

Table 5.5 presents the NDVI analysis that detects temporal change of vegetation biomass across the years they started to irrigate in the study area. The result indicates that the natural vegetation biomass has increased since the establishment of the irrigation systems. However, the results suggest that plots and surrounding areas that are irrigated for more years have a non-linear relationship with changes in NDVI. Differences in vegetation cover are higher for schemes with 10 to 20 years of establishment compared to those with less than 10 years of establishment, but those with 20 to 30 years show the smallest change in NDVI. Irrigation schemes that are more than 30 years old show higher differences in NDVI, similar to those aged between 10 to 20 years. A possible explanation for the low NDVI difference for those plots that started to be irrigated 20-30 years ago is that it was the time when promotion of small-scale agriculture came to the political agenda of the government. Immense effort was made an effort to benefit rural households by including their plots into nearby communally developed irrigation schemes which might not have considered environmental impacts of irrigation use.

Table 5. 5. Temporal change of vegetation biomass across the year they started to irrigate in the study area

No. of years of irrigation experience	No. of plot	Before irrigation	NDVI in 2016	NDVI difference
<10 years	634	0.04 (0.004)	0.209 (0.006)	0.169*** (0.006)
Between 10-20 years	311	0.037 (0.011)	0.219 (0.007)	0.181*** (0.009)
Between 20-30 years	61	0.19 (0.018)	0.29 (0.017)	0.101*** (0.015)
More than 30 years	31	0.11 (0.018)	0.294 (0.025)	0.184*** (0.032)

Source: Author's computation from own survey and images acquires form NASA/US geological survey earth observation satellites
Note: Standard errors in parenthesis

5.5.1.3. Descriptive analysis of negative environmental impacts of irrigation

The most common negative environmental externalities indicated by farm household is a reduction in soil fertility. Approximately 27% of irrigators reported that their soil fertility level has been deteriorating since they stared to use irrigation. Similarly, around 18% of the irrigated plots face water logging problem. Discussions with irrigators indicated that farmers follow crop-water requirement rates when irrigating their plots. However, interviews with local irrigation experts suggest that irrigators often use excess irrigation thinking that more water results in higher yields. That is why most of the time, instead of using furrow irrigation on their plots they prefer applying flood irrigation which may result in waterlogging.

In the study areas, soil salinity has been observed on around 17% of the plots. Discussion with irrigators who have plots in Gerjele and Timuga *kebeles* indicate that there is a severe soil salinity problem. The main reason for salinity in the area is the availability of a high-water table. The irrigation experts at the *woreda* pointed out that when there is constant water availability at the surface in such semi-arid areas, evaporation will be high and through time there would be salt accumulation in the topsoil. Lowering the water table is considered to be a solution to this problem. Furthermore, farmers were asked whether they have observed any change in the formation of gullies[41] after the establishment of the irrigation scheme. The occurrence of erosion due to irrigation was observed in only 5% of the plots. However, the figure is much higher (21%) when farm households were asked about their perception towards soil erosion as a general environmental threat. Our FGD findings confirm that it is especially true with surface irrigation, where the soil conveys and distributes water through a field by gravity. However, those who use

[41] Gullies are incised channels that are larger than rills and the erosion occurs in areas where water runoff is concentrated, and as a result cuts deep channels into the land surface.

pressurized systems (sprinkler and drip irrigation) and private micro-irrigation pumps to distribute water did not point out erosion as a serious negative impact of irrigation.

Table 5. 6. Perceived effects of using irrigation water on irrigation plots and adjacent sites

Variables	%
Positive changes in environmental conditions	
Allow to cultivate additional plants on their plot such as animal feed, trees…	75.1
Negative changes in environmental conditions	
Water logging	17.8
Soil salinity	16.5
Soil fertility	27.3
Soil erosion	5.0

Source: Author's computation based on own survey data.

5.5.2. Sustainable agriculture land management practices

5.5.2.1. Descriptive Analysis

Understanding the ongoing land degradation problems, farmers apply diversified types of sustainable agricultural practices both in their rainfed as well as irrigated plots. As mentioned earlier, the analysis includes three kinds of land management systems: sustainable cropping systems such as rotation and fallowing; fertilizers (chemical fertilizer with manure or compost), and soil and water conservation methods, composed of contour ploughing, planting trees/bushes in rows (agroforestry), terraces, trenches, cover cropping and strip cropping.

Table 5.7 presents sustainable land management practices applied on irrigated and rainfed plots in the study areas. In line with previous studies by Bekele and Drake 2003; Gebreselassie et al., 2016 crop rotation, fallowing and chemical fertilizers are the most common practices adopted by most farmers in both rainfed and irrigated agricultural systems. Compared to irrigated plots, fallowing is practiced in a higher number of rainfed plots (by 6 percentage points). This is partly due to larger land size holdings as well as the higher number of rainfed plots than irrigated plots. Regarding fertilizer use, farm households use more compost (11%) and chemical fertilizer (75%) on their irrigated plots than their rainfed plots which was approximately 9.7% and 56%, respectively. However, it is noteworthy to mention that use of chemical fertilizer alone is not counted as SLM practice. It should be combined with manure or compost. In this case, in only 11% and 14% of rainfed and irrigated plots, households applied chemical fertilizer with manure or compost. On the other hand, physical land conservation investments such as construction of trenches, strip cropping, cover cropping, and planting trees/bushes/ in rows (agroforestry) are the least adopted SLM measures by farm households. This is possibly due to the fact that these land management practices could remove land out of agricultural production. In the descriptive analysis, significant differences are not observed between many of the practices applied among the two farming systems. The finding also reveals that the level of physical land management practices is comparable between the two farming systems.

Table 5. 7. Mean separation tests of sustainable agriculture practices applied in plots with and without access to irrigation

Sustainable agricultural practices	Rainfed		Irrigated		Rainfed verses irrigated
	Mean	SE	Mean	SE	
Sustainable cropping system					
Crop rotation	0.598	0.012	0.608	0.015	
Fallowing	0.303	0.012	0.244	0.013	***
If rotation or fallowing applied	0.661	0.012	0.657	0.014	
Organic fertilizers					
Manure	0.162	0.009	0.151	0.011	
Compost	0.097	0.007	0.110	0.010	***
Manure or compost used	0.230	0.011	0.236	0.013	
Chemical fertilizer (DAP, Urea, NPS)	0.562	0.012	0.748	0.013	***
Organic or chemical fertilizer used	0.684	0.012	0.840	0.011	***
Combining use of chemical fertilizer and manure or compost together	0.110	0.008	0.144	0.010	**
Soil erosion control practices					
Contour ploughing/pit planting	0.169	0.009	0.170	0.011	
Tree/bush/ shrub rows	0.136	0.009	0.153	0.011	
Terraces or bunds	0.296	0.011	0.279	0.014	
Trenches	0.074	0.007	0.046	0.006	***
Cover cropping	0.104	0.008	0.105	0.009	
Strip cropping	0.049	0.005	0.041	0.006	
Either of the S & W conservation practices used	0.519	0.013	0.509	0.015	
Average number of soil erosion control practices adopted	0.829	0.024	0.794	0.028	
Number of SLM technologies applied	1.818	0.037	1.762	0.043	*
No of observation	1084		1037		

Source: Author's computation using own survey data
Note: Statistical significance at *p<0.1, **p<0.05, ***p<0.01

The results also show that there are significant differences in the number and type of land management practices among plots benefiting from different combinations of water management systems and irrigation technologies (see Table 5.8). Adoption of crop rotation and chemical fertilizers are higher across all irrigation systems. Around 76%, 97% and 86% of pump users in farmer-managed irrigation, jointly managed pressurized irrigators, and open access users apply crop rotation. Overall, the use of organic fertilizer alone as well as combined with chemical fertilizer is negligible in the study areas. Especially in plots that are in jointly managed gravity systems and pump irrigators that access irrigation source openly, organic fertilizer was applied only in 13% and 4%, respectively. Instead, there is a high number of chemical fertilizer users among farmer managed pump users (92%), jointly managed pressurized users (94%) and open access irrigators (89%). As discussed in Pender et. al 2001, fertilizer use has increased significantly since 1991 and has been promoted by agricultural extension and credit programs. In addition, given the limited availability of farmyard manure (FYM), the demand for FYM for energy within and outside of farm households shifts FYM allocation away from improving soil fertility with detrimental impacts on agricultural productivity (Mekonnen et al. 2017; Teklewold 2012; Mekonnen and Kohlin 2008).

Table 5. 8. Summary statistics of sustainable agricultural practices applied in irrigated plots with various alternative

Sustainable agriculture practices	Private +pump	Farmer +pump	Farmer +gravity	Jointly +pump	Jointly +gravity	open +pump
Sustainable cropping systems						
Crop rotation	0.43	0.76	0.58	0.97	0.53	0.86
Fallowing	0.21	0.24	0.21	0.11	0.24	0.35
If rotation or fallow practiced	0.52	0.77	0.57	0.96	0.59	0.89
Organic fertilizer						
If manure or compost used	0.25	0.20	0.36	0.13	0.33	0.04
Chemical fertilizer (DAP, Urea, NPS)	0.70	0.92	0.69	0.94	0.74	0.89
Whether organic or chemical fertilizer applied	0.99	1.16	1.07	1.10	1.09	1.04
Chemical fertilizer with manure and compost	0.138	0.149	0.232	0.125	0.029	0.082
Erosion mitigating S & W conservation practices						
Contour ploughing/pit planting	0.11	0.19	0.15	0.10	0.18	0.24
Tree/bush/ shrub rows	0.14	0.10	0.13	0.17	0.20	0.03
Terraces or bunds	0.14	0.57	0.30	0.79	0.22	0.27
Trenches	0.00	0.03	0.05	0.01	0.07	0.10
Crop covering	0.11	0.08	0.02	0.03	0.15	0.05
Strip covering	0.02	0.01	0.03	0.08	0.03	0.13
Either of the S & W conservation practices applied	0.40	0.68	0.45	0.81	0.47	0.53
Average number of S & W conservation practices applied	0.52	0.98	0.65	1.17	0.0.81	0.80
Average number of SLM practice adopted	1.30	2.12	1.63	2.36	1.72	2.02

Source: Author’s computation based on own survey data

The finding of the study shows that among soil and water conservation mechanisms adopted, trenches and strip cropping are less common across all irrigation systems, whereas contour ploughing, bunds and planting trees and shrubs in rows (agroforestry) are more common among irrigators in the sample plots. In particular, farmers managed pump users (68%) and jointly managed pressurized users (81%) invest on at least one of the S&W conservation mechanisms. Overall, out of the three SLM systems (sustainable cropping system, fertilizer use and erosion mitigating S&W conservation practices), the highest number of SLM practices was adopted by jointly managed irrigators using pressurized systems (2.36).

5.5.2.2. Multivalued treatment effect results

This section presents the conditional means (the potential outcome means - POM) of the most widely used SLM technologies in the irrigation sites by water management system and complementary irrigation technology, after controlling for other characteristics of each plot. The simple comparison based on the result from unconditional means of number of sustainable land management practices in different categories along the alternatives may be misleading because it does not account for factors that may influence the outcome variables. Table 5.9 presents the multivalued treatment effect results of potential outcome means (sustainable land management practices applied) of each combination of water management and technology alternative. This analysis includes three kinds of land management systems: (i) sustainable cropping systems such as rotation and fallowing; (ii) fertilizers (chemical fertilizer with manure or compost), and (iii) soil mitigating S&W conservation methods, composed of contour ploughing, planting trees/bushes in rows (agroforestry), terraces, trenches, cover cropping and strip cropping.

After controlling for other characteristics of each plot, the multivalued treatment effect results of potential outcome means reveal similar result as the unconditional means. Compared with other categories of SLM, adoption of soil erosion mitigating mechanisms are not common in the alternative combination of water management systems and irrigation technologies applied. This is perhaps due to their labour-intensive nature, since the opportunity cost of labour is higher in irrigated areas where farmers may have greater ability to use purchased inputs.

In all SLM categories except fertilizer use, the evidence shows that a greater number of land management practices in jointly managed pump irrigated plots. Usually, this kind of system uses pressurized irrigation which operates through drip/sprinkler water appliance system. The estimated mean number of sustainable cropping system, fertilizer applied, and physical land management practices adopted are 1.17, 0.12 and 1.66, respectively. The higher number of SLM technologies in this kind of water saving irrigation system is explained by the nature of irrigation structures installed in the irrigated fields that influences adoption of SLM technologies such as contour ploughing, planting tree/shrubs in rows (agroforestry), strip cropping and fertilizer use. Pressurized system generally uses drips or sprinklers in fields that directly determine the spacing of crops. In addition to other features and equipment, filters are used, and fertilizers are generally applied with the irrigation water (Phocaide, 2007). Contrary to the hypothesis, collectively farmers managed irrigated plots and those that include government administration do not benefit from SLM practices. Inconsistent with the hypothesis provided earlier, plots that are in privately managed and open access irrigation systems have a higher number of SLM practices than gravity irrigators in either of the management systems. This suggests that these irrigation systems enhance complementarities with SLM practices, where the application of various SLM technologies supports irrigation outcomes.

Table 5. 9. Estimated average potential number of sustainable management technologies adopted in plots with various combinations of water management and water lifting technology

Outcome variables	Privately accessed + pump (1)	Collectively farmers managed+ pump (2)	Collectively farmers managed+ gravity (3)	Jointly managed +pump (4)	Jointly managed +gravity (5)	Open access+ Pump (6)
	Coef	Coef	Coef	Coef	Coef	Coef
Sustainable cropping system	0.76***	1.03***	0.82***	1.17***	0.68***	1.09***
	(0.08)	(0.11)	(0.11)	(0.12)	(0.05)	(0.08)
Fertilizer (chemical fertilizer with manure or compost)	0.28**	0.57**	0.29***	0.12	0.06	0.05
	(0.12)	(0.21)	(0.73)	(0.24)	(0.08)	(0.05)
Physical soil and water conservation	0.58***	0.85***	0.65***	1.66***	0.83***	0.93***
	(0.10)	(0.10)	(0.10)	(0.25)	(0.08)	(0.14)
Sustainable land management practices	3.64***	3.65***	2.16***	3.83***	2.49***	3.02***
	(0.55)	(1.24)	(0.21)	(0.29)	(0.26)	(0.16)

Source: Author's estimation based on own survey
Note: Statistical significance at *p<0.1, **p<0.05, ***p<0.01. Standard errors in parenthesis

On the other hand, gravity irrigators in farmers-managed systems have adopted the least number of SLM practices in almost all cases with 2.16 SLM practices adopted. This kind of irrigation system is mostly characterized as traditional irrigation system constructed using local materials which generally leads to large seepage losses and a deterioration of the water volume to be distributed.

5.6. Conclusion and Policy Implications

The government of Ethiopia has put irrigated agriculture at the heart of its development strategy. While the potential benefits of irrigation are great, the actual achievements in many irrigated areas of the country are substantially below the potential due to poor water management leading to waterlogging, salinity, acidity, soil erosion, sedimentation, and other related problems. However, the empirical foundation for understanding the environmental changes following the establishment of irrigation schemes and possible SLM strategies to overcome land degradation problems is far from being established. A clear understanding of the impacts of past investments in irrigation is an essential prerequisite for improving future interventions in order to promote irrigation development which enhances positive impacts while minimizing the adverse effects such as land degradation and to propose strategies for appropriate investments in soil and water conservation measures and land improvement.

This chapter explores the potential impacts of changes in environmental conditions in irrigation schemes using descriptive analysis in conjunction with analysis of remotely sensed data. The role of various irrigation water management systems and technologies in the adoption of sustainable agricultural land management practices is also investigated employing multivalued treatment effects approach. The analysis includes three kinds of land management practices: sustainable cropping systems such as rotation and fallowing; application of fertilizers (chemical fertilizer with manure or compost), and soil and water conservation methods, composed of contour ploughing, planting trees/bushes in rows (agroforestry), terraces, trenches, cover cropping and strip cropping. Our analysis uses a unique household and plot-level survey conducted recently in ten districts of the country. Furthermore, using geo-referenced data from the farms, Landsat images were extracted for each plot and immediate surrounding areas before and after the start of irrigation to assess differences in vegetation biomass.

The descriptive results suggest that the establishment and application of irrigation has improved the vegetation cover in the irrigated fields and the surrounding areas. Farm households noted that the presence of irrigation water allows them to cultivate livestock feed along the border of their plots and enables them furthermore to practice agroforestry on their plot. The effects of irrigation have been visible even in the surrounding communities and by those who do not irrigate. There has been a change in the environment of the villages that use irrigation when compared to nearby rainfed villages. Areas in the vicinity of irrigation schemes, including the irrigated command area, are covered with different kinds of trees, bushes and grasses. Moreover, the micro-climate of the surrounding area has been improving, according to insight from FGD with irrigators and KII.

The result of the NDVI analysis is consistent with results from discussion with irrigators. On average, the general trend of vegetation biomass observed for plots in all types of irrigation water management systems has been increasing since the rural households started to irrigate. The highest score is noted in plots and surrounding areas that are in privately managed irrigation systems with pump lifting mechanisms (0.23) and groundwater as the irrigation source (0.21).

At the same time, farm households have observed some negative environmental changes after the development of irrigation on their plots. Around 18% and 17% of the irrigated plots face water logging and soil salinity problem, respectively. Approximately 27% of irrigators reported that their soil fertility level has been deteriorating since the establishment of the irrigation scheme. Erosion due to irrigation water was observed in only 5% of the plots. However, the figure is much higher (21%) when farm households were asked about their perception towards soil erosion as a general environmental threat.

To address the land degradation challenges, farmers adopt various types of sustainable agricultural practices. Crop rotation and use of chemical fertilizers are higher in irrigated compared to rainfed plots. Around 76%, 97% and 86% of pump users in farmer-managed systems, jointly managed pressurized irrigators and open access users apply crop rotation, respectively. Overall, the use of organic fertilizer alone as well as combined with chemical fertilizer is negligible in the study areas, especially in plots that are located in jointly managed gravity systems and pump irrigators that access irrigation source openly. Instead, there is a high number of chemical fertilizer users among farmer managed pump users (92%), jointly managed pressurized users (94%) and open access irrigators (89%). Moreover, while trenches and strip cropping are less common, contour ploughing, bunds and planting trees/bushes in rows (agroforestry) are common among irrigators in the sample plots.

Using a multivalued treatment effect approach, the conditional means (the potential outcome means) of the most widely used SLM technologies in the irrigation sites are computed by water management system and complementary irrigation technology, after controlling for other characteristics of each plot. Compared with other categories of SLM, adoption of soil erosion mitigating (S&W conservation) mechanisms are less common throughout the irrigation system types. This implies that irrigators substitute labour-intensive practices for purchased inputs, since the opportunity cost of labour is higher in irrigated areas.

In all categories except fertilizer use, a greater number of land management practices has been adopted in jointly managed pump-irrigated plots. The estimated average numbers of sustainable cropping system, fertilizer applied (chemical fertilizer combined with manure or compost), and physical land management practices adopted in jointly managed pump-irrigated plots are reported as 1.17, 0.12 and 1.66, respectively. The overall estimated average number of SLM practices adopted is 3.83. Contrary to the hypothesis, collectively farmers managed irrigated plots and those that include government administration do not benefit from SLM practices. Unexpectedly, plots that are in privately managed and open access irrigation systems have a higher number of SLM practices than gravity irrigators in either of the management systems. This implies that these kinds of irrigation systems generate more benefits for farmers with the employment of SLM practices. On the other hand, farmer-managed gravity irrigation systems have adopted the lowest number of practices in almost all cases. These findings highlight the need for interventions that support SLM in traditional gravity irrigation structures, including capacity building of irrigators on the adoption and application of various land management practices in conjunction with irrigation water use on their fields.

6. SUMMARY, CONCLUSIONS, AND IMPLICATIONS

The government of Ethiopia has promoted irrigation with the aim of reducing poverty among the largely agriculture-dependent population in the face of climate variability and change and population growth. Recognizing the country's water resources potential, irrigation development has become a central element of the country's agricultural and rural development strategy. While irrigation's role in food security and rural growth is widely recognized, there are concerns regarding the overall performance of irrigation in the country both for human well-being and the environment. This study assessed the institutional set-up as well as the technologies in use in various types of irrigation systems in Ethiopia and examined their impact on three factors central to poverty alleviation: profit generation, farmers' empowerment, and environmental sustainability.

The study used data collected from multiple sources. The main dataset for this study is a comprehensive household and plot-level, cross-section survey of irrigating farm households in four regions of Ethiopia: Tigray, Amhara, Oromia and Southern Nations, Nationalities, and Peoples' Region (SNNPR). The survey was conducted in 2016/17 in ten districts of these regional states using a multi-stage stratified random sampling method. Data collected on plots were linked with monthly temperature and precipitation data as well as Landsat images to assess changes in vegetation health in irrigated and surrounding areas. Moreover, in order to enhance the validity of the data, published and unpublished sources were reviewed, and qualitative information was gathered using open-ended questions by undertaking focus group discussion, key informant interviews, and community level survey.

The study assesses institutions supporting irrigation at various scales, starting from the national perspective and down to the local level. The findings suggest that even if the policies, strategies and the legal instruments are fairly well specified, and the relevant organizations supporting irrigation management have been established, the organizations in place fail to meet their expected functions and are unable to enforce the rules and regulations. A careful examination of the profile of ministries depicts that there are overlaps in mandates between different ministries in charge of irrigation. Insight from KIIs reveals that the current horizontal and vertical information-sharing mechanisms in place do not ensure institutional harmony nor efficient information and resources flows. Ministries with a mandate for irrigation, as well as regional and district-level irrigation agencies attempt to fulfil their responsibilities without considering an interdisciplinary and integrated approach which is fundamental in the field of water resources management at each level. There is a need for coordinated efforts and long-term commitment from all relevant stakeholders. Capacity building programs should be implemented to strengthen the whole institutional set-up of the irrigation sector at each level and to build interdisciplinary and integrated water resource management. Furthermore, instead of making numerous reforms repeatedly in the sector at different levels, evidence-based reforms and interventions should be encouraged through enhanced R&D.

At the local level, there are various irrigation institutions in place resulting from the devolution of irrigation management functions, ranging from 'water fathers' to formal water users' associations. There are also irrigation schemes which are jointly managed by users and government agencies. Furthermore, there are various forms of irrigation without any formal governance. These include individual farm households who develop their own irrigation source privately as well as farmers who independently draw water from 'open-access' water source.

The results of the study demonstrate that despite the existence of diversified types of water management systems in the country, there are important problems noticed in each setting that affect actors and their activities and therefore, outputs. In principle, irrigation water users associations (IWUAs) are supposed to be self-managed organizations governed by their members and their executive committees. However, the results suggest that irrigation institutions in jointly (farmer and government) managed systems fail to meet their expected functions and are unable to enforce rules and regulations regarding cost recovery and conflict prevention and resolution mechanisms. Traditional user-managed systems may provide insights on the organization and development of the institutional and legal aspects of water administration and management of modern irrigation associations, since they have long years of using and managing irrigation water.

Starting from exploring the difference between rainfed and irrigated agriculture systems in input use, crop pattern, value of output and market participation, chapter 3 analyses the profitability (net return) of alternative combinations of irrigation water management systems and irrigation technologies in Ethiopia. There are statistically significant differences in input use between rainfed and irrigated plots. The use of improved seed, chemical fertilizer and labour were significantly higher on irrigated than rainfed fields. This suggests that due to access to irrigation water, there is increased intensification of agriculture which is expected to affect factor markets with wider effects on the economy. Furthermore, higher yields, higher cropping intensity and year-round farm production lead farm households to increase market-oriented production which enhances farm households' market participation. While just under half of households sold products from rainfed plots in 2015/16 *Meher* season (earned an average of USD 509/ha ~ ETB 11,346/ha), two-third of farm households sold their irrigation products through various marketing channels, mainly district market, village market and on farm and earned on average around USD 786/ha ~ ETB 19,690/ha, with significant variation among plots in various irrigation practices. This indicates the contribution of irrigation to the whole economy through the agricultural output market. The level of magnitude of benefit by irrigators significantly depends on market and infrastructure accessibility, since most of the crops grown on irrigated plots are perishable. Hence, improving market access should be a crucial part of rural development strategies.

Across all types of irrigation systems, using motor pumps on privately developed water sources leads not only to the highest net farm return (USD 1,787 ~ ETB 39,830/ha/irrigation season) among the alternatives given, but also farmers would not be better off if they had decided to adopt another combination of water management system and lifting technology. The finding of the research also points out that pump irrigation managed by farmer groups is a viable alternative in areas where water resources are too limited for all farmers to be engaged in private pump irrigation (USD 1,709/ha ~ ETB 38,094/ha). That is, instead of practicing irrigation individually, farmers are in a better position by developing a well and making a decision to share the irrigation water collectively among group members. It indicates that self-organization and management for irrigation water distribution should be encouraged, since it is one strategy to enhance benefit from irrigation and minimize costs related with construction of wells and fixed and variable cost of using pumps. These findings also imply that using motor pumps in privately as well as collectively developed water sources can be a viable option in agroecological zones with sufficient groundwater. Moreover, the policy to support groundwater exploitation and importing micro-irrigation technologies free of duty further supports the spread of the highest-return irrigation methods. The finding of the research also suggests that the promotion of privately accessed and micro irrigation technologies such as motor pumps by the government and development partners needs to be accompanied by ways to provide appropriate and accessible repair and maintenance services of irrigation lifting technologies and accessories to beneficiary farmers

Furthermore, among the given combinations, the least average net farm return is recorded by farm households that adopted jointly managed canal irrigation, at around USD 546/ha (ETB 12,160/ha). This category includes farmers working in large-scale irrigation schemes such as Koga and Tibila. This result highlights that large investments by the government and development partners in the initial development of irrigation projects may not be enough to witness the expected magnitude of positive impact on the community, but instead active engagement and participation of all stakeholders at each step in the management of the irrigation schemes is essential. This can be one instrument to avoid the principal-agent problem which is persistent in this kind of irrigation management system and to enhance a sense of belonging within the irrigation community. On the other hand, using jointly managed pressurized irrigation systems leads to the third highest net return effect (around USD1,349/ha ~ ETB 30,069/ha). This kind of irrigation system requires large investment at the initial stage as well as skilled manpower for its O&M and involves higher costs of energy. Therefore, adequate user involvement and strengthening of institutional setup for proper operation, maintenance and irrigation service provision is needed for the sustainability of the system. In the case of farmer group managed canal irrigation, the estimated average potential net return is lower than most of the alternatives given, i.e., around USD 825/ha (ETB 18,389 ETB/ha). This finding suggests eventual need of intervention for replacement of structures by more modern ones.

Pumping in open access systems provides the highest average potential net return (USD 17.93 hundred ~ ETB 39.97 thousand per ha). On top of the existing weak local governance systems, smallholders desire to avoid high transaction costs of communal and joint irrigation systems and strive for independence and flexibility in crop production and water use decisions are clear indicators of why these systems currently work in many places. Moreover, the local availability of affordable irrigation technologies, low initial investment, and high profit margins are the driving forces for its high adoption rate. However, the result of FGDs with irrigators imply that this spontaneous and unregulated spread of open access pump irrigation is leading to growing competition for scarce water supplies, conflicts among farmers, and mining of small water sources which may negatively affect the sustainability of irrigation in terms of livelihood benefits as well as management and use of the limited natural resource. Hence, emphasis should be given to immediate mobilization and establishment of local level institutions for irrigation water management to efficient and equitable use of the natural resource and for its sustainable use. In line with this, a focus on R&D is needed to provide relevant information on streamflow and aquifer levels to guide the sustainable use of water resources.

In chapter 4, factors that determine individual as well as collective empowerment in multiple scales of devolved irrigation water management systems and irrigation technologies in use in Ethiopia are explored. The first part of the analysis examines empowerment as an individual's achievement. In this case empowerment is proxied by access and decision-making power on using, managing, and conserving irrigation water. Even though collectively managed irrigation systems might promote the most equitable distribution of benefits and empower the greatest number of people, the results are mixed. Compared to irrigators drawing water from open access sources using pumps, all other farmers are more likely to be more empowered using the proxies identified in this study. Irrigators with pump irrigation technologies in either of the management systems also achieve higher yields, such as those for onions. These results suggest the importance of flexibility, reliability, efficiency and equitable water allocation and delivery for empowerment. Compared to jointly managed pump irrigation schemes, all other irrigation types have lower quality of irrigation structures. The findings also suggest that compared to plots located in farmer-managed canal irrigation systems, other plots are positively associated with producing marketable crops, indicating the lack of reliability of irrigation water supply in farmer-managed canal irrigation system. The results also support the government's focus on pump lifting technologies. If provision of these technologies is supported by defined irrigation water management systems, they have the potential to lift rural farm households from poverty.

The second part of the analysis of chapter 4 focuses on users-managed and users-and-agency managed irrigators, since in these cases irrigation water is treated as a common pool resource and in order to fulfil their goals irrigators mobilize themselves to different collective actions. Empowerment is indicated by collective participation, decision making capacity and strength of the irrigation governance structure. The results suggest that groups of farmers practicing gravity irrigation are positively associated with contribution for the initial establishment of the irrigation scheme they are in and the day-to-day operation and maintenance of the system, whereas they are negatively correlated with being a formal member of WUAs. This has high impact on strengthening of the governance structure of the irrigation system. All the beneficiaries need to be included in WUAs as members. Membership should be compulsory, and members should have full knowledge of their rights and obligations. Otherwise, it makes the decision-making processes and the enforcement of rules and regulations for water use very difficult to implement. It also creates opportunities for free riders. Furthermore, efforts should be exerted to enhance the capacity of irrigators in farmer managed as well as jointly managed systems for enhanced governance and management of the systems and to ensure the long-term sustainability of irrigation water use. The result also shows that farmers who participate in jointly managed pump irrigation and apply sprinkler/drip irrigation are more likely to be more empowered. They are with less conflict occurrence, more likely to be formal members of WUA and attend WUA's meetings more frequently. This is possibly because one of the advantages of this kind of application method is to improve water use efficiency which has substantial impact on minimizing conflicts arising from illegal water diversions. Thus, while emphasizing the promotion and expansion of irrigation technologies, more effort should be focused on improving irrigation scheduling and application methods.

In chapter 5, using descriptive and remotely sensed data, the potential impacts of irrigation on the environment are explored. Moreover, this chapter assesses the adoption of SLM practices to address environmental degradation for various types of irrigation water management systems and irrigation technologies. Insights from FGDs suggest that the establishment and application of irrigation has improved vegetation cover in the irrigated fields and the surrounding areas. Farm households witnessed that the presence of irrigation water allows them to cultivate livestock feed and other plants along the border of their plots and enable them to practice agroforestry on their plot. Irrigation impacts have transcended beyond the immediate irrigating households. Even in the surrounding community, the effect of irrigation has been very visible. The scheme areas is covered with different kinds of trees, bushes and grasses. As a result, these effects together with the presence of the water sources and lining canals attract different kinds of birds and other animals. Moreover, the micro-climate of the surrounding area has been improving, according to insight from FGD with irrigators and KII. The result of the NDVI analysis is consistent with the FGD result. On average, the general trend of vegetation biomass observed for plots in all types of irrigation water management systems has been increasing since the rural households started to irrigate. The highest NDVI score is noted in plots that are in privately managed irrigation systems with pump lifting mechanism (0.23) and irrigate from groundwater (0.21).

On the other hand, farm households have observed negative environmental changes after they started to irrigate their plots. Around 18% and 17% of the irrigated plots face waterlogging and soil salinity problems, respectively and approximately 27% of irrigators reported that their soil fertility level has been deteriorating since the establishment of the irrigation scheme. In response to the land degradation problems, farmers apply diversified types of sustainable agricultural land management practices. Crop rotation and use of chemical fertilizers are higher in all irrigation systems compared to rainfed plots. Around 76%, 97% and 86% of pump users in farmer-managed systems, jointly managed pressurized irrigators and open access users apply crop rotation, respectively. Overall, the use of organic fertilizer alone as well as combined with chemical fertilizer is negligible in the study areas, especially in plots that are located in jointly managed gravity systems (3%) and pump irrigators that access irrigation source openly (8%). Instead, famers apply chemical fertilizer on their irrigated plots, specifically, farmer-managed pump users (92%), jointly managed pressurized users (94%) and open access irrigators (89%). The study also found that trenches and strip cropping are less common, whereas contour ploughing, bands and planting trees/shrubs in rows (agroforestry) are more common among irrigators in the sample plots.

The econometric analysis shows that compared with other categories of SLM practices, adoption of soil erosion mitigating (S&W conservation) mechanisms are less common throughout the alternatives. This implies that irrigators substitute labour intensive practices for purchased inputs, since the opportunity cost of labour is higher in irrigated areas due to more cropping season and high intensity of crop types. In almost all categories of SLM technologies, the results show that a greater number of land management practices have been adopted in jointly managed pump irrigated plots. The estimated average number of sustainable cropping systems, fertilizer applied (chemical fertilizer combined with manure or compost), and physical land management practices adopted are 1.17, 0.12 and 1.66, respectively. Furthermore, plots with pump irrigation technology in either of the management systems have adopted a higher number of SLM practices (3.64, 3.65 and 3.83 in privately managed, farmer-led and jointly managed irrigation systems, respectively). This implies that those kinds of irrigation systems enhance complementarities among technologies on farm fields. On the other hand, gravity irrigators in either of the management systems have adopted the least number of practices (2.16 and 2.49 in farmer-led and jointly managed irrigation systems, respectively) in almost all cases. These findings underscore the need for interventions in traditional farmer-led and jointly managed gravity irrigation schemes.

Understanding the nature and magnitude of impacts and identifying the existing gaps within the irrigation sector at different levels will contribute towards better designing and implementation of relevant policies and institutions for effective scaling out/up of best practices of various water management and irrigation technologies in the country. A clear understanding of the impacts of past investments in irrigation is an essential prerequisite for improving future interventions in order to promote irrigation development which enhances positive impacts while minimizing adverse effects such as environmental degradation. In addition, the analysis of institutions and water management systems and their design features provides useful policy makers and other key actors who are involved in designing and implementing decentralization and devolution reforms in the use and management of natural resources. Overall, this study can be a valuable input for a policy design of a country such as Ethiopia that has a vision to build a climate resilient green economy.

Despite all these insights and contributions of the study, it is not without limitations, and some major ones deserve mentioning. First, in the analysis of irrigation water institutions, since water institution is a complex entity, the study opted to focus on certain key features of existing institutional arrangements and recent institutional changes in the three main components of the irrigation sector of the country, i. e., law, policy, and administration. In the study, the institutional environment surrounding irrigation, which characterizes the overall social, economic, political and resource contexts within which the irrigation institutional structure evolves and interactions within the irrigation sector is not analysed. Second, the econometric analysis is based on cross sectional data. It is recommended that future research should be based on a more robust panel data approach to identify the impacts of using and managing different types of irrigation systems and technologies. Third, the empowerment and environmental analyses include objective as well as subjective indicators to measure the outcome variables. However, the validity of self-reported indicators is questioned frequently, since they may be subject to biases due to several reasons. Fourth, even if the potential positive and negative health effects of irrigation in the surrounding community is an important area of concern in analysing the economics of irrigation systems in Ethiopia, this study does not cover its effect. Hence, this area could provide an entry point for future research. Despite these limitations, it is believed that the chapters included in this thesis provide policy relevant insights on the existing gaps in the institutional set up of irrigation systems in Ethiopia and how multiple scales of irrigation water management systems and complementary technologies influence the three factors central to poverty alleviation: farm return, empowerment of farmers and farmer organizations, and environmental sustainability of using irrigation.

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